CERTIFICATE

This is to certify that the thesis entitled **"Effect of surface soil moisture on root growth and yield in rabi sorghum"** submitted in partial fulfilment of the requirements for the degree of **'Master of Science in Agriculture'** of the Andhra Pradesh Agricultural University, Hyderabad, is a record of the bonafide 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.

Dr. M. Ranga Reddy
Chairman of the Advisory Committee

Thesis approved by the Student's Advisory Committee:

Chairman: Dr. M. Ranga Reddy
Professor and Head
Dept. of Agronony and
Principal, College of Agriculture
Rajendranagar
Hyderabad 500 030

Members: 1. Dr. B. Bhaskar Reddy
Associate Professor
Department of Agronomy
College of Agriculture
Rajendra Nagar
Hyderabad 500 030

2. Dr. P.S. Sarma
Associate Professor
Dept. of Plant Physiology
College of Agriculture
Rajendranagar
Hyderabad 500 030

CERTIFICATE

Mr. Elasha Abdel Hay Elasha Abu Elbashir has satisfactorily prosecuted the course of research and that the thesis entitled **EFFECT OF SURFACE SOIL MOISTURE ON ROOT GROWTH AND YIELD IN RABI SORGHUM** submitted is the result of original research work and is of sufficiently high standard to warrant its 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.

Date: 25-10-93

Major Advisor:

Dr. M. Ranga Reddy
Professor and Head
Department of Agronomy and
Principal,
Andhra Pradesh Agricultural
University,
Rajendranagar
Hyderabad 500 030

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Finally, this endeavor, its pursue and completion is credited to the lord.

ELASHA ABDEL HAY ELASHA ABU ELBASHIR

DECLARATION

I declare that this thesis entitled **EFFECT OF SURFACE SOIL MOISTURE ON ROOT GROWTH AND YIELD IN RABI SORGHUM** is a bonafide record of work done by me during the period of research at ICRISAT, Patancheru. This thesis has not formed in whole or in part, the basis for the award of any degree or diploma.

Date: 25 – 10 – 93 **ELASHA ABDEL HAY ELASHA ABU ELBASHIR**

Name of the Author	:	**ELASHA ABDEL HAY ELASHA**
Title of the thesis	:	**EFFECT OF SURFACE SOIL MOISTURE ON ROOT GROWTH AND YIELD IN *RABI* SORGHUM.**
Degree to which it is submitted	:	**MASTER OF SCIENCE IN AGRICULTURE (AGRONOMY)**
Faculty	:	**AGRICULTURE**
Department	:	**AGRONOMY**
Major Advisor	:	**DR M. RANGA REDDY PROFESSOR AND HEAD AGRONOMY DEPARTMENT**
University	:	**ANDHRA PRADESH AGRICULTURAL UNIVERSITY**
Year of submission	:	**1993**

Abstract

The experiment was conducted at ICRISAT Center (India) during 1992 *rabi* season. The experiment was laid out in a split plot design having nested classification, with irrigation levels in the main plots and genotypes in the subplots.

The 45 mm seedling irrigation level have significantly increased the nodal roots number, total root length, and total root mass per plant compared to the other treatments. The same was observed with genotypes at the end of the season.

Root growth measured in various ways increased during the various growth stages irrespective of irrigation levels and genotypes and they reached their maximum after flowering time. Irrigation seedling treatments were significantly different for all the root parameters during nodal root initiation, and for nodal root number and total root length also during panicle initiation. Genotypes were significantly different for all the root attributes during 50% flowering and harvest for all of them except for nodal root number.

The root length density continued to increase with 45 mm seedling irrigation treatment in the 0 to 100 cm depth and to decrease with the control between 50% flowering and harvest time. The difference at both growth stages for both irrigation

seedling treatments and genotypes were significant.

The above ground crop growth (Stem, leaf, shoot and total plant dry weight) for irrigation levels and genotypes was more with 45 mm seedling treatment. Total plant dry weight increased linearly with time until it reached its maximum after 50% flowering time. At this time the contribution of roots was only 7 per cent.

The genotypes were significantly different for all above ground parameters at nodal root initiation, 50% flowering and harvest time. Irrigation seedling treatments were not significant at any growth stage for all above ground attributes except for green leaf dry weight which is significant at 50% flowering.

The root/shoot ratio for genotypes was significantly different at anthesis, nodal root initiation and panicle initiation. The irrigation seedling treatments were not significant at all these stages. The root/shoot ratio was more at nodal root and panicle initiation stages and tend to decline or remain constant at 50% flowering and harvest time.

Genotypes were significantly different for yield and yield attributes where the irrigation seedling treatments were not.

The water used and water use efficiency values were comparable with other results. The slight increase in the water use efficiency values was due to 100 cm depth of sampling which resulted in a slight underestimation of the water used and hence the slight overestimation in the water use efficiency values.

Most of the nutrient analysis parameters were found to be not significantly different both at 50% flowering and harvest time.

INTRODUCTION

CHAPTER I

INTRODUCTION

Globally, sorghum (*Sorghum bicolor* (L.) Moench) ranks fifth in importance among cereals and sixth among important dietary sources of energy for the world's population (Cock, 1985). Although tropical in origin, but it is distributed geographically between 45°N and 35°S and ecologically between 300-1400 mm annual rainfall and 0 to >1000 m above sea level. The large genotypic diversity of sorghum makes the crop adaptable to most regions where maize or millet can be grown (Seetharama *et al.*, 1988). Sorghum occupies about 47 million ha worldwide with Asia (19.6 million ha) as a leading continent, followed by Africa (15.7 million ha), North and Central America (2.7 million ha), Australia (0.73 million ha) and USSR (0.18 million ha) (Doggett, 1988).

Maximum harvested yields of > 15 T/ha in the temperate and >8 T/ha in the semi-arid tropics have been reported (Seetharama *et al.*, 1988), but average farmers yield in the semi-arid tropics (where the majority of the crop is grown) are about 0.8 T/ha, in comparison to 3.6 T/ha in the high technology, temperate regions.

Agroclimatology of Sorghum

The potential yields in the semi-arid tropics are limited by the length of the growing season which is determined by the seasonal rainfall and the water-holding

capacity of the soils (Seetharama *et al.*, 1988). Total rainfall, its length, distribution, and intensity affect, plant growth such as seedling emergence, early leaf and root growth and nutrient uptake.

The growing season in Africa ranges from 90 days in the Sahel and Sudan Savanna vegetation zones to 270 days towards the equator. The soils of Africa especially in the west are Alfisols poor in nutrients (especially phosphorous) and with low water-holding capacity.

In the sorghum growing regions of India, the length of the growing season ranges between 90-180 days. These regions (about 80%) fall mostly under Vertisols or Alfisols are fertile enough to sustain modest yields except where there are acute nitrogen, phosphorous or zinc deficiencies. The distinctive feature in sorghum production in India is the cultivation of up to 40% of the total sorghum area on stored moisture in the vertisols of the Deccan region (Seetharama, 1988).

Average solar radiation in the semi-arid tropics (17-21 $mj/m^2/day$) is adequate during the season. The temperature extremes are more critical in determining crop growth and yield (Peacock and Wilson, 1984). The optimum temperature for photosynthesis is about 40°C, and 30-35°C for growth (Eastin, 1983). High temperature especially during years when rains end early, may result in severe terminal drought stress. High temperature during vegetative growth may be less critical than early or late stage especially if roots have access to water (Seetharama, 1988).

Postrainy season sorghum in India is the third most important Indian cereal accounting for 13 per cent of the gross cropped area in the semi-arid parts of the country (Tarhalkar 1986). It is grown on about 16 million ha including both the rainy (June-September) and postrainy or *rabi* (September-February) seasons (Seetharama *et al.*, 1990).

During *rabi*, mostly it is sown in the Deccan plateau between 10 and 20°N latitude covering more than the land occupied by maize and more than half of that planted to pearl millet. Despite this, *rabi* sorghum accounts only for less than 30 per cent of the annual sorghum production (Tandon and Kanwar, 1984). Average farmer's yields are about 0.5 T/ha. In contrast to its rainy season counterpart, the *rabi* sorghum yields have remained stagnant (Vidyabhushanam, 1986), despite its good grain and fodder quality. The possible reasons for the low productivity of *rabi* sorghum are environmental (climatic and edaphic) and management factors (Seetharama *et al.*, 1990).

Nodal Root System

Since there is about 6 million ha in India grown during the postrainy (*rabi*) season in drying soils, it becomes important to have rapid seedling establishment for high and stable yields (Soman and Seetharama, 1992). The early vigour is critical if the crop is to use nutrient from the rapidly drying upper soil layers and reduce evaporation from these layers. Both seedling establishment and early crop vigour in the *rabi* sorghum environment depends largely on the rapid initiation and

extension of the crown or nodal roots, as the single seminal (primary) root of sorghum usually lasts for 10-30 days after sowing (Freeman, 1970). Bur *et al.* (1977) found that seminal roots can remain active for a longer period when nodal root initiation is delayed, but they can not absorb adequate nutrient and water to sustain plant growth. Blum and Ritchie (1984) found that when the top 0.3 m soil layer is wet (70% field capacity), nodal root initiation and establishment proceed at a maximum potential rate, but the development of a secondary root system can be prevented or delayed if moisture is deficient at the crown depth (Cornish *et al.*, 1984).

Soman and Seetharama (1992) have found genotypic variation in the time of nodal roots initiation and nodal root length, but not in number. They also reported that the variation in the growth of the root system (especially of nodal root growth) was independent of the variation in the shoot growth. Also they found the rapid nodal root initiation under drying soil to result in better early growth in sorghum. Seetharama *et al.* (1990) obtained high heritability value for nodal root length (h^2=0.66) indicating that the genetic advance is possible for this trait. Combining such root- related traits with other useful agronomic characters is necessary for crop improvement and yield increment. In connection with, this an experiment was conducted with the following objectives:

1. To evaluate the effects of differences in early secondary root growth on subsequent crop water and nutrient uptake.

2. To understand how such differences will influence crop growth and crop yield.

REVIEW OF LITERATURE

CHAPTER II

REVIEW OF LITERATURE

Rabi sorghum accounts for nearly 40 per cent of the total sorghum area in India (Seetharama *et al.* 1990), but accounts for only 30 per cent of the total sorghum production (Tandon and Kanwar, 1984). Despite its importance as an intercrop component and its superior grain and fodder quality, yields of *rabi* sorghum remain stagnant compared to its rainy season crop counterpart (Seetharama *et al.* 1986).

2.1 THE ROOT SYSTEM OF OTHER CROPS

Vincent and Gregory (1985) have shown that differences among chickpea genotypes in their early root growth and establishment, could lead for differences in the way the seedlings respond to environmental conditions and hence affect later growth. In their study, the Syrian land local land race ILC 1929 produced the largest root system, outyielded other genotypes when sown during spring on stored soil moisture.

In wheat, Proffitt *et al.* (1985), concluded that the depth of water front penetration of 18 mm/irrigation/4 days compared to 30.5 mm/irrigation/12 days affect root growth producing differential rooting distribution patterns, depth of

penetration and root length density. On the same crop, Hurd (1968) reported that the pattern of roots of different varieties help to explain their yield performance at different moisture levels.

In soybean, Hoogenboom *et al.* (1987), found that during the early stages of vegetative development, root growth occured in the upper regions of the soil and new roots proliferated in wetter regions with advancing season. They also mentioned that towards late season, draughted plants with relatively small root system were particularly susceptible to draught-stress injury. Consequently, if plants had developed a smaller shoot/root ratio during early vegetative stages, they can maintain turgor and a high photosynthetic carbon fixation rates during the critical seed-filling stages of reproductive development.

Kislev and Korach (1979) on macaroni wheat, cucumber, lentil, bitter vetch and sorghum extensively studied the methods used by the seedlings to affix themselves to soil and to produce sufficient force to counter balance the penetrating radicle.

2.2 THE ROOT SYSTEM OF SORGHUM

Blum and Arkin (1984), concluded that sorghum root distribution in the profile in response to irrigation or rainfall is controlled by the inhibitive effects of a dry top soil on crown root establishment and the associated growth compensation in existing roots. Hackett (1973) reported that despite the rapid root development,

sorghum tended to maintain stable relationship between the overall number, lengths, surface area, and volume of the root members as do other species.

2.2.1 Root Morphology, Morphogenesis and Functional Characteristics

Yamazaki and Nekamoto (1983) reported some morphological differences such as stem diameter, the number and diameter of the primary roots and frequency of the secondary roots along the primary root axes in different species including sorghum.

Seetharama *et al.* (unpublished), found that the sorghum root system is comparable to that of maize, but sorghum roots are finer, more fibrous and support small leaf area than those of maize.

Freeman (1970) summarized the genesis of primary root in sorghum based on the work of Chi (1942) and Paulson (1962). The primary roots emerge from the side of the colorhiza. Root hairs arise from the epidermal cells just behind the region of elongation and the lateral roots emerge from the primary roots just above the root hair zone.

Mirhadi and Kobayashi (1980) found that nodal roots elongated from the buds of lower internodes 3-4 days after emergence and are produced in concentric whorls with rapid pace initially which slowed down at later stages.

Blum *et al.* (1976) pointed that sorghum has eight whorls of nodal roots appearing under field conditions beginning at 10 days after emergence (the first),

panicle initiation (five), anthesis (the sixth), and grain filling stage (the remaining two).

Kanitkar *et al.* (1968) pointed that nodal root numbers vary from 16-32 and their size is correlated to the size of the node from which they originate (Freeman, 1970).

According to Myers (1980) nodal roots proliferated and reached a maximum branching around the final leaf stage. Their establishment signals the death of the seminal roots of the seedlings. It is worth mentioning that brace roots are also nodal roots originating from whorls at higher nodes. Their function apart from anchorage, is water and nutrient uptake.

Bur *et al.* (1977) and Passioura (1983) concluded that the sorghum life cycle can not be completed with full dependence on seminal roots, due to their insufficient nutrient and water uptake. Nodal roots when once initiated , function in nutrient and water uptake and support of the plant till maturity.

Kannan (1981) found that the recovery of the Fe-stressed plants were due to nodal roots only.

