

**IDENTIFICATION OF MORPHO-PHYSIOLOGICAL
TRAITS RESPONSIBLE FOR DROUGHT
TOLERANCE IN RICE**

M.Sc.(Ag.) **THESIS**

by

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INDIRA GANDHI AGRICULTURAL UNIVERSITY
RAIPUR (C.G.)

2002

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Thesis

Submitted to the

Indira Gandhi Agricultural University, Raipur

by

ANILKUMAR ZAMSINGH YERNE

IN PARTIAL FULFILMENT OF THE
REQUIREMENTS FOR THE
DEGREE OF

Master of Science

In

**Agriculture
(PLANT PHYSIOLOGY)**

Roll No.1822

IDNo.PG/AG/2000/44

SEPTEMBER, 2002

Dedicated

to

my beloved

Parents

Shri Zamsingh Yerne

&

Smt. Krushna Tai Yerne

ACKNOWLEDGEMENT

I avail this opportunity to pay my deepest regard and profound sense of indebtedness to my Major Advisor and Chairman of the Committee Dr. Ravindra Kumar, Assistant professor, Department of Plant Physiology, College of Agriculture, Raipur (C.G.), who took immense interest and shaped the research program and sagacious guidance throughout the present study period. His scholarly suggestions, president admonition and affectionate nature have been a source of great inspiration to me. His yeoman service during drafting and editing of this manuscript was inestimable value.

I extend my immensely grateful thanks to member of advisory committee Dr. M. I. Khan, professor and Head, Department of Plant Physiology, Dr. R.O. Das Asstt. Professor (Soil science), Dr. R.K. Bajpai Sr. Scientist (Agronomy), and Dr. R.R. Saxena, Asstt. Professor (Agril statistics) for their valuable guidance and constructive criticism during the course of investigation.

It is with extreme pleasure that I thanks Dr. (Smt.) Arti Guhey and Dr.(Smt.) Pratibha Katiyar, Department of Plant Physiology, College of Agriculture Raipur, (C.G.) and my seniors Shri Sanjeev Malaiya for their impressive help, excellent advice, constant encouragement and affectionate guidance.

I am highly obliged to Hon'ble Dr. V.K. Patil, Vice-Chancellor, I.G.A.U. Raipur (C.G.), Dr. R.S. Tripathi, Director of Research Services, IGAU. Raipur (C.G.) and Dr. M.N. Shrivastava, Dean and Director of Instructions, I.GAU Raipur (C.G.) for providing necessary facilities for the investigation.

I owe my special thanks to my OSLA group (Ashish, Naresh, Parwarkar, Sanjay and Vilas) which we formed here and could not forget those days which we spend together.

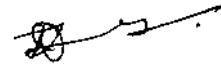
/ thank host of my pear group, Nitin, Lalit, Sajjad, Bhosle Brother, Gajanan, Girish, Prashant, Sajjad, Juniors, Pankaj, Prashant, Sudhram, Gangaram, Rama, Harish and Seniors, Kujur, Sagar, Pawar, Kurwanshi for their love and co-operation.

Last but not least I express my deep feeling of affection and love for my respected Baba and Aai for their kind blessings, understanding and constant encouragement every time help of my Dearest Sunil and Sushma and whole family which lead me to see this day of achievement and satisfaction.

The financial help provided by IRRI, Philippines to conduct the studies is duly acknowledged.

I am also thankful to Shri Ajay Kaushik for the excellent typing jobs for brining this manuscript into its present form.

Thanks are also due to them who directly or indirectly a source of my help and inspiration whose mention did not find place in this desired submission.

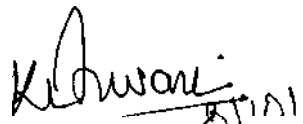


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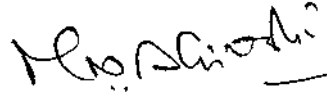
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This is to certify that the thesis entitled "**IDENTIFICATION OF MORPHO-PHYSIOLOGICAL TRAITS RESPONSIBLE FOR DROUGHT TOLERANCE IN RICE**" submitted by **Shri ANILKUMAR ZAMSINGH YERNE** to the Indira Gandhi Krishi Vishwavidyalaya, Raipur in partial fulfilment of the requirements for the degree of M.Sc.(Ag.) in the **Department of Plant Physiology** has been approved by the Student's Advisory Committee after oral examination in collaboration with the external examiner.