2.3 PLASTICITY AND COMPENSATORY GROWTH

Jordan *et al.* (1979a) concluded that when nodal root numbers were severely reduced from 10 to 3, compensatory growth within the remaining members was

capable of maintaining root length and volume, but not root mass under irrigation, soil fertility and soil compaction condition but not under limiting water and nutrient conditions. Jose *et al.* (1990) reported that the draughted sorghum plants continued to produce new nodal roots but their number was less than the control. Also they reported a marked reduction in the viability of the root tips and root cortex due to drought stress and that rewatering of the draughted plants when they reached the first wilting point failed to increase the number and length of the nodal roots components but not the seminal root components.

2.4 ROOT GROWTH IN RELATION TO SHOOT GROWTH

2.4.1 Root Volume and Mass

Except the study made by Rice and Eastin et al. (1986), all other studies terminated before flowering.

According to Blum *et al.* (1977a,b), a linear relationship exists between total root length and leaf area, and between root volume and leaf area until panicle initiation.

Jordan *et al.* (1979b) concluded that plants with large leaf area were more likely to have large root volumes and total length of nodal roots prior to panicle initiation.

Myres (1980) and Kaigama *et al.* (1977) found that total root weight increased until final-leaf visible stage and remained constant until maturity under field conditions. At ICRISAT (1988) the root mass increased even after flowering during postrainy season.

Total root weight ranged in different studies from 1-3 T/ha (Myres, 1980, Kaigama *et al.*, 1977).

From different studies (Reddy, 1985 and Zartman and Woyewodzic 1979),the root growth patterns were found to be well within a common range of about top 50 cm soil layer.

2.4.2 Root Length

Chalam and Venkateswarlu (1965) reported a maximum distance of 200 cm for vertical and lateral spread. Vertical extension in nodal roots proceeds at a higher rate from the 5-leaf stage until panicle initiation, but slows down at later growth stages e.g soft dough.

According to Mc Clure and Harvey (1962) maximum lateral spread of roots occured during panicle development stage (panicle initiation-Anthesis) and the greatest root activity occured in the 38 cm region laterally from the plant to a depth of 90 cm.

A greater proportion of root length is found in the upper layers up to anthesis, later senescence in these layers takes place combined with slight but significant increase in root length at lower depths. Fukai *et al.* (1986) found that tiller removal increased root growth at flag leaf stage but not at maturity.

2.4.3 Root/shoot Ratio

Myers (1980) stated that root/shoot ratio declined with age. Wani *et al.* (1988) found that the ratio decreased with nitrogen application under controlled experiment.

Wright *et al.* (1983) have shown no appreciable differences in root-shoot balance due to height differences.

Evetts and Burnside (1973) found that the lower root/shoot ratio of sorghum as compared to that of weed species was useful for the suppression of weed growth.

Michael and Sieler- Kelbitch (1972) concluded that, root-shoot relations are not adequately understood as roots studies are difficult to handle.

2.4.4 Root Length Density

Seetharama *et al.* (1988) found that with two preflowering irrigations mean root length density increased by more than 50 per cent compared to roots of unirrigated crops, but root length density at 120 and 150 cm soil depth was less with preflowering irrigation compared to non irrigated sorghum plants.

The sharp increase in root length density between late flowering to dough stage is due to root branching and elongation stimulated by the demand for water (ICRISAT annual report, 1989).

2.5 PRODUCTIVITY

According to Rao and Ramanath (1989) and Seetharama *et al.* (1978) *rabi* sorghum in India shares commonalities with sorghum crops grown on residual soil moisture in Africa or in the Mediterranean (e.g., Israel) or temperate regions (e.g, Texas, USA). The most important difference between African postrainy and Indian *rabi* sorghums is that the former are cropped on receding flood plains after burning the vegetation where soil fertility is not limiting. The temperate or Mediterranean sorghums are planted in saturated highly fertilized soils (Seetharama *et al.*, 1990) The same author summarized the environmental factors limiting *rabi* sorghum productivity as climatic, edaphic, insects and disease problems and management factors.

2.5.1 Climatic Factors

Virmani *et al.* (1982) pointed that the probability of receiving rainfall of more than 10 mm is about 60 per cent during the first week of October; soon after, it decreases rapidly by about 2-5 per cent per week.

2.5.2. Solar Radiation

Solar radiation during *rabi* is about 6 per cent less than during *Kharif* (Sivakumar and Virmani, 1982), but the conversion of incident solar radiation to dry matter by *rabi* sorghum is half of that during *Kharif* (Sivakumar and Huda, 1985). This difference is due to lower leaf area indices and reduced radiation-use efficiency during *rabi* (Seetharama *et al.*, 1982b)

2.5.3 Temperature

Eastin *et al.* (1983) pointed that sorghum is relatively insensitive to heat during vegetative stage, with varying effects during panicle development. Heat sensitive stages being microsporogenesis and megasporogenesis.

Sivakumar and Virmani (1982) found slight differences in the mean daily temperatures during *rabi* (24.9°C) and *Kharif* (27.9°C) seasons, but the diurnal variations are greater during *rabi*. Rao *et al.* (1977) and Choudhari (1989) attributed the reduction in growth and grain yield of *rabi* sorghum to lower night temperature.

2.5.4. Open-pan Evaporation and Saturation Vapour-pressure Deficit

Open pan evaporation rates range between 3-5 mm/day during *rabi*. The saturation vapor pressure deficit increases during *rabi*, but its implications are not yet sufficiently studied (Monteith, 1986).

2.6 EDAPHIC FACTORS

Tandon and Kanwar (1984), concluded that yield differences between shallow and deep Vertisols can be up to 1 T/ha.

2.6.1 Soil Water Storage

Tarhalkar (1986) estimated that about 175 mm of water is required for successful *rabi* sorghum cropping. The highest water use efficiency reported for *rabi* sorghum is 50 Kg/ha/mm (Seetharama *et al.*, 1984). Water use efficiency for *rabi* sorghum can be increased by mulching on shallow soil (Mane and Shingte, 1982) and nitrogen fertilization (Kanwar *et al.*, 1984).

2.6.2 Soil Nutrient Content

Kharif fallowing (weed free field conditions) increases water and nitrogen reserves (Rego *et al.*, 1982) and a good measure against nitrogen deficiency especially if an unfertilized Kharif crop was followed.

2.6.3 Soil Cracking

Although it results in tremendous water loss, but there is no documented evidence of its impact on yield. Intercultivation helps to conserve soil moisture (Seetharama et al. 1990).

2.6.4. Soil Temperature

The information pertaining to the effects of soil temperature on root growth is scanty. Peacock and Heinrich (1984) felt that this relationship is similar to that between leaf extension and temperature. Martin *et al.* (1935) in a glasshouse trial found more nodal roots with higher temperature, especially between 25-35° C than in the range of 15-25° C.

2.7 INSECTS AND DISEASE PROBLEMS

Shoot fly, root and stalk rot incidence are the main problems for *rabi* sorghum (Seetharama *et al.*, 1990).

2.8 MANAGEMENT FACTORS

2.8.1 Date of Sowing

Nwanze *et al.* (1990) attributed the delayed sowing of *rabi* sorghum to the shoot fly incidence associated with early sown crops. Reddy *et al.* (1987) estimated a 68 per cent decrease in grain yield and 37 per cent decrease in stover yield when sowing of *rabi* cultivars was delayed 10-weeks. On the other hand, advancing the sowing date (4 weeks) increased the yield by 2.5 T/ha (Sprat and Chowdhary 1978), but had no significant effect on yield without adequate fertility (Umrani, 1989, Kale, 1989)

2.8.2 Depth of Sowing

Kanitkar *et al.* (1968) found that the practice of deep sowing (>30 mm) may severely affect water and nutrient uptake from the top soil layer.

2.8.3 Irrigation

Tarhalkar (1986) estimated that about less than 12 per cent of the *rabi* sorghum is irrigated, usually once or twice during the season. Percentage of yield gains ranged from 414 per cent (Hari Krishna, 1981); 133-225 per cent with one and 284-411 per cent with two irrigations as compared to dryland crops (Verma, 1978). Plaut *et al.* (1969) reported that most of the grain sorghum yield was obtained with three irrigation or with two irrigations when the second was applied between heading and milk stage. They also reported the main yield component affected by irrigation was 1000 grain mass.

2.8.4 Fertilization

Kanwar *et al.* (1984) showed that water use and water use efficiency can both be significantly increased with nitrogen fertilization. The optimum nitrogen varied from 25-85 Kg/ha, while the optimum phosphorous was about 11 Kg/ha. Rego *et al.* (1982) mentioned the advantage of deep fertilizer placement in receding moisture situations during *rabi*.

Under intensive cropping, phosphorous and potassium nutrition is important, phosphorous as a promoter for root growth (Venkateswaralu and Venkatasubbaiah 1984) and potassium for better grain growth and leaf-water relations (Beaton and Sekhon 1985)

2.8.5 Plant Density and Row Spacing

A plant density of 90,000-135,000 plants/ha and a row spacing of 75-90 cm is recommended (CRIDA, 1989), but farmers use narrow rows of 30 cm with high densities to maximize fodder yield and quality. The practice was found to subject *rabi* sorghum to terminal stress as well as root and stalk-rots (ICRISAT, 1983).

2.8.6 Soil Physical Conditions (Tillage and Other Cultural Practices)

Generally root growth is promoted in a well-cultivated highly drained soil due to better root penetration. Baligar and Nash (1978) found greater root length in coarse (2-6 mm) than in fine aggregated soil; however, small aggregates resulted in greater nutrient availability to roots. Baligar et.al. (1981) found that a bulk density of 1.85 Mg m^{-3} affected sorghum root growth adversely.

Choprat and Nicou (1976) found that deep ploughing before sowing increased root densities. ICRISAT (1986) showed the advantage of deep tillage in Alfisols on root growth. The author recorded yields of 3.22, 2.76, 2.52 T/ha for deep ploughing (0.25 m), mold board plowing (0.15 m), and traditional tillage (0.1 m) respectively.

2.9 GROWTH REGULATORS

Wright *et al.* (1983) found no effect of gibberellic acid application on root growth, but in pot experiments naphthalene acetic acid (NAA) and cycocel (CCC) spray increased root mass.

MATERIALS AND METHODS

CHAPTER III

MATERIAL AND METHODS

3.1 EXPERIMENTAL SITE

3.1.1 Location

The experiment was conducted at ICRISAT Center (India) during 1992 *rabi* season. The site is located at an altitude of 545 m above sea level, 18°N, 78°E in Patancheru village, state of Andhra Pradesh (ICRISAT, 1985).

3.1.2 Climate

The climate of ICRISAT Center is a typical semi-arid tropical environment characterized by a short period of rainfall (3-4 months) and a prolonged dry spell (8-9 months).

Three distinct seasons characterize this environment:

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

- *Rabi* or postrainy season extending from mid- October to January. This season is relatively dry, cool with short days. Cropping is done on stored

soil moisture. The experiment under study was raised during this season.

o Summer, the hottest season. It starts in February and continued till rains commence in June. Usually crops are raised under irrigation.

The mean seasonal maximum temperature is 32.5°c and the minimum is 10.0°c. The daily pan evaporation ranges from 0.6 to 7.2 mm.

3.1.3 Soil

The experimental site used was a Vertisol (Typic Pellustert, Kasireddipalli series), medium deep (1.5 m) with a pH of 8.5, EC of 0.58 m. mhos/cm, organic carbon of 0.4% and a bulk density of 1.3 g/cc.

3.2 EXPERIMENTAL DETAILS

3.2.1 Treatments

Three irrigation levels were used. These were:

1) No irrigation or control(Io).
2) 20 mm irrigation level given at nodal root initiation (I1).
3) 20 mm at nodal root initiation plus 25 mm at panicle initiation making a total of 45 mm (I2).

All irrigations were given using sprinkler system during the night time when wind velocity was at a minimum. The germination of the crop was effected by 20.4

mm rainfall received immediately after sowing.

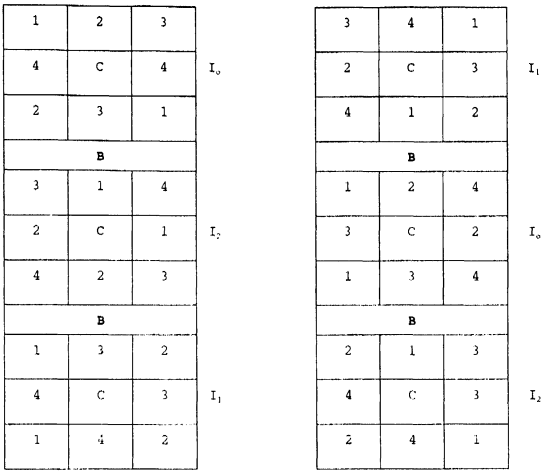
Four genotypes differing in their root characteristics were used (Soman p and Seetharama N 1992). Each genotype was repeated twice to give two sets. The genotypes were;

1) E36-1
2) LAKADI
3) M35-1
4) NAGA WHITE

3.2.2 Experimental Design and Layout

The treatments were arranged in a split plot design with nested classification in the subtreatments, with two replications.

Main plot treatments were three irrigation levels and the Sub plot treatments were four genotypes repeated twice within each main treatment giving two sets (or four total plots) for each genotype x treatment interaction. The field layout of the experiment at BL3 during *rabi* season 1992 is as follows:



Field layout of the experiment at BL3 during rabi season 1992.

Main Plots (Irrigation levels)

I_0 = Control (no irrigation); I_1 = 20 mm at nodal root initiation;
I_2 = 45 mm, 20 mm at nodal root initiation + 25 mm at panicle initiation.

Subplots (genotypes), each repeated twice to give two sets.

1 = E36-1; 2 = Lakadi; 3 = M35-1; 4 = Nagawhite

C = Center plot grown by M35-1 for mooisture observation.

B = Border plot also grown by M35-1.

Gross plot size = 9 x 3 m

Net harvested area = 2.5 x 1.5 m

The gross plot size was 9 meter length, 4 rows width, with a row spacing of 75 cm between rows. Total experimental area was 1782 m^2.

Before sowing a basal dose of 125 Kg/ha urea and 75 Kg/ha of diammonium phosphate was incorporated. Sowing was carried out using a precision John Deer Planter with four units. Seedling were thinned to a final spacing of 15-20 cm between hills at 3 weeks after emergence.

Intensive weed control (manual) and plant protection measures against pests, mainly the shoot fly, were carried out whenever necessary.

3.3 OBSERVATIONS AND MEASUREMENTS

3.3.1 Plant Growth Analysis

The plant growth analysis was done for both the root and the shoot systems starting two weeks after the emergence of the crop (2 WAE).

A) Underground portion

Plants were sampled at four different growth stages. These were;

1) First sample at nodal root initiation 2 WAE.
2) Second sample at panicle initiation 3 WAE.
3) Third sample at 50% flowering of each genotype 7-9 WAE.
4) Fourth sample at harvest stage of each genotype 14-16 WAE.

3.3.2 Sampling Procedure

During early growth stages (nodal root initiation, panicle initiation), as the plants were still young, coring for roots was not done. Instead plants were sampled by digging directly to an approximate depth of 60 to 75 cm. The aim was to recover as much as possible of their root systems. The area sampled was 50 cm length of two rows (1.5 m). At later growth stages (50% flowering and harvest) and as the root systems of the different genotypes were well developed, a coring method was used to estimate root growth. The following procedure was adopted:

1) A sampling area of two rows each 50 cm length was considered. Plants in this area were dug out to about 25 to 30 cm to recover all the nodal and brace roots attached to the shoot (i.e. nodal number).
2) The top 10 cm soil (after plants were dug) was removed and all visible remaining roots collected. The weight of the soil removed from this area was recorded.
3) A subsample of 10 Kg loose soil was taken, soaked in water overnight, sieved thoroughly to recover most roots.
4) Six cores, each 100 cm deep were taken in the sampling area after the 10 cm top soil removed. This was carried out by a coring cylinder 5 cm in diameter. The soil from the cores was also soaked in water overnight, sieved thoroughly and roots recovered.
5) The root weight in both loose (10 cm top soil) and core soil (100 cm

deep) were measured for each sub sample.

6) Total root weight on the top 10 cm was calculated from the sub sample.

7) Total root length was also calculated to the total sampling area from the sub sample cores.

8) The total root weight from both the 10 cm top soil and the 100 cm soil depth gave an estimate to the total root weight for each genotype at each irrigation treatment.

For total root length, the thick root portions were measured by a scale. For the thin portions a sub sample of 0.5 g (fresh weight) of the 10 cm top soil and of 5 g for the core samples were considered. The length of these was determined using a Delta T Area meter separately. Total length from both the top 10 cm soil and the cores were calculated based on the total root weight for each parameter.

The parameters recorded for the underground portion were;

3.3.3 Nodal Root Number

Nodal roots number were determined at each growth stage for each sample by counting directly.

3.3.4 Total Root Length

For this parameter the sample was separated into two portions;

i) The thick roots (> 0.5 mm diameter)

ii) The thin roots (< 0.5 mm diameter)

During early stages (nodal root initiation, panicle initiation), all roots were thin and accordingly their length was measured directly using a Delta T Area Meter (MK2) to give an estimate for nodal root length. During later stages (50% flowering, harvest), roots became thicker. The thicker portion was measured by a scale, the thin portion by a Delta T Area Meter (MK2). The values of thicker and thinner root portions gave an estimate of total nodal root length at these growth stages. Root length measurement was taken on fresh roots.

3.3.5 Total Root Mass

Roots were transferred to an oven at 80°C after their length was measured and dried for 48 hours. Root mass at each growth stage for each sample was determined.

3.3.6 Root Length Density

Root length density is the ratio of the root length in the sampling area to the soil volume in that area. Root length density was calculated during 50% flowering and harvest stages where coring was used.

B) Aboveground Portion

A sampling area of 0.75 m^2 (2 rows x 0.5 m) per plot was considered during each sample. Samples were taken at five growth stages, at nodal root initiation, panicle initiation, panicle development (5 WAE), 50% flowering and at harvest stages. Plant number in the sampling area was determined. Plants were transported to the lab, separated into leaf blades, stems, leaf sheaths and reproductive parts. The parameters recorded for aboveground portion were:

3.3.7 Plant Height

Plant height of different samples at each growth stage was measured for all genotypes. The plant height was measured from the base of the plant to the tip of the final leaf.

3.3.8 Leaf Number

Total green leaf number was determined at all growth stages except harvest time.

3.3.9 Leaf Area

From the destructive samples at each growth stage, leaf blades were separated, cleaned and leaf area determined. At nodal root initiation and panicle initiation leaf area was measured on the whole sample. At panicle development and 50% flowering, a subsample of 1/3rd total fresh leaf weight was measured. Leaf

area at harvest stage was not taken. Leaf area was determined using an LI- COR LI 3100 leaf area meter.

3.3.10 Leaf Dry Weight

Leaf blades were transferred to an oven at 80°C till constant weight was obtained. Leaf dry weights were recorded at each sample for different growth stages.

3.3.11 Stem Dry Weight

For each sample at each growth stage, stems and leaf sheaths were transferred to an oven at 80°C till constant dry weight was obtained. Dry weights for the four genotypes were recorded.

3.3.12 Shoot Dry Weight

The combined dry weights of stems, peduncles and leaves were considered to constitute the shoot dry weights for each genotype at each sample during different growth stages.

3.3.13 Total Plant Dry Weight

Shoot dry weights, panicles dry weights and root dry weights were summed to constitute total plant dry weight for each genotype at different samples during different growth stages.

3.3.14 Root/shoot Ratio

The proportion of root weight to shoot weight was calculated to constitute root/shoot ratio for all samples at different growth stages.

3.3.15 Stover Dry Weight

The genotypes were evaluated to their ability to produce stover at harvest stage. The shoot and panicle dry weights minus seed dry weight gave an estimate to the stover dry weight.

3.3.16 Biomass

The sum of the shoot, and panicle dry weights at harvest gave an estimate to total aboveground biomass.

3.3.17 Yield and Yield Components

The final sample with an area of 250 cm length of two rows each 75 cm spacing (2.5 x 1.5 m) was harvested. The number of plants harvested were counted, panicles separated and oven dried at 80°C till a constant weight was obtained. The following yield parameters were measured:

1) Panicle length
2) Grain number per panicle
3) Panicle weight
4) 100 seed weight

After oven drying, heads were threshed manually and yield determined.

3.3.18 Harvest Index (HI)

The proportion of biological yield transferable to economic yield is the HI.

It is worth mentioning that the underground and aboveground portions were not significant with respect to the following parameters, and their probabilities were not given in the analysis of variance table, these were:

i) Sets

ii) Irrigation x sets

iii) Set 1 VS set 2

iv) Irrigation x set 1 VS set 2

v) Genotype x set 1 VS set 2

vi) Irrigation x genotype x set 1 VS set 2

3.4 NUTRIENT ANALYSIS

The analysis of nutrient was carried out at two growth stages, at 50% flowering and at harvest stages. At 50% flowering, leaves, stems and panicles were mixed grounded together. At harvest, the nutrient analysis was carried out for both seed and the rest of the plant. The following observations were recorded at each growth stage:

1) Percent nitrogen and phosphorous.

2) Total nitrogen and phosphorous in the plant.

3.5 WATER USE AND WATER USE EFFICIENCY

The amount of water used to a depth of 100 cm as well as the efficiency of using water at each irrigation level was calculated. The equation used for the calculation was:

ET = Change in soil water content + Irrigation + Rainfall - Drainage - Runoff

The drainage and run off were assumed to be nil during the *rabi* season.

Where ET stands for evapotranspiration.

RESULTS

CHAPTER IV

RESULTS

4.1 CLIMATE

The meteorological data during the experimental period at ICRISAT Center are shown as **Appendix 1**. Total rainfall during the period was 100.6 mm. The maximum was received during week 46 coinciding with the growth stages of panicle development and 50% flowering. The crop was given no irrigation other than the treatments under study.

The daily maximum and minimum atmospheric temperatures were recorded for all the weeks of the experimental period (Fig. 1 and Appendix 1). In addition to this also the air temperature and the soil temperature (2 and 5 cm soil depth) was monitored during the life cycle of the crop (Fig. 2 and **Appendix 2**).

4.2 UNDERGROUND PORTION

4.2.1 Nodal Roots, Total Root Length and Total Root Mass Per Plant During the Season

At the end of the growing season, the irrigation seedling treatments were significantly different with respect to nodal roots, total root length and total root mass per plant (Table 1, Fig. 3,5,7). Genotypes were also significantly different for the root variables measured, but the differences among genotypes differed for

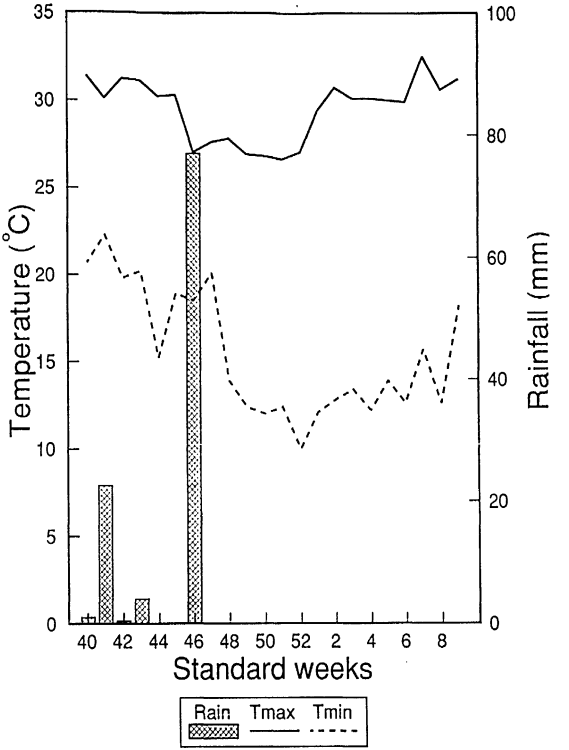


Fig. 1. Temperature (Max. and Min.°C) and rainfall (mm) during the growing season

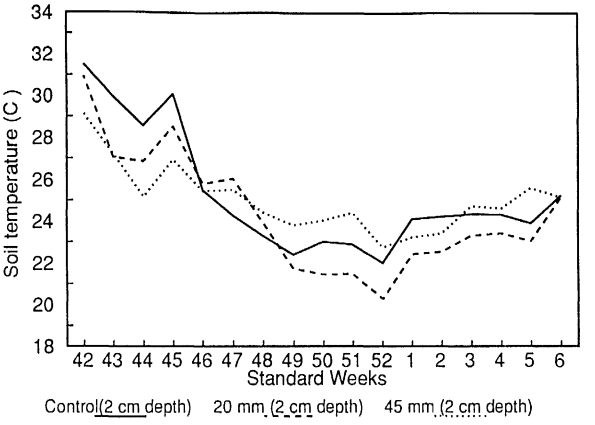


Fig. 2a. Soil temperature (°C) at 2 cm soil depth

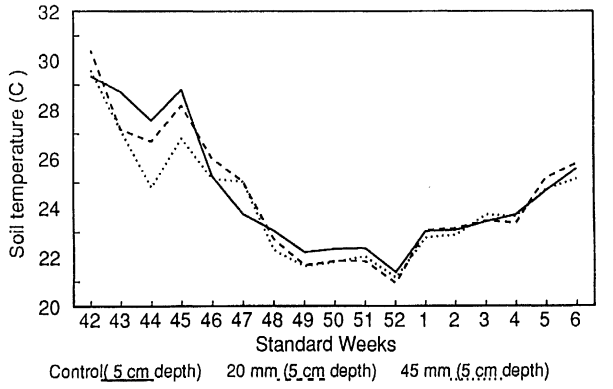


Fig. 2b. Soil temperature (°C) at 5 cm soil depth

Table 1. **Analysis of varience table showing degrees of freedom (DF), F-Probability (F-PR) for nodal root number per plant ($NRPL^{-1}$), total root length per plant ($TRLPL^{-1}$) and total root mass per plant ($TRMPL^{-1}$).**

Source of Variation	DF	F-PR		
		$NRPL^{-1}$	$TRLPL^{-1}$	$TRMPL^{-1}$
Sample	3	xxx	xxx	xxx
Irrigation	2	xx	x	x
Sample x irrigation	6	-	-	-
ST1 VS ST2	1	-	-	-
Genotypes	3	xxx	xxx	xxx
Sample x ST1 VS ST2	3	-	+	-
Irrigation x ST1 VS ST2	2	-	-	-
Sample x genotype	9	xxx	xxx	xxx
Irrigation x genotype	6	-	-	-
ST1 VS ST2 x genotype	3	-	-	-
Sample x irrigation x ST1 VS ST2	6	-	-	-
Sample x irrigation x genotype	18	-	-	-
Sampl. x ST1 VS ST2 X Geno.	9	-	-	-
Irrigation x ST1 VS ST2 x genotype	6	-	-	-
CV(%)		8.1	29.8	20

- Not significant
xxx $P< 0.001$
xx $P< 0.01$
x $P< 0.05$
+ $P< 0.10$

different root variables. M35-1, Naga White, and Lakadi had a maximum of 18 nodal roots per plant compared to 14 nodal roots per plant for E36-1. Total root length per plant for E36-1, Lakadi, and M35-1 reached a maximum of 13000-15000 cm per plant compared to only 7400 cm per plant for Naga White. The same genotypes scored a maximum total root mass of 3-4 g per plant compared to 2.6 g per plant for Naga White (Fig. 4,6,8). In Naga White the greater nodal roots per plant were not reflected in maximum total root lengths per plant or total root mass per plant.

4.2.2 Nodal Roots, Total Root Length and Total Root Mass Per Plant During Different Growth Stages

Nodal roots, total root length, and total root mass per plant increased rapidly during the various growth stages during the season irrespective of irrigation levels and they reached a maximum by either flowering for nodal roots per plant (Kanitkar *et al.*, 1986, Myers, 1980), (Fig. 9) or by flowering or harvest time for total root length and total root mass per plant (Fig. 11,13). The irrigation seedling treatments were significantly different for the root variables at early growth stages (Nodal root initiation, panicle initiation) for nodal root number and total root length per plant but only at nodal root initiation for total root mass(Fig. 9,11,13).