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EXTERNAL EXAMINER


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Date: 21/10/2009

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This is to certify that the thesis entitled "**IDENTIFICATION OF MORPHO-PHYSIOLOGICAL TRAITS RESPONSIBLE FOR DROUGHT TOLERANCE IN RICE**" submitted in partial fulfilment of the requirements for the degree of "**Master of Science in Agriculture**" of the Indira Gandhi Krishi Vishwavidyalaya, Raipur, is a record of the bonafide research work carried out by **Shri ANILKUMAR ZAMSINGH YERNE** under my guidance and supervision. The subject of the thesis has been approved by Student's Advisory Committee and the Director of Instructions.

No part of the thesis has been submitted for any other degree or diploma (certificate awarded etc.) or has been published/ published part has been fully acknowledged. All the assistance and help received during the course of the investigations has been duly acknowledged by him.

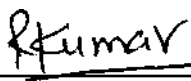
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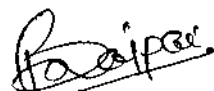
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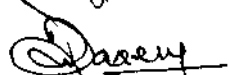
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LIST OF ABBREVIATIONS

Abbreviations	Description
CD	Critical difference
cm	Centimetre
DAS	Days after sowing
Fig.	Figure
g	Gram
ha	Hectare
K	Potassium
kg	Kilogram
LAI	Leaf area index
m	Metre
mm	Millimetre
N	Nitrogen
NS	Non significant
°C	Degree Celsius
P	Phosphorus
SEm	Standard error of mean
t	Tonne

Introduction

CHAPTER – I

INTRODUCTION

More than 50 per cent of 40 million hectare of rainfed lowland rice in South and south-east Asia is affected by drought annually, which has contributed to significant yield losses. In Chhattisgarh state drought is a recurrent phenomenon which leads to partial or total crop failure.

Morpho-physiological traits that confer drought resistance may be used as indirect selection criteria to improve grain yield under drought. For example, Fischer *et al.* (1989) used specific physiological traits as indirect selection criteria for improving maize (*Zea mays* L.) yield under drought. In rice, O'Toole (1982), Fukai and Cooper (1995) and Nguyen *et al.* (1997) proposed several putative drought resistant traits that may contribute to grain yield under drought in rainfed lowlands. These traits should be evaluated for their contributions to adaptation under drought and on how they might be used to improve the efficiency of rice breeding programs. If they can be evaluated with rapid reliable techniques in the early generations for genetic improvement, then using these traits as indirect selection criteria may enhance the rate of improvement of drought-resistant cultivators.

A double haploid (DH) F₂ lines population of rice (cross CT-9993-5-10-1-M/ IR-62266-42-6-2, designated IR-68586) was developed at International Rice Research Institute, Philippines and adopted with drought

tolerance in rice. This population is being subjected to field and laboratory tests in several collaborating institutions in order to phenotype for drought tolerance. The data have been acquired for osmotic adjustment, root penetration ability, root development traits etc. in various collaborative institutes.

The current studies were consist of four DH Lines along with one parent i.e. IR-62266-42-6-2 for evaluation of different morpho-physiological traits associated with drought tolerance under field conditions. The following were major objectives of current studies.

1. To study the dry matter production and its partitioning in various plant parts under irrigated and rainfed conditions.
2. To study the effect of drought on photosynthesis and transpiration in various double haploid lines.
3. To examine the leaf water status and root characteristics among different double haploid lines under irrigated and drought conditions.
4. To examine the effect of drought on grain yield and its attributes.
5. To identify the traits, related to drought resistance in rice.

Review of Literature

CHAPTER - II

REVIEW OF LITERATURE

Plant water deficit affect practically every aspect of plant growth. They are characterized by the decrease in water content, turgor and total plant water potential, resulting in wilting, partial or complete closure of stomata, decrease in cell enlargement, plant growth, decrease in photosynthesis, disturbance of many metabolic process and finally death (Kramer, 1983).