The four genotypes showed a grand growth between the growth period panicle initiation and 50% flowering for nodal roots, total root length and total root mass per plant as compared to either initial growth stages (nodal root initiation,

panicle initiation) or later growth stages (50% flowering, harvest) (Fig. 8,10,12). The genotypes were significantly different at 50% flowering for all the root parameters and at panicle initiation and harvest for total root length and at harvest for total root mass(Fig. 10,12,14)

4.2.3 Root Length Density

Root length density (cm root length cm^{-3} soil volume) was maximum at 50% flowering for M35-1 and Lakadi (0.25,0.26). Root length density continued to increase but with a lesser magnitude for E36-1 and Naga White even after 50% flowering (Table 2). At 50% flowering and harvest, the difference between the four genotypes were significant(Table 3).

The effect(s) of irrigation levels on root length density were in agreement with other results (ICRISAT, 1989). With the control treatment, root length density decreased between 50% flowering and harvest growth stages. With 45 mm seedling irrigation level, root length density continued to increase between the two growth stages presumably due to root branching at deeper horizons in the 45 mm seedling treatment. The difference between irrigation levels at both growth stages were not significant (Table 2 and 3)

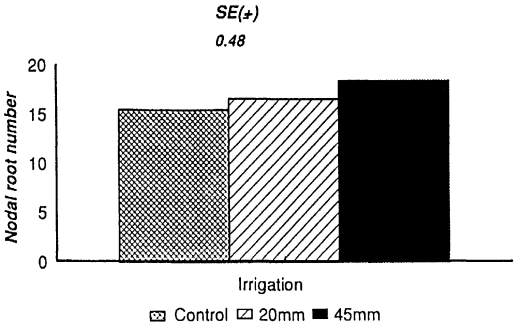


Fig. 3. Nodal root number per plant at the end of the season as a function of irrigation treatments

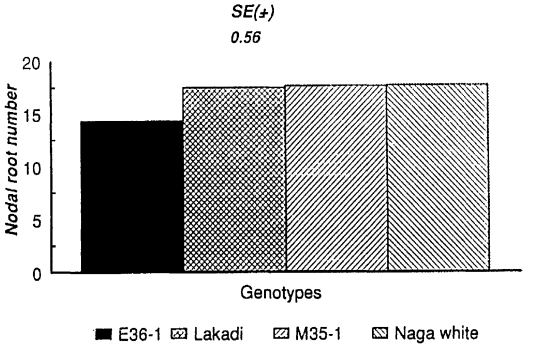


Fig. 4. Nodal root number per plant of four genotypes at the end of the season

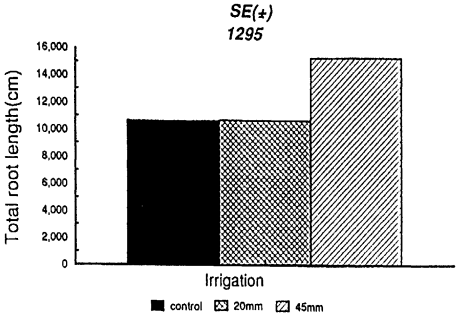


Fig. 5. Total root length per plant as a function of irrigatio
at the end of the season

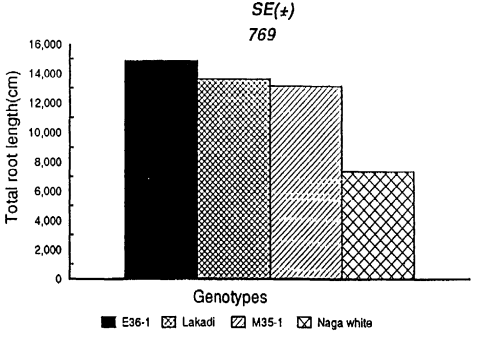


Fig. 6. Total root length per plant of four genotypes at the end of the season

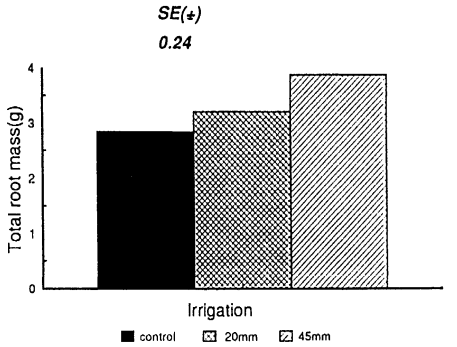


Fig. 7. Total root mass per plant at the end of the season as a function of irrigation treatments

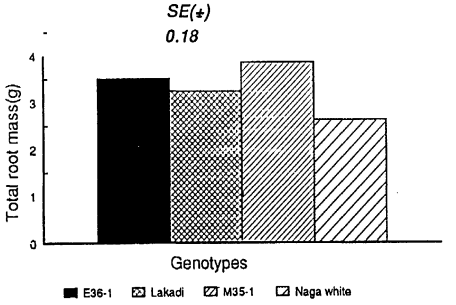


Fig. 8. Total root mass per plant of four genotypes at the end of the season

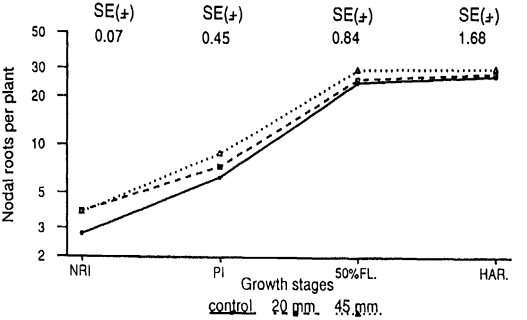


Fig. 9. Nodal roots per plant for irrigation treatments at four growth stages

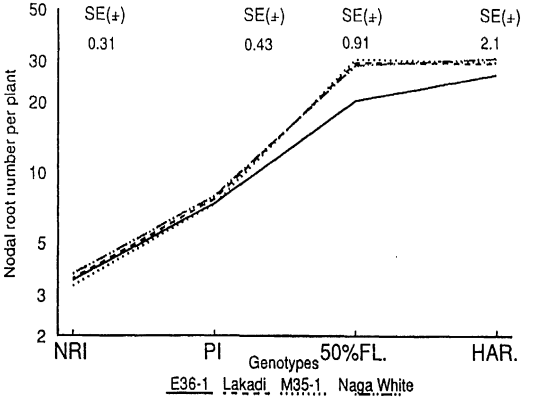


Fig. 10. Nodal root number per plant of four genotypes at four growth stages

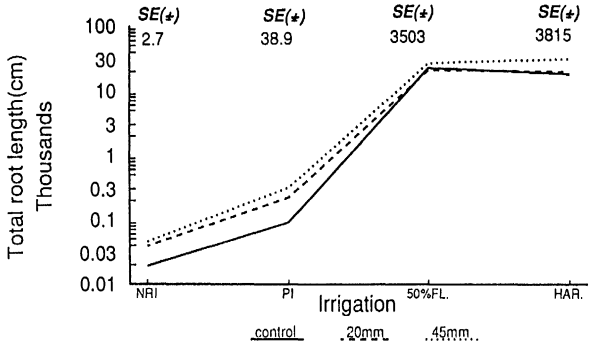


Fig. 11. Total root length at four growth stages as a function of irrigation treatments

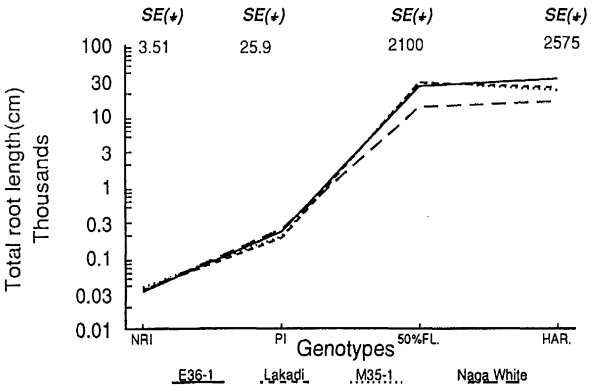


Fig. 12. Total root length per plant for four genotypes at four growth stages

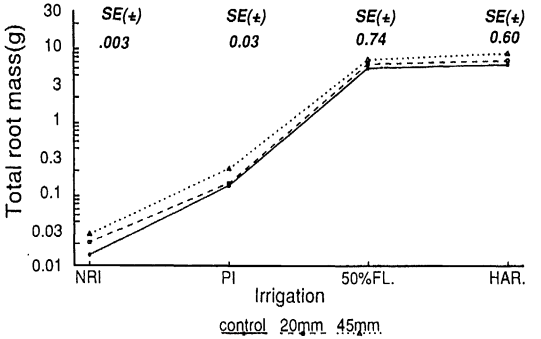


Fig. 13. Total root mass per plant(g) function of irrigation at four growth stages

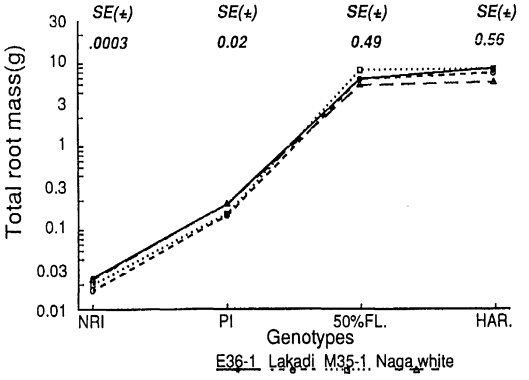


Fig. 14. Total root mass per plant(g) at four growth stages for four genotypes

Table 2. **Mean root length density values (cm/cm^3) for genotpes and irrigation treatments at 50% flowering (50% FL.) and harvest (HAR).**

Genotype/Irrigation	Root length density (cm/cm3)	
	50% FL.	HAR
E36-1	0.21	0.28
Lakadi	0.26	0.23
M35-1	0.25	0.20
Naga White	0.11	0.13
SE(±)	0.01	0.02
CV(%)	17.5	20.7
I0	0.20	0.17
I1	0.19	0.18
I2	0.23	0.28
SE(±)	0.03	0.03
CV(%)	27.7	33.8

Table 3. Analysis of Variance table for root length density showing degrees of freedom (DF), F-Probability values (F-PR) at 50% flowering (50%FL.) and harvest (HAR).

Source of variation	DF	F-PR at	
		50% FL.	HAR
Irrigation	2	-	-
ST1 VS ST2	1	-	-
Genotype	3	xxx	xxx
Irrigation ST1 VS ST2	2	-	-
Irrig. x Geno.	6	-	-
ST1 VS ST2 X Geno.	3	-	-
Irrig. x ST1 VS ST2 x Geno.	6	-	-

- Not signnificant
xxx P< 0.001

4.3 ABOVEGROUND PORTION

4.3.1 Stem Dry Weight, Leaf Dry Weight, Shoot Dry Weight and Total Plant Dry Weight Per Plant

Stem dry weight, leaf dry weight, shoot dry weight and total dry weight per plant for irrigation levels as well as the four genotypes were significantly different from each other at the end of the season (Table 4 and Figs. 15,16).

The stem, leaf, shoot, and total dry weights increased steadily right from nodal root initiation stage till all reached a maximum by harvest time for both irrigation levels and genotypes. The growth stage between panicle initiation, panicle development was the active growth period and during it a 10-16 folds increase in stem dry weight compared to only 4-7 folds increase for the same parameter during the growth period panicle development, 50% flowering (Fig. 17).

Genotypes were significantly different for all aboveground parameters during growth stages, nodal root initiation, 50% flowering and harvest(Fig. 19,21,23,25). Irrigation seedling treatments were not significantly different for all the parameters at all growth stages except at 50 % flowering for leaf dry weight per plant (Fig. 18, 20, 22, 24).

The interaction of irrigation x genotype was significant (Fig. 26).

Table 4. **Analysis of variance table for stem dry weight(STDWPL^{-1}) leaf dry weight (LFWPL^{-1}), shoot dry weight (SHDWPL^{-1}), and total plant dry weight (TDWPL^{-1}) showing degrees of freedom (DF) and F-Probability (F-PR).**

Source of variation	DF	F-PR			
		STDWPL^{-1}	LFDWPL^{-1}	SHDWPL^{-1}	TDWPL^{-1}
Sample	3	xxx	xxx	xxx	xxx
Irrigations	2	xx	xx	xx	xx
Sample x Irrigation	6	+	x	x	x
ST1 VS ST2	1	-	-	-	-
Genotypes	3	xxx	xxx	xxx	xxx
Sample x ST1 VS ST2	3	-	-	x	x
Irrig. x ST1 VS ST2	2	-	-	-	-
Sample x Genotype	9	xxx	xxx	xxx	xxx
Irrig. x Geno.	6	-	-	-	-
ST1 VS ST2 X Geno.	3	-	-	-	-
Samp.xIrrig.xST1 VS ST2	6	-	-	-	-
Samp.xIrrig. x Geno	18	-	-	-	-
Samp. ST1 VS ST2 x Geno.	9	-	-	-	-
Irrig. ST1 VS ST2 x Geno.	6	-	-	-	-
CV(%)		20.2	15.9	18.5	14

- Not significant
xxx P< 0.001
xx P< 0.01
x P< 0.05
+ P< 0.1

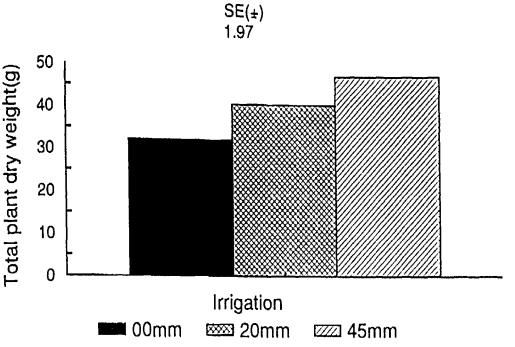


Fig. 15. Total plant dry weight per plant(g)at the end of the season as a function of irrigation treatments

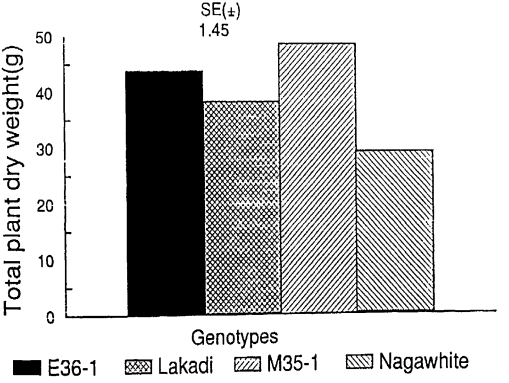


Fig. 16. Total plant dry weight(g)at the end ofthe season function of genotypes

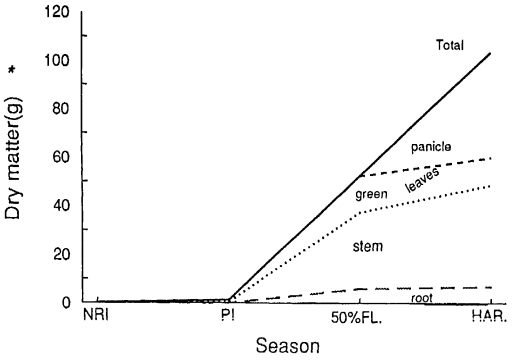


Fig. 17. Above-ground total dry matter production per plant in relation to under-ground total dry matter production per plant

**** Means of irrigations and genotypes***

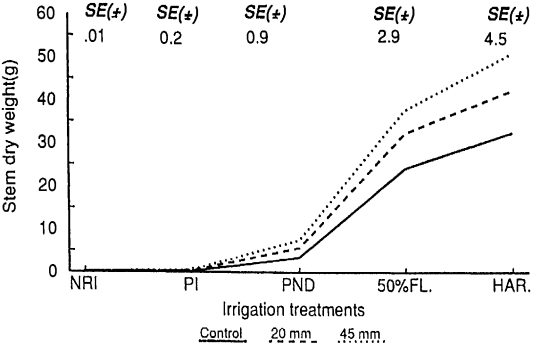


Fig. 18. Stem dry weight per plant(g) during five growth stages as affected by irrigation treatments

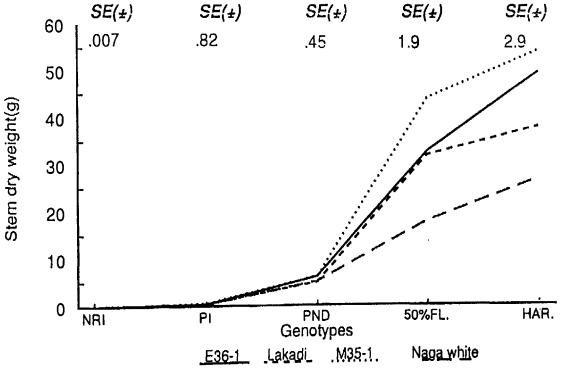


Fig. 19. Stem dry weight per plant(g) for four genotypes at five growth stages

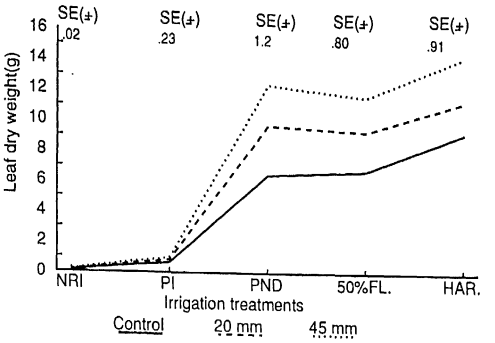


Fig. 20. Leaf dry weight per plant(g) during five growth stages as a function of irrigation treatments

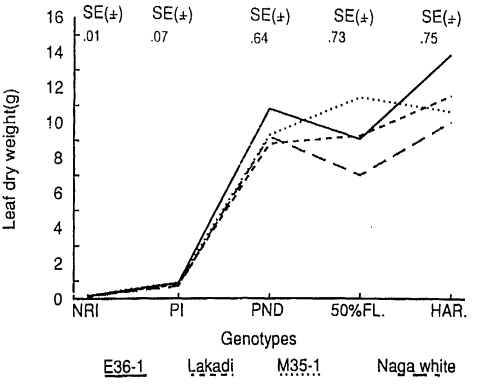


Fig. 21. Leaf dry weight per plant(g) during five growth stages as a function of genotypes

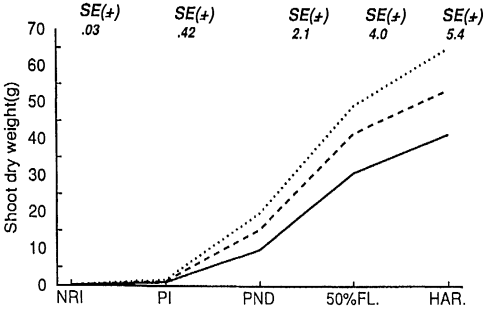


Fig. 22. Shoot dry weight per plant(g) during five growth stages function of irrigation treatments

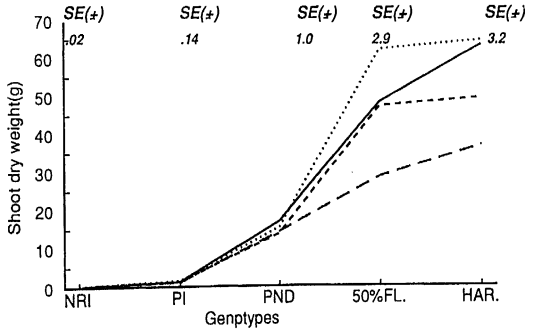


Fig. 23. Shoot dry weight per plant(g) during five growth stages function of genotypes

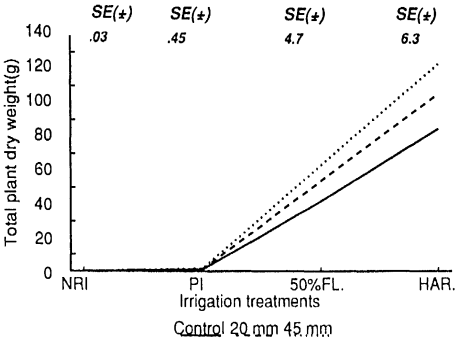


Fig. 24. Total plant dry weight(g) at four growth stages function of irrigation treatments

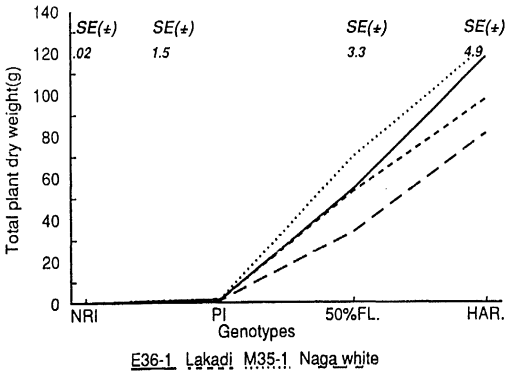


Fig. 25. Total plant dry weight(g) of four genotypes at four growyh stages

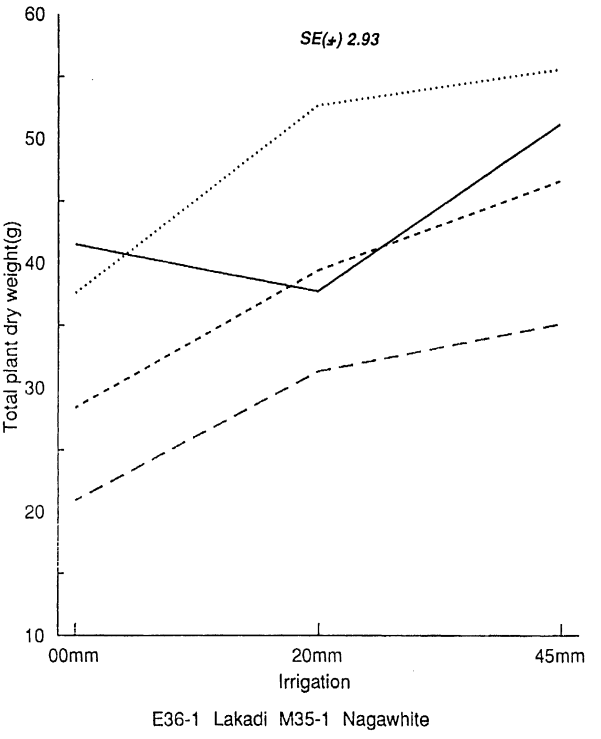


Fig. 26. Total plant dry weight(g) as a function of irrigation x genotype interaction

4.3.2 Root/Shoot Ratio

The root/shoot ratio increased during the season irrespective of the level of irrigation till it reached a maximum by 50% flowering and then declined with time (Fig. 27). The same trend was observed for the four genotypes. At anthesis as well as nodal root initiation and panicle initiation, the genotypes were significantly different from each other, but not the irrigation seedling treatments (Fig. 28). The anthesis values for Naga White, Lakadi, E36-1 and M35-1 were 0.21, 0.15, 0.14, and 0.14 respectively. At anthesis when roots were well developed, the root/shoot ratio for the control was greater than that of the 20 mm or 45 mm irrigation seedling treatments. This may be to more moisture effects manifestations on the shoot system rather than the root system.

4.3.3 Green leaf Area(cm^2) and Leaf Number Per Plant

Leaf area (cm^2) and leaf number per plant increased rapidly during the season reaching their maximum magnitude between panicle development and 50% flowering stages. At 50% flowering stage, leaf area and leaf number per plant decreased due to senescence (Table 5). Genotypes were significantly different at nodal root initiation for leaf area and leaf number, and at panicle development for leaf number only. The irrigation seedling treatments were only significant at 50% flowering for leaf area (Table 5).

Table 5. **Mean leaf area and leaf number as a function of irrigation seedling treatments and genotypes.**

Irrig./ Geno.	LA (cm^2)				LN			
	NRI	PI	PND	50%FL	NRI	PI	PND	50%FL
I0	24.2	109	1598	1280	5.1	6.9	9.8	9.0
I1	26.4	167	2362	1874	4.9	6.7	9.8	9.0
I2	31.9	232	3128	2291	5.1	6.9	10.3	9.1
SE(±)	5.8	59.1	310	124	0.1	0.2	0.3	0.04
CV(%)	41.2	34.2	25.5	29	9.2	7.0	7.7	1.6
E36-1	27.4	181	2578	1635	4.8	6.8	10.3	9.0
Lakadi	23.1	163	2215	1633	5.6	7.0	10.5	9.0
M35-1	38.0	185	2177	2035	4.8	6.5	10.3	9.1
Naga White	21.5	147	2481	1959	5.0	7.0	8.8	9.0
SE(±)	2.3	16.7	174	152	0.1	0.1	0.2	0.04
CV(%)	41.2	34.2	25.5	29	9.2	7.0	7.7	1.6

LA: Leaf area
LN: Leaf number

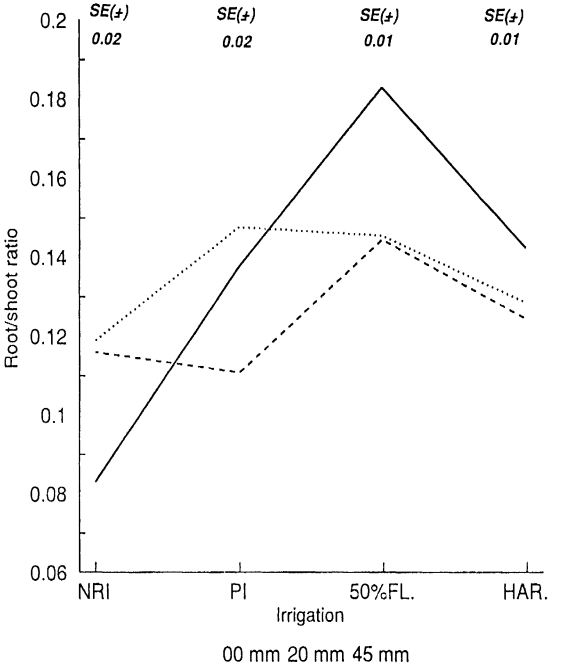


Fig. 27. Root/shoot ratio as affected by irrigation treatments during four growth stages

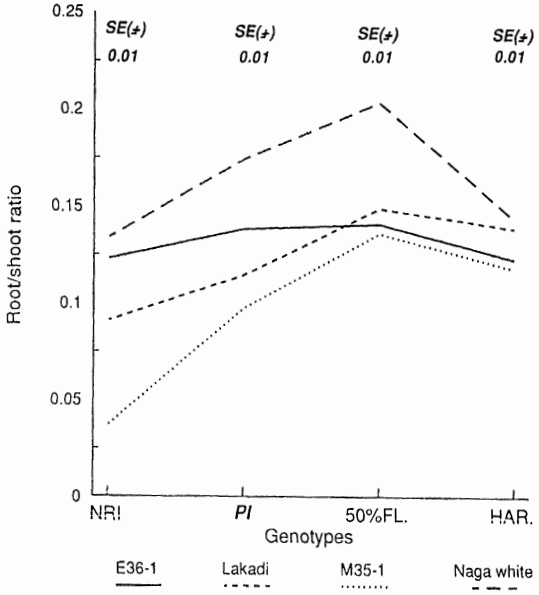


Fig. 28. Root/shoot ratio of four genotypes at four growth stages

4.4 YIELD AND YIELD ATTRIBUTES

4.4.1 Plant Height, Panicle Length, Grain Number Per Panicle, 100 Seed Mass, Yield, Stover Weight, Biomass and Harvest Index, Function of Irrigation and Genotypes

Differences between irrigation levels were not significant with respect to grain number per panicle, 100 seed mass, yield, stover weight, biomass, and harvest index, but the differences were significant for plant height and panicle length (Table 6). Genotypes were significantly different for plant height, panicle length, 100 seed mass, yield, stover weight, biomass, and harvest index (Table 7). At harvest, M35-1 with a maximum yield of 3.25 T/ha where as Naga White had a minimum of 1.56 T/ha (Fig. 29). By applying 20 mm and 45 mm irrigation seedling treatments the yield advantage in biomass production over the control was 1.24 and 1.70 T/ha respectively.