Although drought is a major problem for rice grown under rainfed lowland and upland condition, progress in breeding to improve drought resistance has been slow. A major reason for slow progress in drought resistance is the complexity of the drought environment, which often results in the lack of clear identification of the target environments. There is need to identify the relative importance of the three common drought types, early-season drought which often causes delay in transplanting, mid intermittent stress which can have a severe cumulative effect and late stress which affects particularly late maturing genotypes. In addition, under rainfed lowland rice, flooded and non-flooded soil conditions may alternate during the growing season, and affect nutrient availability or cause nutrient toxicity. Several drought resistance mechanisms and putative traits which contribute to resistance have been identified, including drought escape via-appropriate

phenology, root characteristics, specific dehydration avoidance and tolerance mechanism and drought recovery. Some of these mechanism, traits have been shown to confer drought resistance and others show potential to do so. The most important is the appropriate phenology which matches crop growth and development with the water environment. A deep root system with high root length density at depth is useful in extracting water thoroughly in upland conditions, but does not appear to offer much scope for improving drought resistance in rainfed lowland rice where the development of a hard pan may prevent deep root penetration under water limiting environments. Genotypes which maintain the highest leaf water potential generally grow best but, it is not known if genotypic variation in leaf water potential is solely caused by root factors (Fukai and Cooper, 1995). This chapter describes patterns of water stress development in rice fields, reviews genetic variation in morpho-physiological traits for drought resistance and suggests how knowledge of stress physiology can contribute to plant breeding programme that aim to increase yield in water-limiting environments.

A brief review of research work about the effect of drought stress on rice morpho-physiological traits responsible for drought tolerance is summarized below:

2.1 Role of dry matter production and its partitioning in various plants parts in improving drought tolerance

Kumar *et al.* (1987) studied three varieties of wheat (*Triticum aestivum* L.) cvs. WH 147, P-1200, *Triticum durum* Desf cv. DWL 5023) in

sandy loam soil with two irrigation treatment (i) no post sowing irrigation (ii) six post sowing irrigation. The pattern of dry matter accumulation in leaf, stem and reproductive organs were recorded at bi-weekly intervals starting from fifteen days after seedling (DAS) through maturity. Leaf weight increased from initial vegetative phase till 75 DAS, stem weight up to 105 DAS and the declined there after till maturity irrespective of genotypes and environments. The pattern of pre-anthesis and post-anthesis contribution of assimilates to grain yield differed markedly between *durum* and *aestivum* wheats. The preanthesis contribution to grain yield increased with moisture stress. The preanthesis contribution to grain yield was markedly higher in cv- WH-147 under non irrigated condition as compared to P 1200 and DWL 5023.

Lilley and Fukai (1994a) found that water deficit is known to retard phenological development. Four contrasting rice cultivars (CPIC 8, Lemout, Riknto Norimir and todoroki wase) were subjected to water deficit during either vegetative or reproductive growth stages. Biomass production during water deficit was less than 56 per cent of that in irrigated condition.

Chauhan *et al.* (1996) reported the effect of soil moisture stress on growth and development of two upland rice cultivars (Brown gora, a traditional cv. and Vandana an improved cv.) at 100, 80, 60 and 40 per cent of water holding capacity. Results revealed that improved cv. Vandana transpire less water and exhibited higher stomatal diffusive resistance than

the traditional cv. Brown gora under stress condition. The effect of moisture stress became more apparent during later period of stress when water was applied at 60 and 40 per cent of water holding capacity. The reduction was 67.3 and 40.3 per cent in dry matter accumulation and 53.4 and 54.4 per cent in leaf area at 40 per cent water holding capacity in Brown gora and Vandana, respectively at 35 days after stress imposition.

Hoque and Kobata (1998) conducted studies to determine whether drought resistant rice cultivars exhibit higher dry-matter production under wet and dry compacted soil conditions in the vegetative stage, and to investigate the dominant factors governing resistance to soil compaction. Three rice cultivars, (drought-sensitive Nipponbare, and drought-resistance Senshou and Dular) were grown in pots at four soil bulk densities (SBD) ranging from 1300 to 1600 dry soil kg m⁻³. Root and shoot dry matter production was slightly smaller in Nipponbare. Senshou and Dular also maintained a higher dry matter production, both in relative and absolute values, than Nipponbare under the water shortage conditions from days 29 to 39 after sowing.