4.4.2 Interaction Effect

The irrigation x genotype interaction was significant with respect to plant height and grain number per panicle (Table 8). The Naga White genotype although with greater number of grains per panicle but it was not reflected into maximum yield presumably due to low 100 seed mass (Table 7).

Table 6. **Plant height (PLH), panicle length (PNL), grain number per panicle ($GRNPN^{-1}$), 100 seed mass (100SM), yield, stover weight (STOWT), biomass (BIO), and harvest index (HI) as affected by irrigation treatments.**

Irrig.	PLH (cm)	PNL (cm)	$GRNPN^{-1}$	100 SM (g)	Yield (T/ha)	STOWT (T/ha)	BIO (T/ha)	HI
I0	152	15.8	1004	3.15	2.30	3.45	5.75	0.40
I1	172	18.0	1222	3.21	2.61	4.38	6.99	0.37
I2	178	18.7	1306	3.25	2.74	4.71	7.45	0.37
SE(±)	3.17	0.34	43.2	0.18	0.27	0.42	0.67	0.01
CV(%)	4.16	5.70	5.2	8.00	14.70	14.20	14.10	13.0

Table 7. **Plant height (PLH), panicle length (PNL), grain number per panicle ($GRNPN^{-1}$), 100 seed mass (100SM), yield, stover weight (STOWT), biomass (BIO.), and harvest index (HI) of four genotypes.**

Geno.	PLH (cm)	PNL (cm)	$GRNPN^{-1}$	100 SM (g)	Yield (T/ha)	STOWT (T/ha)	BIO (T/ha)	HI
E36-1	156	20.3	1096	3.60	2.93	4.49	7.42	0.40
Lakadi	154	8.9	1114	3.08	2.48	4.92	7.39	0.34
M35-1	212	18.5	1182	3.69	3.25	5.55	8.80	0.37
Naga white	148	22.2	1318	2.45	1.56	1.75	3.31	0.47
SE(±)	2.23	0.29	60.8	0.08	0.19	0.20	0.33	0.01
CV(%)	4.6	5.7	5.2	8.0	14.7	14.2	14.1	13.0

Table 8. **Irrigation x genotype interaction of plant height (PLH) and grain number per panicle ($GRNPN^{-1}$).**

	E36-1		Lakadi		M35-1		Naga white	
	PLH (cm)	$GRNPN^{-1}$	PLH (cm)	$GRNPN^{-1}$	PLH (cm)	$GRNPN^{-1}$	PLH (cm)	$GRNPN^{-1}$
I0	150	1137	137	1000	187	989	136	891
I1	158	0999	157	1097	223	1241	151	1553
I2	159	1153	169	1245	228	1317	159	1511
SE(±)	4.6 PLH	101 $GRNPN^{-1}$						
CV(%)	4.6 PLH	5.20 $GRNPN^{-1}$						

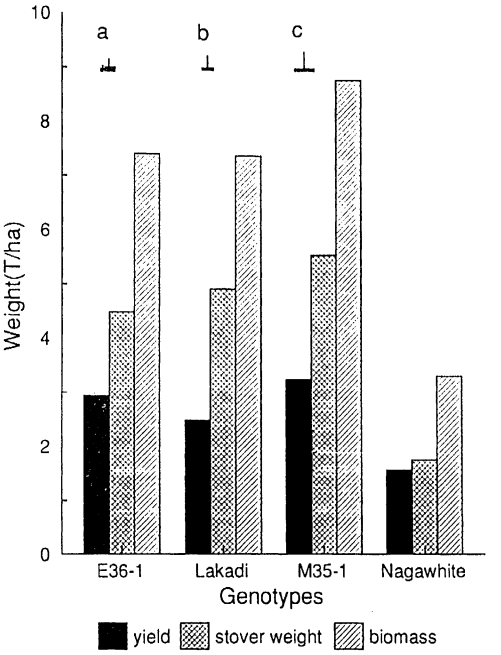


Fig. 29. Yield, stover weight and biomass(T/ha) of four genotypes at harvest

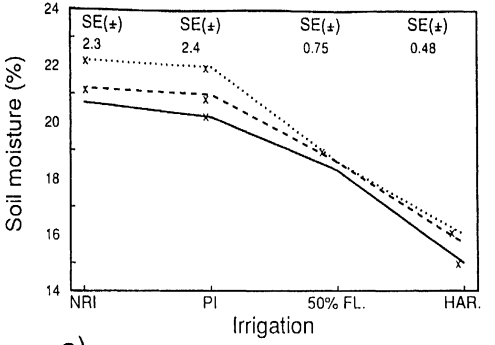
* Vetical bars are standard errors, a (for yield),b (for stover weight) and c (for biomass)

4.5 WATER USED AND WATER USE EFFICIENCY

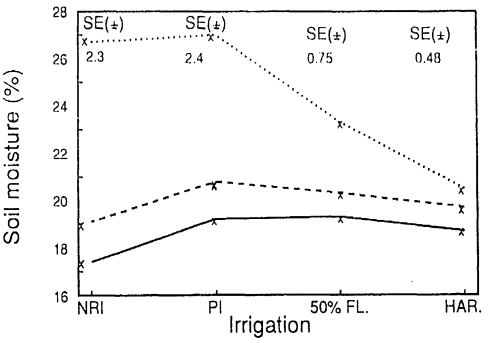
Water use efficiency was higher with the control treatment and low at the 45 mm seedling irrigation level (Table 9). The total amount of water used by the crop during the season seemed to be low presumably due to the fact that the profile was only sampled to a depth of 100 cm. The values of water used by the crop were significantly different for the 45 mm irrigation seedling level as compared with the other treatments. The per cent soil moisture for irrigation treatments at 0-50 and 50-100 cm soil depth were significant at early stages (Fig. 30).

4.6 NUTRIENT ANALYSIS

Most of the nutrient parameters were not significantly different at 50% flowering or at harvest growth stages (Table 10 and 11). This may imply that the irrigation levels had no significant impact on nutrient absorption and the differences between genotypes were due mainly to differences between the irrigation seedling treatments and not to differences in nutrient availability to the genotypes.



a)



b)

Fig. 30. % soil moisture at a) (0-50 cm) and b) (50-100 cm) soil depth for irrigation seedling treatments at four growth stages

Table 9. Water used and water use efficiency (WUE) at different irrigation treatments.

Irrigation Treatment	Yield T/ha	Biomass T/ha	Water used mm	WUE(*) Kg grain/ha/mm	WUE(*) Kg Bio./ha/mm
Control	2.30	5.75	128	18.0	44.9
20 mm	2.62	6.99	173	15.1	40.4
45 mm	2.74	7.45	225	12.2	33.1
SE(±)	0.27	0.67	30.1	1.6	3.5
CV(%)	14.7	14.1	12.2	13.1	14.3

* The profile was sampled to a depth of 100 cm.

Table 10. **Nutrient analysis at flowering and harvest showing the per cent nitrogen and phosphorous at flowering (%NFL), (%PFL), and harvest stages (%NHAR), (%PHAR) and total nitrogen and phosphorous at both stages (TNFL), (TPFL), (TNHAR), (TPHAR).**

Irr./ Gen	%NFL	%PFL	TNFL (gN/m^2)	TPFL (gP/m^2)	%NHAR	%PHAR	TNHAR (gN/m^2)	TPHAR (gP/m^2)
I0	1.75	0.25	5.34	0.77	0.72	0.09	2.85	0.36
I1	1.62	0.24	6.88	0.99	0.63	0.08	2.92	0.38
I2	1.65	0.22	7.50	0.99	0.73	0.08	3.91	0.43
SE (±)	0.08	0.02	0.67	0.13	0.11	0.002	0.68	0.04
1	1.57	0.23	6.06	0.89	0.77	0.09	3.94	0.43
2	1.81	0.26	6.60	0.93	0.64	0.08	2.73	0.34
3	1.63	0.23	6.75	0.94	0.58	0.07	2.94	0.35
4	1.70	0.23	6.89	0.93	0.79	0.11	3.31	0.44
SE (±)	0.06	0.008	0.46	0.07	0.004	0.004	0.27	0.03
CV (%)	12.7	11.6	14.4	20.0	19.9	17.9	29.5	13.8

NB
1 E36-1
2 Lakadi
3 M35-1
4 Naga white

Table 11. **Nitrogen and phosphorous percentage in the grain (%NGR, %PGR) and total nitrogen and phosphorous both in the grain and the whole plant (TNGR; TPGR; TNWP; TPWP).**

IRR. GEN.	%NGR	%PGR	TNGR (gN/m^2)	TPGR (gP/m^2)	TNWP (gN/m^2)	TPWP (gP/m^2)
I0	1.44	0.35	4.15	1.00	7.00	1.36
I1	1.51	0.34	5.00	1.14	7.92	1.53
I2	1.47	0.32	5.02	1.07	8.93	1.50
SE(±)	0.09	0.03	0.33	1.00	1.00	0.12
1	1.53	0.30	4.84	0.95	8.78	1.37
2	1.49	0.36	4.94	1.16	7.67	1.49
3	1.43	0.29	4.71	0.95	7.65	1.30
4	1.43	0.40	4.40	1.23	7.71	1.67
SE(±)	0.03	0.01	0.33	0.09	0.46	0.10
CV(%)	6.3	15.0	9.9	13.6	17.9	11.3

NB
1 E36-1
2 Lakadi
3 M35-1
4 Naga white

DISCUSSION

CHAPTER V

DISCUSSION

5.1. UNDERGROUND GROWTH DURING NODAL ROOT INITIATION AND PANICLE INITIATION

At nodal root initiation, the seedling irrigation treatments were significant for all the underground attributes. At panicle initiation, nodal root numbers and total root length per plant were significant but not the total root mass.

Genotypes at both nodal root and panicle initiation stages were not significant except for total root length at panicle initiation time, and as a result the initiation of nodal roots for genotypes proceeded without being severely reduced (Jordan *et al.*, 1979a). The root length was the most sensitive root parameter to seedling stage soil moisture treatments. This was evident from the significant variation in root length between genotypes at panicle initiation, but not in the other root parameters (nodal numbers and total root mass).

5.2 ABOVEGROUND PORTION AT EARLY GROWTH STAGES

In contrast to the underground root parameters, the aboveground portion (stem, leaf, shoot and total plant dry weight) at early growth stages (nodal root initiation, panicle initiation and panicle development) continued without variation

between the irrigation seedling treatments. This may be due to differential nodal root initiation (due to irrigation treatments not inflicting significant aboveground variation as the nodal roots were still young at these stages).

Genotypes showed a significant variation in aboveground attributes at nodal root initiation stage but not at panicle initiation and panicle development. The slight difference observed between genotypes at panicle initiation suggests the existence of a balance between above and underground growth parameters, and accordingly the different genotypes had the same under and aboveground differences at this stage.

5.3 ABOVEGROUND PORTION AT LATER STAGES

By harvest time, the aboveground parameters (stem, leaf, shoot and total plant dry weight) reached their maximum. At 50% flowering and harvest time the seedling irrigation treatments did not vary between them, but there was a trend of increase in aboveground portions with 45 mm seedling irrigation treatment as compared to 20 mm or control treatment. Leaf area but not leaf number was significantly different at 50% flowering for irrigation treatments.

Genotypes at both 50% flowering and harvest time showed a significant vacation between them and this was particularly true for M35-1 and E36-1 with respect to stem, leaf, shoot and total plant dry weight. The values of green leaves area and their number at 50% flowering were lower as compared to those at panicle

development stage presumably due to leaf senescence at 50% flowering.

5.4 UNDERGROUND PORTION AT LATER STAGES

The increase in root parameters (nodal root number, total root length and total root mass) and its termination with a maximum either at 50% flowering or harvest was in agreement with other studies (Myres, 1980; Fukai *et al.*, 1986). The irrigation seedling treatments though were not significant at 50% flowering and harvest time for underground portions, but tended to increase at both stages with 45 mm seedling treatment. Genotypes were significant for all the root parameters both at 50% flowering and harvest time.

5.5 NUTRIENT AND WATER UPTAKE

Although the nutrient and water uptake did not reach the significant level for both the seedling irrigation treatments and genotypes, but there was a consistent increase in the amount of water used and nutrient uptake with 45 mm treatment compared with 20 mm and control. The nutrient uptake during 50% flowering was consistently greater for Naga White, lakadi and M35-1. This was due to greater secondary root initiation in these genotypes as compared to E36-1 (Fig. 10). The low final yield in Naga White may be due to less adaptations of this genotype to *rabi* environment and the early flowering. The final greater yield in E36-1 may be due to more adaptations and more compensatory growth mechanisms in root characteristics.

In this study, it was evident that, the significant differences in the secondary root growth between the seedling irrigation treatments and its tendency to vary between genotypes during early growth stages (nodal root initiation and panicle initiation) had contributed to better crop water and nutrient uptake. This was clear from the greater nutrient uptake at 50% flowering and harvest in 45 mm seedling treatment and its tendency to increase further (particularly for N) with M35-1 and E36-1. This point may help explaining the significant differences between genotypes in the aboveground characters at later stages, which was presumably due to differential secondary root growth with varying surface soil moisture and genotypes at early stages, which was differentially capable to support plant waters and nutrient uptake and resulted in an ultimate significant growth observed in root parameters at later stages.

5.6 ROOT LENGTH DENSITY

The effect of irrigation levels on root length density was comparable with other studies (ICRISAT, 1989). The root length density continued to decrease between the growth stages (50% flowering and harvest time) due to control treatment, where the root length density continued to increase between the growth stages with 45 mm irrigation seedling level. This may be due to more root branching at deeper soil layers contributing to total root length density in 45 mm irrigation seedling treatment (ICRISAT, 1989). This study has also shown that the root length density can continue to increase even after flowering. The low root

length density values of Naga White as compared to other genotypes at the two stages and with its final low yield might suggest the importance of the root length density to yield. It is to be mentioned that, Naga White was not an adapted *rabi* cultivar and it is a photoperiodic sensitive cultivar and flowered earlier than the other genotypes.

Table 12. Relationship between root length density (RLD) at harvest and yield for four genotypes.

Genotype	RLD cm/cm^3	Yield
E36-1	0.28	2.93
Lakadi	0.23	2.48
M35-1	0.20	3.25
Naga White	0.13	1.56
SE (±)	0.02	0.19
CV (%)	20.7	14.7

5.7 ROOT/SHOOT RATIO

The significant increase in the root/shoot ratio at nodal root initiation and panicle initiation may be explained by the greater root activity and development at early growth stages as compared to that of the shoot system. The decline in the ratio after 50% flowering was also noticed in different studies (Wani *et al.*, 1988). The low root/shoot ratio at maturity (as compared to 50% flowering values) was presumably due to the reduced root growth after flowering or the death of root

portions after 50% flowering where nutrients and assimilates are directed towards the grain. The low root/shoot ratio was reported to be advantageous in suppressing the weed growth under most conditions (Evetts *et al.*, 1973), a point in favour of M35-1 and E36-1.

5.8 YIELD AND YIELD ATTRIBUTES

Though the seedling irrigation treatments had no effect on final grain number and 100 seed mass, but it seemed that the early large growth differences between irrigation seedling treatments have an impact on final harvested grain number. The increasing influence with time factors such as compensatory root growth, soil water depletion, etc., may have had played a major role to counter act the effects of the irrigation seedling treatments. This was evident from values near the boarder level of significance ($P<0.1$) (Table 13).

The significant differences between the different genotypes for all yield and yield components could be related to the significant differences in the root attributes (nodal root number, length and mass) resulted due to varying surface soil moisture levels during early growth stages. The initiation of the root parameters at early stage resulted in a well established shoot system produced on adequate supply of water and nutrients during subsequent growth stages (50 flowering, harvest) (Table 10 and 11). The combined effects of the root and shoot parameters resulted in a well developed source capable of supporting a well developed sink, since yield realization is the ultimate manifestation of the source potential. Due to this,

genotypes such as M35-1 which have the ability to initiate more secondary roots during early stages of growth (Fig. 4 and 18) are able to support the plant with adequate water and nutrients (more for M35-1) through subsequent growth and ultimately may have had contributed to yield (more for M35-1) (Fig. 29).

Table 13. Probabilities of difference among treatments for various measures of crop growth during nodal root initiation (NRI), panicle initiation (PI), 50% flowering (50% FL) and harvest (HAR).

	Treatment differences significant at P<			
	NRI	PI	50% FL	HAR
Nodal root number	0.01	0.11	0.09	0.53
Total root length	0.04	0.70	0.54	0.70
Total root mass	0.002	0.29	0.44	0.19
Total plant weight	0.54	0.60	0.16	0.10

SUMMARY

CHAPTER VI

SUMMARY

Sorghum (*Sorghum bicolor* (L.) Moench) is fifth in importance among cereals and sixth among important dietary sources of energy. Globally, it occupies 47 million ha with Asia as a leading continent (19.6 million ha) followed by Africa (15.7 million ha).

Though the majority of the crop is grown in the semi-arid tropics, but average farmer's yield are about 0.8 T/ha in comparison to 3.6 T/ha in the high technology, temperate regions. The potential yields in the semi-arid tropics are limited by the length of the growing season, rainfall and water holding capacity of the soils (Seetharama et al., 1988).

In india, it is the third major cereal grown on an area about 16 million ha in both the rainy and the *rabi* season accounting for 13% of the gross cropped area in the semi-arid parts of the country (Tarhalkar, 1986).

The *rabi* sorghum of India is grown in stored soil moisture in about 6 million ha accounting to less than 30% of the annual sorghum production in India (Tandon Kanwar, 1984). Since it is grown in drying soils, early seedling establishment and early vigor becomes crucial for stable yields (Soman and Seetharama, 1993). Both the seedling establishment and the early vigor in the *rabi*

sorghum environment depends largely on the rapid initiation and extension of the nodal roots which can supply the crop with adequate nutrient and water to sustain plant growth.

Different environmental factors (climatic, edaphic, insect, disease problems, and management) contribute to the low levels of productivity in *rabi* sorghum. The yield levels of 715 Kg/ha and 575 Kg/ha in both India and Sudan calls for more joint efforts to be directed to the management of the growing environment of *rabi* sorghum.

In this study, variation in rooting characteristics between different genotypes may be a factor that can be exploited in improving *rabi* sorghum productivity. To test this hypothesis an experiment was laid out in a split plot design with nested classifications in the sub treatments with three irrigation treatments during the crop establishment stage (Control, 20 mm, 45 mm) as a main plot, four genotypes (Lakadi, E36-1, M35-1, and Naga White) each repeated twice to constitute two sets as sub treatments and two replications.

Total rainfall at ICRISAT Center during the experimental period was 100.6 mm. The crop germinated and established on 20.4 mm rainfall. The irrigation treatments were applied between 1 to 2 weeks after the emergence of the crop.

At the end of the season levels of irrigation seedling treatments as well as genotypes were significantly different from each other with respect to nodal roots

number, total root length, and total root mass per plant. Naga White genotype, had greater number of nodal roots per plant, yet at the end of the season it had less total root length as well as less total root mass. This was attributed to short but thick nodal roots which did not produce a comparable high total root length and total root mass as the other genotypes (M35-1 and E36-1).

Nodal roots number, total root length, and total root mass for both irrigation seedling treatments and genotypes increased during the vegetative growth stages, and reached their peak by either flowering or harvest time. The trend of increase in root parameters within genotypes was great for M35-1, E36-1, and Lakadi as compared to Naga White. Genotypes were significantly different at 50% flowering and harvest for all root attributes while the treatments at nodal root initiation and panicle initiation stages.

Root length density which measures the root length per unit volume of soil, continued to decrease with the control treatment, but increased with 45 mm seedling irrigation level between the growth stages (50% flowering and harvest time). The differences between the two treatments at both growth stages were significant. The three genotypes E36-1, Lakadi, and M35-1 had greater but significantly different final root length density compared to Naga White. The trend of increase in root length density with 45 mm seedling irrigation level was explained by greater root branching at lower soil profiles resulting in greater total root length as well as total root mass per unit of soil volume.

The aboveground growth parameters (stem, leaf, shoot, and total dry weights per plant) continued to increase steadily during the season irrespective of irrigation levels or genotypes. At the end of the season, total plant dry weight for irrigation levels as well as genotypes were significantly different from each other. The stems and panicles contributed more than 80 per cent to the total plant dry weight compared to only 7 per cent contribution by the root mass. The greater growth of roots and the shoots observed in some genotypes e.g. M35-1, explains the significantly different yield between this genotype and the other genotypes.

Total plant dry matter increased at a linear function during the different growth stages reaching its maximum after flowering time and then remained constant or declined thereafter, presumably due to leaf senescence.

At the end of the season, the genotypes were significantly different from each other, M35-1 with the lowest root/shoot ratio, Naga White with the largest.

Both leaf area and leaf number increased steadily during the season reaching their maximum before 50% flowering time and decreased thereafter due to leaf senescence. Leaf area and leaf number for genotypes were significant at nodal root initiation but not for irrigation treatments.

At harvest time, genotypes were significantly different from each other with respect to grain number per panicle, 100 seed mass, yield, stover weight, biomass, and harvest index. M35-1 the classic *rabi* variety was significantly different from

the other genotypes with respect to these attributes. It seemed that the genotypic differences in the root characteristics during the early stages had contributed to more nutrient and water uptake which may had resulted in the significant differences in the shoot parameters observed at later stages. This had finally contributed to explain the differences in yield, stover weight, and biomass in the high yielding genotypes tested.

With control treatment WUE was 18.0 Kg grain/ha/mm as compared to 12.2 Kg grain/ha/mm for the 45 mm irrigation treatment. At 50% flowering the 45 mm irrigation treatment was significantly different from the other treatments in the 50-100 cm soil depth. At harvest time all the treatments were the same for per cent soil moisture irrespective of the soil depth.

The nutrient uptake and concentration at flowering and harvest time though were not significantly different for the irrigations and genotypes, but there was a trend of increase with 45 mm seedling irrigation treatment, M35-1 and E36-1 genotypes.

The trend of more water and nutrient uptake was explained as a result of significant initiation of root attributes at early stages due to different treatments and a trend of differences between the genotypes in the root parts at the same stages.

LITERATURE CITED

Baligar V C and Nash V E 1978 Sorghum root growth as influenced by soil physical properties. Communications in Soil Science and Plant Analysis 9:583-594.

Baligar V C, Nash V E, Whisler F D and Myhre D L 1981 Sorghum and soybean growth as influenced by synthetic pans. Communications in Soil Science and Plant Analysis 12:97-107

Beaton J D and Sekhon G 1985 Potassium nutrition of wheat and other small grains. pp 701-752 In Potassium in agriculture. American Society of Agronomy, Madison W I, USA.

Blum A and Arkin G F 1984 Sorghum root growth and water-use as affected by water supply and growth duration. Field Crops Research 9:131-142.

Blum A, Arkin G F and Jordan W R 1977a Sorghum root morphogenesis and growth. I- Effect of maturity genes. Crop Science 17:149-153.

Blum A, Burnett E, Arkin G F and Jordan W R 1976 Root growth in juvenile sorghum plants. Sorghum Newsletter 19:133-134.

Blum A, Jordan W R and Arkin G F 1977b Sorghum root morphogenesis and growth. 2-Manifestation of heterosis. Crop Science 17:153-157.

Blum A and Ritche J T 1984 Effect of soil surface water content on sorghum root distribution in the soil. Field Crops Research 8: 169-176.

Bur R, Morad P and Berducan J 1977 Importance of seminal and adventitious roots for growth and cation nutrition in grain sorghum (*Sorghum doctina*). Plant and Soil 47:1-12.

Chalam G V and Venkateswarlu J 1965 Introduction to agricultural botany in India. Asia Publishing House, Volume I, Asia Publishing House, Bombay pp 358.

Chi Hsiu-Hui 1942 Histogenesis in the roots of (*Holcus sorghum* L.) Iowa State Journal of Science 16:189-205.

Choprat J L and Nicou R 1976 Influence du labour sur le development radiculaire de differents plantes cultivees au Senegal consequences sur leur alimentation

hydrique. Agronomi Tropicale 31:7-27.

Choudhari S D 1989 Production technology and a new line of work to improve *rabi* sorghum production. Paper presented during the working group meeting on production technology of *rabi* sorghum, held at the Central Research Institute for Dryland Agriculture (CRIDA), Hyderabad, September 19, 1989.

Cock J H (1985) Cassava. New potential for a neglected crop. International Agricultural Development Service, Boulder, USA, pp 191.

Cornish P S, Mc William J R and So H B 1984 Root morphology, water uptake, growth and survival of seedlings of ryegrass and phlaris. Australian Journal of Agricultural Research 35: 479-492.

CRIDA (Central Research Institute for Dryland Agriculture) 1989 Technological advances in production technology of *rabi* sorghum grown under dryland conditions. Paper presented during the working group meeting on production technology of *rabi* sorghum, held at CRIDA, Hyderabad, September 19, 1989.

Doggett H 1988 Sorghum. 2nd ed. pp 1. Longman group UK Limited, 1988.

Eastin J D 1983 Sorghum. In Potential Productivity of Field Crops under Different Environments pp 181-204. Manila, Philippines, International Rice Research Institute.

Eastin J D, Sullivan C Y, Bennett J M, Dhopte A M, Geriik T J, Gonzalez V A, Lee K W, Ogunlela V and Rice J R 1983 Sorghum rot and stalk rots, a critical review : Proceedings of the consultative group discussion on Research Needs and Strategies for control of sorghum rot and stalk rot diseases, 27 November-2 December 1983, Bellagio, Italy, In ICRISAT (International Crops Research Institute for the Semi-Arid Tropics), Patancheru, Andhra Pradesh, 502 324, India 1984.

Evetts L L and Burnside O P 1973 Early root and shoot development of nine plant species. Weed Science 21:289-291.

Freeman J E 1970 Development and structure of sorghum plant and its fruit. pp 28-72. In Sorghum production and utilization (ed Wall J S and Ross W M). AVI publishing company, Westport, USA.

Fukai S, Liwa C J, Henderson C W L, Maharajan B B, Hermades R C, Scarle C, Herbert S W and Foale M A 1986 The field performance of induced

uniculm grain sorghum (*Sorghum bicolor*) in South-East Queensland, Australian Experimental Agriculture, 22:393-403.

Hackett C 1973 A growth analysis of young sorghum root system. Australian Journal of Biological Sciences. 26:1211-1214.

Hari Krishna J 1981 Using rainfall for supplemental irrigation of Vertisols in India. Rainwater and dryland Agriculture pp 76-83 (New Delhi, Indian National Academy of Sciences).

Hoogenboom G, Huck M G and Peterson C M 1987 Root growth rate of soybean as affected by draught stress. Agronomy Journal 79: 607-614.

Hurd E A 1968 Growth of roots of seven varieties of spring wheat at high and low moisture levels. Agronomy Journal 60: 201-205.

ICRISAT (International Crops Research Institute for the Semi-Arid Tropics) 1983 Annual Report for 1982. Patancheru, Andhra Pradesh, 502 324, India pp 220-221.

ICRISAT (International Crops Research Institute for the Semi-Arid Tropics) 1986 Annual Report for 1985. Patancheru, Andhra Pradesh, 502 324, India pp 7.

ICRISAT (International Crops Research Institute for the Semi-Arid Tropics) 1988 Annual Report for 1987. Patancheru, Andhra Pradesh, 502 324, India pp 26-28 and 295-297.

ICRISAT (International Crops Research Institute for the Semi-Arid Tropics) 1990 Annual Report for 1989. Patancheru, Andhra Pradesh, 502 324, India pp 10.

Jordan W R, Mc Cray M and Miller F R 1979a Compensatory growth in the crown root system of sorghum. Agronomy Journal 71: 803-806.