Cixin *et al.* (2000) studied a population of 123 double haploid (DH) lines, derived from a cross between indica variety IR-64 and japonica variety, Azucena. Panicle dry weight was observed at different stages, at 10-day intervals. Based on a rice genetic linkage map of 175 molecular markers enzyme markers, QTLs for the developmental behaviour of panicle dry

weight were determined dynamically using the composite interval mapping method in combination with the conditional analysis method. The number of unconditional QTLs for panicle dry weight detected was 14. However only three QTLs were detected at the final stage. Conditional QTL analysis of rice panicle dry matter accumulation could provide on insight into both spatial and temporal patterns of gene expression. The result also indicated that two sets of genes might be involved in the process of panicle dry matter accumulation.

2.2 Effect of drought on photosynthesis and transpiration rates

Pal and Varade (1980) reported that the transpiration rate remained nearly constant at high soil moisture contents and decrease as the soil moisture content start decreasing.

Dabas and Sheoran (1984) observed the effect of water stress on photosynthesis and stomatal conductance in two species of Brassica. Water stress was created by withholding irrigation at different growth and development stages under controlled condition. Photosynthetic rates were higher in *Brassicajuncea* (Raya) than in *Brassicacompesteris*. However, the reduction in photosynthesis was more in raya than brown sarson with decreasing leaf water potential and it was more during later growth stages. Stomatal conductance also followed similar trends.

Uprety and Sirohi (1985) studied the effect of water stress on the photosynthesis of wheat varieties C-306 and Kalyaansona. They showed that

drought affected both stomatal and non stomatal components of photosynthesis. The comparatively higher photosynthesis in variety C-306 under drought condition might probably be by the maintenance of higher turgor due to higher water potential of its leaves.

Lu-CM *et al.* (1993) studied the effect of water stress on the photosynthesis in rice cv. Shanyou 3. The photosynthetic rate in rice leaves was highly susceptible to water stress. The photosynthetic rate decreased by -60 per cent when the leaf water potential decreased from -6.2 to -12.5 bar. The decrease of photosynthetic rate was parallel to that of stomatal conductance. The decrease of photosynthetic rate was due to the combined effect of stomatal and non-stomatal factors. The non-stomatal factors were the decrease in ribulose biphosphate carboxylase activity and ribulose-bisulphate regeneration rate, including inhibition of photosynthetic electron transport rate which affected the activity of photophosphorylation.

Balasubramanian *et al.* (1993) studied the groundnut cultivars grown in dryland and irrigated areas. The studies were conducted in field during two rainy season, three cultivars (JL-34, TMV-2 and Kadiri-3) were grown under irrigated and dryland condition. The objective of studies was whether cultivars for irrigated (JL-24) and dryland (TMv-2 and Kadiri-3) areas differed in their assimilation and plant water status when drought occurred at any stage of growth. Seasonal photosynthesis rate decreased by 22 per cent

but the transpiration rate decreased only 9 per cent in dry lands in one system resulting in lower transpiration efficiency.

Sairam (1994) studied the effect of moisture stress imposed at tillering and anthesis stages on four drought susceptible (HD-2339, Hd-2001, WL-711, WH-147) and four drought tolerant (C-306, NI-5439, WH-147) and Pissi local and DL-153-2 genotypes of wheat. He reported that transpiration rate decreased under moisture stress. Tolerant genotypes generally had lower rate of transpiration than the susceptible genotypes.

Tiwari *et al.* (1998) observed in rice (*Oryza sativa* L.) that photosynthetic rate declines and stomatal resistance goes up under water stress conditions. Dingkuhn *et al.* (1999) studied in an upland field experiment during the 1997 under the irrigated and drought condition. It was concluded that stomatal conductance was controlled by a soil moisture dependent root signal under drought conditions.

2.3 Role of leaf water status and root characteristics in improving the drought tolerance

Chang *et al.* (1972) reported that most effective defense mechanism available to the rice plant is a good root system consisting to deep and mostly thick root which enables to plant to avoid the adverse effect of internal water deficit.

Hsiao (1973) reported that cell enlargement usually begins to -0.4 Mpa, but stomatal closure does not begin until the water potential fall to -0.8 to -1.0 Mpa in some plants and much lower in others.

Pal and Varade (1980) reported that the leaf water potential of leaves declined exponentially with decreasing soil water potential.

Row and Venkateshwarlu (1983) conducted studies in root boxes showed that the potential root systems in terms of length, volume, weight and thickness were greater in Lalnakanda 41, mtu 17 (tails) and Rasi while IR-20 had a relatively shallow systems. Root volume, dry weight and number of thick roots were more in 'A' zone (0-30 cm depth) which gradually decreased in depth irrespective of the stature of the plant. The dry matter in 'C' zone (60-90 cm depth) was 2-3 times more in tails than in dwarfs. Dwarf plants concentrated much in 'A' zone while the proposition of distribution was relatively balanced in tall types.

Patil *et al.* (1984) showed the extent of free proline accumulation in plant parts in five maize genotypes. Plants were grown in pots and irrigated regularly upto 30 days. After 30 days drought stress was induced by withholding irrigation. Free proline content and relative water content (RWC) were estimated in root leaf sheath and leaf with the advance in stress, RWC decrease while free proline increased. Among the plant parts leaf relative water content decrease when the drought stress progresses.

Singh and Singh (1984) demonstrated that crop canopy temperature responds to changes in leaf water potential and therefore can be used for monitoring irrigation. The canopy minus air temperature difference (AT) was related to water potential in field grown wheat under two differential water supplies at 50 per cent and 65 per cent depletion of available soil moisture in the root zone soil. They showed that increasing water stress decrease water potential markedly.

Singh and Singh (1989) studied the effect of various degrees of plant water stress on diurnal variation in leaf water potential of wheat revealed that leaf water potential decreased during the day upto 1300 hours.

Singh *et al.* (1990) observed significant genotypic differences in water potential, osmotic potential and pressure potential in wheat genotypes. Gradual water stress in soil culture reduced these parameters. Differences in above parameters were significant with respect to genotypes and stage. Tolerant genotypes like C-306 and WT-245 showed lower reduction in water potential and osmotic potential on account of water stress. They concluded that water potential is a useful criteria for identifying drought tolerant genotypes.

Krishnayya and Murty (1991) studied five upland rice varieties subjected to soil moisture stress of 25 per cent field capacity at seedling stage. The increasing soil moisture stress, decreases the relative water content and positive turgor inspite of reduced leaf water potential during

stress also had optimum photosynthesis and solute accumulation as evident from osmotic potential.

Lilley and Fukai (1994b) reported that rice showed significant genotypic variation in physiological response to water deficit. Leaf water potential were studied in four rice cultivars during water deficit imposed either before panicle initiation or after panicle initiation. The four rice cultivars chosen, CPIC 8, Lemont, Rikntonorin 12 (RN) and Todoroki wase (TW) were known to have different responses to water deficit. Cultivars RN had poor water extraction and was most sensitive to water deficit. TW also had poor water extraction but plants were small and this cultivars escaped severe stress, particularly in the vegetative phase. CPIC-8 and Lemont extracted more soil water and were less sensitive to water deficit.

Lilley and Fukai (1994c) reported the ability of plant to extract soil water during water deficit. Rooting pattern and soil water of four rice (*Oryza sativa* L.) cultivars were investigated during a period of water deficit, during the vegetative or reproduction stage of growth. The four rice cultivars chosen (PIC-8, lemont, Rikuto-Norin 12 (RN) and Todoroki wase (TW) were known to have differing in responses to water deficit, when grown under upland conditions. Root growth ceased in all cultivars when water deficit was imposed at either the vegetative or reproductive stage. The cultivars differed in their inherent rooting pattern. Root length density was large in the surface soil layers and declined with depth. Extractable soil water and water

extraction rate were related to root length density and water extraction were similarly ranked among cultivars (CPIC 8 > lemont > RN > TW).

Yadav *et al.* (1997) reported that deep thick root system have a positive effect on the yield of upland rice under water stress conditions. Molecular marker-aided selection could be useful for the improvement of root morphological traits, which are otherwise difficult to score. A doubled haploid population of 105 lines derived from an indica (IR-64) x Japonica (cv. Azucena) cross was studied and the genes controlling root morphology and distribution (root thickness, maximum root length, total root weight, deep root weight, deep root weight tiller¹) were used. These results will allow the derivation of isogenic lines introgressed with these common segments, separately in indica and japonica backgrounds.