Jordan W R, Miller F R and Morris D E 1979b Genetic variation in root and shoot growth of sorghum in hydroponics. Crop Science 19:468-472.

Jose R, Pardales J R and Kono Y 1990 Development of sorghum root system under increasing draught stress. Japanese Crop Science 59(4) 752-761.

Kaigama B K, Teare I D, Stone L R and Powers W L 1977 Root and top growth of irrigated and non irrigated grain sorghum. Crop Science 1: 555-559.

Kale S P 1989 *rabi* (Winter) sorghum production technology. Paper presented during the 19th annual sorghum workshop, AISCIP, May 8-10, Tamil Nadu

Agricultural University, Coimbatore.

Kanitkar N V, Sirur S S and Gokhale D H 1968 Dry Farming in India. (3rd ed), ICAR, New Delhi pp 470.

Kannan S 1981 The reduction of PH and recovery from chlorosis in Fe-stressed sorghum seedlings: the principal role of adventitious roots. Journal of Plant Nutrition 4: 73-78.

Kanwar J S, Rego T J and Seetharama N 1984 Fertilizer and water-use efficiency in pearl millet and sorghum in Vertisols and Alfisols of Semi-Arid India. Fertilizer News 29: 42-52.

Kislev M and Korach E 1979 Mechanisms of root penetration of seeds germinating on the soil surface. Annals of Botany 43: 87-92.

Mane V S and Shingte A K 1982 Use of mulch for conserving moisture and increasing the yield of sorghum in dryland. Indian Journal of Agricultural Science 52: 458-462.

Martin J H, Taylor J W and Leuke L 1935 Effect of soil temperature and depth of planting on the emergence and development of sorghum seedlings in the green house. Journal of American Society of Agronomy 27: 660-665.

Mc Clure J and Harvey C 1962 Use of radiophosphorus in measuring root growth of sorghum. Agronomy Journal 54: 457-459.

Michael G and Sieler - Kelbitch H 1972 Cytokinin content and kernel size of barley lines affected by environmental and genetic factors. Crop Science 12: 162-165.

Mirhadi M J and Kobayashi Y 1980 The relationship between the growth of plant organs of grain sorghum hybrid. Japanese Journal of Crop Science 49: 420-427.

Monteith J L 1986 Significance of the coupling between saturation vapor pressure deficit and rainfall in monsoon climates. Experimental Agriculture 22: 329-338.

Myers R J K 1980 The root system of a grain sorghum crop. Field Crops Research 3: 53-64.

Nwanze K F, Reddy Y V R and Soman P 1990 The role of leaf surface wetness in larval behavior of the sorghum shoot fly (*Athrigona soccata*) Entomologia

Experimentalis et Applicata. 56: 187-195.

Passioura J B 1983 Roots and draught resistance. Agricultural Water Management 7: 265-280.

Paulson I W 1962 Embryogeny and seedling development to floral transition of (*Sorghum vulgare*). Ph.D thesis, Iowa State University, Iowa, USA.

Peacock J M and Heinrich G M 1984 Light and temperature responses in sorghum. pp 143-158 In Agrometerology of sorghum and millet in the Semi-Arid Tropics. Proceeding of the International Symposium, 15-20 November 1982 held at ICRISAT (International Crops Research Institute for the Semi-Arid Tropics) Patancheru, 502 324 India.

Peacock J M and Wilson G L 1984 Sorghum. In the physiology of Tropical Field Crops (eds P R Goldswothy and R A Fischer) pp 249-297. New York, John Wiley and Sons.

Plaut Z, Blum A and Arnon I 1969 Effect of soil moisture regime and row spacing on grain sorghum production. Agronomy Journal 61: 344-347.

Proffitt A P B, Berliner R P and Oosterhuis D M 1985 A comparative study of root distribution and water extraction efficiency by wheat grown under high and low frequency irrigation. Agronomy Journal 77: 655-662.

Rao N G P, Vidyabhushanam R V and Rana B S 1977 Recent developments in sorghum breeding in India; In plant breeding, paper 2. 3rd International Congress of the SABRAO Section 7: 7-18.

Rao R M M S and Ramanath B 1989 Production technology of *rabi* sorghum improvement. Paper presented at the AICSIP annual workshop, 2-4 March 1988, C S Azad University of Agriculture and Technology, Kanpur.

Reddy B V S 1985 Consultancy report to ILCA/Embarapa/IPA. IPA, AV, GAL., San Martin, Bonji 50000, Recifepe, Brazil.

Reddy B V S, Seetharama N and House L R 1987 Sorghum in postrainy season: Effect of soil moisture and date of sowing on days to flower, and grain and stover yields of diverse cultivars. Experimental Agriculture 24: 31-36.

Rego T J, Morghan J T and Sardar S 1982 Some aspects of soil nitrogen relating to double cropping of a deep Vertisol in the Semi-Arid Tropics. 12th International Congress of Soil Science 6: 116.

Rice J R and Eastin J D 1986 Grain sorghum root response to water and temperature during reproductive development. Crop Science 26: 547-551.

Seetharama N, Flower D J, Jayachandran R, Krishna K R, Peacock J M, Singh S, Soman P, Usha A and Wani S P 1988 Assessment of genotypic differences in sorghum root characteristics. Proceedings of the International Congress of Plant Physiology, New Delhi, India, February 15-20 1988.

Seetharama N, Huda A K S and Monteith J L 1988 Sorghum in the Semi-arid Tropics: Agroclimatology, physiology and modelling. Paper presented during the symposium on cereals, International Plant Physiology Congress, Feb. 15-20, 1988. New Delhi, International Crops Research Institute for the Semi-Arid Tropics, Patancheru, Andhra Pradesh 502 324 India.

Seetharama N, Mahalakshmi V, Bidinger F R and Sardar Singh 1984 Response of sorghum and pearl millet to draught stress in Semi-Arid India. pp 159-173 In Agrometerology of Sorghum and Millet in Semi-Arid Tropics, International Crops Research Institute for the Semi-Arid Tropics, Patancheru, India.

Seetharama N and Singh S (Unpublished) ICRISAT Journal Article NO. 903, pp 3 , International Crops Research Institute for the Semi-Arid Tropics, Patancheru, India,

Seetharama N, Singh S and Reddy B V S 1986 Crop productivity in stored soil moisture environment: A case study with the postrainy season (*rabi*) sorghum in India. ICRISAT (International Crops Research Institute for the Semi-Arid Tropics), Patancheru, Andhra Pradesh, 502 324, India.

Seetharama N, Singh S and Reddy B V S 1990 Strategies for improving *rabi* sorghum productivity. Proceedings of the Indian National Science Academy B56 No. 5 and 6 pp 455-467.

Seetharama N, Sivakumar M V K, Sardar S and Bidinger F R 1978 Sorghum productivity under receding soil moisture in Deccan Plateau. Paper presented at the International Symposium on Biological Application of Solar Energy 1-5 December 1978, Madurai University, India.

Seetharama N, Wade L J, Peacock J M, Verma P K, Rego R J and Sardar Singh 1982b Effect of nitrogen and water stress on leaf area development in sorghum pp 595-600 In Plant nutrition, Commonwealth Agricultural Bureaux, A Scaife, Slough, United Kingdom.

Sivakumar M V K and Huda A K S 1985 Solar energy utilization by tropical sorghum. Agricultural Forest Meteorology 35: 47-57.

Sivakumar M V K and Virmani S M 1982 The physical environment; in sorghum in the eighties. International Crops Research Institute for the Semi-Arid Tropics, Patancheru, India, pp 83-100.

Soman P and Seetharama N 1992 Genotypes and environmental variation in nodal root growth of post-rainy season (*rabi*) sorghum. Experimental Agriculture 28: 331-341.

Sprat E D and Chowdhary S L 1978 Improved cropping system for rainfed agriculture in India. Field Crops Research 1: 103-126.

Tandon H L S and Kanwar J S 1984 A review of fertilizer use research on sorghum. In ICRISAT Research Bulletin No. 8, International Crops Research Institute for the Semi-Arid Tropics, Patancheru, India, 59 pp.

Tarhalkar P P 1986 Agronomical investigations on *rabi* sorghum. A brief review presented at the AICSIP annual workshop, May 14-16 1986, Andhra Pradesh Agricultural University, Rajendranagar, Hyderabad, 5000 30.

Umrani N K 1989 Constraint of productivity in *rabi* sorghum. Paper presented during the workshop group meeting on Production Technology of *rabi* Sorghum, held at the Central Research Institute for dryland Agriculture, Hyderabad, September 19, 1989.

Venkateswarlu J and Venkatasubbaiah V 1984 Response of *rabi* sorghums to applied nutrients and sub-soil fertilization. Paper presented at the Dharward, AISCIP Annual Sorghum Workshop, 3-6 May 1984, University of Agricultural Sciences.

Verma B 1978 Runoff water for black soils of Karnataka. Indian Farm 28: 36-37.

Vidyabhushanam R V 1986 Status of *rabi* sorghum improvement in India. Paper presented at the AICSIP annual workshop, 14-16 May 1986, Hyderabad, Andhra Pradesh Agricultural University.

Vincent C and Gregory P J 1985 Differences in the growth and development of chickpea seedling roots (*Cicer arietinum*). Experimental Agriculture 1986, 22: 233-242.

Virmani S M, Sivakumar M V K and Reddy S J 1982 Rainfall probability estimates for selected locations of semi-arid India. 2nd ed. International Crops Research Institute for the Semi-Arid Tropics, Patancheru, India, 170 pp.

Wani S P, Sharawat K L and Lee K K 1988 Effect of nitrogen levels on nitrate reductase and nitrogenase activity, dry matter accumulation and nitrogen assimilation of pot grown sorghum and pearl millet plants. Unpublished Manuscript submitted to plant and soil.

Wright S A, Jordan W R, Morgan P W and Miller F R 1983 Genetic and hormonal control of shoot and root growth of sorghum. Agronomy Journal 75: 682-686.

Yamazaki K and Nekamoto T 1983 Primary root formation in growing shoots of several cereal crops. Japanese Journal of Crop Science 52: 342-348.

Zartman R E and Woyewodzic R T 1979 Root distribution patterns of two hybrid grain sorghums under field conditions. Agronomy Journal 71: 325-328.

Appendix 1. Meteorological data for the growing season at ICRISAT Center (Rabi season 1992).

STD WEEK	RAIN mm	EVAP mm	TMAX C	TMIN C	RH07 %	RH14 %	WIND kphr	SUNSHINE hr	SOLRAD (MJ/m**2/D)
40	1.0	31.4	31.4	20.7	92.4	57.9	5.6	7.7	17.9
41	22.6	30.6	30.1	22.3	93.4	58.0	9.0	5.9	16.7
42	0.4	39.0	31.2	19.8	84.1	43.0	5.3	8.2	18.7
43	4.0	31.8	31.1	20.2	81.9	43.4	5.0	5.7	14.8
44	0.0	37.3	30.2	15.2	85.3	37.7	4.7	8.2	18.3
45	0.0	42.2	30.3	18.9	82.1	45.6	8.0	8.3	17.6
46	77.0	26.9	27.0	18.5	89.1	57.4	10.4	4.7	12.3
47	0.0	22.8	27.6	20.1	95.3	62.4	7.5	5.0	12.8
48	0.0	29.0	27.8	13.9	92.0	42.7	5.1	9.0	17.5
49	0.0	29.4	26.9	12.4	96.0	42.9	6.2	8.4	17.2
50	0.0	27.6	26.8	12.0	88.6	39.7	5.5	8.9	16.8
51	0.0	25.6	26.6	12.4	97.1	47.1	6.2	7.8	16.6
52	0.0	34.5	27.0	10.0	91.0	30.9	5.4	9.1	17.8
1	0.0	32.0	29.4	12.1	90.4	28.9	5.2	8.2	16.8
2	0.0	34.7	30.7	12.8	87.4	27.7	5.7	9.1	17.4
3	0.0	34.2	30.1	13.4	87.3	28.4	5.2	7.8	17.0
4	0.0	41.8	30.1	12.2	81.9	26.4	5.3	9.2	18.6
5	0.0	40.1	30.0	13.9	84.9	28.4	5.7	9.6	18.7
6	0.0	39.3	29.9	12.6	75.1	25.4	4.9	9.6	20.1
7	0.0	49.2	32.5	15.7	69.9	33.4	5.5	9.9	20.4
8	0.0	53.5	30.6	12.6	61.9	16.1	8.1	10.0	21.8
9	0.0	54.6	31.2	18.2	81.3	41.1	12.8	8.9	20.2

Rainfall and Evaporation data are totals and other data are mean values.

Appendix 2. Soil temperature at (2) and (5) cm soil depth and air temperature (°C) above the crop.

Standard Week	T0 2CM	T0 5CM	T1 2CM	T1 5CM	T2 2CM	T2 5CM	Air Temp.
1	24.1	23.0	22.4	23.1	23.2	22.8	20.8
2	24.2	23.1	22.5	23.2	23.4	22.9	20.9
3	24.4	23.4	23.3	23.4	24.7	23.7	22.3
4	24.3	23.7	23.4	23.4	24.6	23.6	21.6
5	23.9	24.7	23.1	25.2	25.6	24.7	21.8
6	25.3	25.6	25.2	25.8	25.2	25.2	22.5
42	31.5	29.3	30.9	30.4	29.1	29.6	26.4
43	30.0	28.7	27.1	27.2	27.2	27.1	25.3
44	28.6	27.5	26.9	26.7	25.2	24.8	22.5
45	30.1	28.8	28.5	28.1	26.9	26.8	24.5
46	25.5	25.3	25.8	26.0	25.4	25.2	22.5
47	24.3	23.7	26.0	25.1	25.5	25.0	24.1
48	23.3	23.1	24.0	22.7	24.5	22.3	19.8
49	22.4	22.2	21.7	21.6	23.8	21.6	18.7
50	23.0	22.3	21.5	21.8	24.1	21.8	18.6
51	22.9	22.3	21.5	21.8	24.4	22.0	18.5
52	22.0	21.4	20.3	20.9	22.7	21.1	17.3

NB:
T0 Control
T1 20 mm
T2 45 mm