Blum (1999) studied the double-haploid (DH) F2 lines population of rice (cross CT9993-5-10-1-M/ IR-62266-42-6-2, designated IR-68586) developed for the molecular mapping of drought tolerance traits in rice. A subset of 100 lines of this population was evaluated in the field. Lines were planted at Bet Dagan, Israel, in 1997 under fully irrigated and drought stress condition. Drought stress conditions were imposed by subjecting plots to two consecutive drying cycles between tillering and heading growth stages, followed by full irrigation until harvest. Data were collected on plant production, phenology and several indicators of plant water stress. Lines differed significantly for all measured plant phenology and production traits,

under both control and stress conditions. Mean heading date was delayed by 16.7 days under stress compared with the controls. The integrated final effect of the two consecutive drying cycles was outstanding, causing an average reduction of 44 per cent in biomass and 71 per cent in yield. There was a significant environment by line interaction for biomass and yield. Yield of lines under stress ranged from 0 to 140 per cent of that in the controls, whereas yield drought tolerance index ranged from 0.04 to 5.06. Lines differed significantly for all measured indicators of plant water stress, namely, midday canopy temperature, leaf rolling score, leaf death score and leaf relative water content. Plant stress indicators were significantly correlated across lines between biomass and yield under stress and canopy temperature, leaf death score and relative water content. These association support the conclusion that the result of this test indeed reflected real and large genetic variation in drought tolerance within this population.

Tyagi *et al.* (1999) studied the known tolerant and susceptible genotypes of rice under water deficit conditions. Membrane stability, osmotic potential and root biomass at anthesis stage were studied. Drought tolerant genotypes CR-143-2-2, Salam Pikit and JD-9 showed higher membrane stability, root biomass and lower osmotic potential under water stress as compared to susceptible genotypes PR-110 and P-169. Though N-22 should considerably lower root biomass under water stress but it showed higher membrane stability and lower osmotic potential.

Hemamalini *et al.* (2000) observed the root morphology under well water condition and under low-moisture stress in a randomly chosen subset of 56 double haploid lines derived from cross between IR-64 and Azucena at two growth stages during vegetative stage. A molecular map of the same population served as the basis for locating QTLs controlling root morphology and associated traits. The region flanking the RFLP marker RZ-730 and RZ-801 on chromosome 1 were associated with plant height in all three sampling environments. This position corresponds to a semi-dwarfing gene. A total of 15 QTL were detected at the two developmental stages, of which only three QTL were common. Region flanked by R 4157 and RZ 318 chromosome 2 contained QTL for root thickness under two different developmental stages. In total, 21 QTL for different traits were detected under low moisture stress condition. While two QTL from plant height on chromosome 1 and 3 were common, none of the loci for root morphological traits was common between the two different moisture regimes. The chromosomal segment between R4 171 and R4 157 contained QTL controlling tiller number plant⁻¹, total root length, root volume and total root number plant⁻¹. Root volume and total root number plant⁻¹ decreased significantly under stress, whereas, maximum root length and plant height exhibited non-significant increases under stress.

Sinha *et al.* (2000) studied fourteen upland rice varieties of three different isozyme group for selected root and shoot characteristics. Significant varietal differences were observed for all characters except shoot dry weight. Root thickness showed high significant positive correlation with

rooting depth and negative correlation with tiller number. Highest significant correlation recorded between drought score and root thickness of regenerated adventitious roots signified the importance of this trait in varietal improvement. Tropical japonica varieties were found superior to aus and indica in root characters.

2.4 Effect of drought on leaf rolling

Singh and Singh (1989) grown one hundred rice cultivars under rainfed conditions with periods of moisture stress. Leaves were assessed for leaf rolling at vegetative, jointing, advanced reproductive and anthesis stages. Four types of leaf rolling during water stress were identified : rolling that originates from the tip and progresses to the base (vegetative to jointing stages), rolling of the entire leaf (jointing to reproductive stages), helical rolling often from the tip to the middle of the leaf (anthesis, rapid development of stress) and helical rolling towards the leaf base resulting in a non-helical shape.

Ray *et al.* (1996) reported that the root penetration ability is an important factor for rice drought resistance in areas with soil subject to both compaction and periodic water deficits. However, breeding for root penetration ability is inhibited by difficulties associated with measuring root characters.

Tanimoto *et al.* (1999) studied the leaf rolling in rice using 143 cultivars, including indica and temperate and topical japonica types, grown

under low and upland conditions. Leaf rolling was measured with a ruler as the leaf rolling rate: $LRR\% = 1 - \frac{\text{width of the rolling leaf}}{\text{width of the flattened leaf}} \times 100$. When leaves rolled to the abaxial side, LRRs were given minus values. Ranges of LRR in both conditions were 22.1 to 23.1 per cent and 24.7 to 19.5 per cent respectively. Effect of the upland condition on LRR differed among rice ecotypes. Under upland conditions, leaves of japonica type rolled more adaxially and those of indica and Japanese upland cultivars rolled more abaxially than under lowland condition. These finding suggests that greater leaf-rolling rate, the lower values of photosynthesis, transpiration and stomatal conductance was observed under drought conditions as compared to well water controls.

Singh and Singh (2000) reported that effect of morphological and environmental factors found to have profound impact on leaf rolling in rice during water stress. The ridged portion of leaf rolled first followed the smooth one as the water potential of the former was less by 0.48 Mpa than the latter at rolling score five. The process of leaf rolling and unrolling was reversible. Length of leaf was positively whereas leaf angle and specific leaf weight were negatively correlated with leaf rolling.

Zheng *et al.* (2000) observed that drought is the major abiotic stress in rice (*Oryza sativa*) production and yield stability in rainfed lowland and upland ecosystems. Root systems play an important role in drought resistance. The root traits were evaluated in a double haploid (DH)

population derived from cross between IR-64 and Azucena. They showed that consistent QTLs could be used for marker - assisted selection for deep and thick roots with high root penetration ability in rice.

2.5 Role of flag leaf contribution to yield and its stability

Ghosh and Saran (1990) studied the role of flag leaf on grain yield and spikelet sterility in three rice cultivars. All varieties with intact flag leaf produced the higher grain yield. There was a marked improvement in grain yield in all varieties as the flag leaf removal was delayed. Spikelet fertility percentage was low in tall traditional varieties than in semi-dwarfs.

Padmajarao (1992) conducted a field experiment during 1991 (wet season) with twelve early varieties of rice. The studies showed that Vikas, Rasi, Akashi, Telia Hamsa, Tulsi, Annada, Ravi and Abhaya possessing higher flag leaf area and was be positively correlated with several yield attributing parameters such as high density (HD) grains, spikelets, grains and panicle length. Hence, it is suggested that flag leaf area may be considered as a selection criterion for further exploitation of potential yields in rice.

Sen *et al.* (2000) studied defoliation of flag leaf at 0, 2, 4, 6, 8, 10, 12, 14, 18 and 20 days after panicle emergence (DAE) and no defoliation (control) in cv. Pusharjali. They observed that defoliation upto 4-6 DAE reduced the relative growth rate of panicle, but after 4 days it had no adverse effect on panicle growth. All the yield-attributing characters, except panicle length, were significantly reduced when flag leaf was detached within 4-6

DAE. It seems that critical period of flag leaf duration was only upto the 4-6 days of panicle emergence.

2.6 Effect of drought on grain yield and its attributes

Nayak *et al.* (1974) studied three varieties of rice i.e. Padma, Jamuna and IR-8, under flowering stages drought. Drought significantly reduced the grain yield. Amongst the varieties tested, Padma was found to be the best. The variety Padma produced maximum grain per unit of time, per unit area and per unit of water used.

- Row and Venkateshware (1983) studied the yield component of Rasi and IR-20 under moisture stress conditions. The reproductive and ripening phases were vulnerable and crucial for moisture stress which resulted in permanent damage to growth and yield.

Bhardwaj *et al.* (1987) showed that water stress treatments during grain elongation and maturation phases reduce the weight of grain present in the basal position within the spikelets of the middle region of the ear and up to lesser extent than that of the distally located grains in basal and apical region. These differences appear to be related with the vascular supply reaching the grain.

Sairam *et al.* (1990) reported the effect of moisture stress imposed at tillering and anthesis stages on 4 drought susceptible (HD-2329, HD-2009, WL-711, WH-147) and four drought tolerant (C-306, NI-5439, passi local and DL-153-2) genotypes of wheat. The grain yield decreased under moisture

stress. Tolerant genotypes generally had lower rates of transpiration and higher grain yield than the susceptible genotypes under moisture stress. Drought at anthesis stage was more detrimental than at tillering stage.

Sorte *et al.* (1992) exposed, rice cv. Prabhavati, Chanda-2, Chanda-7, Washim-1, Washim-2 and N-27 to 5 d of drought stress at 30, 50, 70 or 90 DAS. Average of cross cultivars water stress at 30, 50, 70 and 90 d reduced grain yield plant⁻¹ by 7, 23, 55 and 48 per cent respectively. Washim-2, was highly susceptible to water stress at all stages, while Prabhavati tolerated water stress at 70 and 90 days after sowing.

Nadarajan and Kumaravelu (1994) showed the relationship between different yield component traits in rice under drought stress and suggested selection strategy for improving grain yield. Single plant yield had significant positive association with plant height, ear length, grain ear⁻¹ and 100 grain weight. The four yield components had high intercorrelation among themselves. Ear length had high and positive direct effect on grain yield. The other components had high positive indirect effect through ear length.

Yadav *et al.* (2001) conducted a pot experiment with eight varieties of wheat grown under normal irrigation (60% ASW) and moisture stress (30% ASW) conditions, to study the effect of different soil moisture regime on grain yield. The grain yield decreased significantly under soil water stress conditions, compared to normally irrigated control. Genotypes K-8027, C.306, K-65 showed more gram yield plant⁻¹ than UP-2003, K-8708, HD-2329, HOW 206 and HUW-234 under 30 per cent available soil water

condition. K-8027 proved to be outstanding variety under moisture stress situation. K-8027 was able to produce the highest plant water status, grain weight/main ear, grain yield/plant. It was also observed that anthesis stage was more sensitive than milk stage.

Naidu *et al.* (2001) screened ten genotypes for drought tolerance under depleting soil moisture condition during post rainy season. Relative water content of leaves (RWC) and leaf area plant⁻¹ decreased in all the genotypes under drought stress condition, where as leaf proline content increased with drought stress. Seed yield decreased drastically in all the genotypes as the crop was subjected to progressive drought stress under receding soil moisture situation.

2.7 Identification of traits, related to drought resistance in rice

O'Toole and Chang (1979) reported that limited moisture supply has a definite impact, either reversible or irreversible on yield attributes in crop plants. The improvement of drought tolerance using secondary traits can stabilize the yield under drought prone conditions.

Nadarajan and Kumaravelu (1993) evaluated twenty short duration rice genotypes for their drought resistance in order to use them in drought resistance breeding programmes. These genotypes were studied under rainfed lowland conditions, where the plants were subjected to drought for more than 15 days in two spell during tillering phase (upto 60 days after sowing). The ability of drought resistance was assessed based on proline accumulation,

relative water content and chlorophyll, stability index in leaves. Five genotypes (Norungan, TPSI, Ottuchandi, TKM-9 and ADT 36) passed the drought resistance screening successfully by scoring significantly superior mean values than grand mean in all the drought resistance parameters studied. Therefore, these five genotypes can be used as potential donors in drought resistance breeding programme.

Fukai *et al.* (1999) reported that recent advances in screening methods for development of drought resistant cultivars research from Thailand in the 1990's for drought that develops early or late in the wet season. There now appears to be good prospects for developing drought resistant cultivars that produce higher yield than existing cultivars when drought develops late in the wet-season. The ability to maintain higher leaf water potential when drought develops late in the season is another desirable character. Maintenance of leaf water potential just prior to flowering is associated with higher panicle water potential, reduced delay in flowering time and reduced spikelet sterility and hence contributes to higher yield. The combination of these characters would ensure high potential yield under favourable conditions and also contribute to resistance against late-season drought. Addition of a drought screening programme that is conducted in the field in the wet-season to the overall breeding programme would enhance the opportunity to select for drought resistance within the breeding materials and increase the chance of developing high yielding cultivars adapted to the drought prone rainfed lowland environments.

Materials and Methods

CHAPTER - III

MATERIALS AND METHODS

The studies entitled "Identification of morpho-physiological traits responsible for drought tolerance in rice" were carried out at the Instructional Farm, College of Agriculture, Indira Gandhi Agricultural University, Raipur (Chhattisgarh) during the *Kharif* season of 2001. The materials used and methodology adopted in investigation are described below:

3.1 Geographical situation

Raipur is situated in the central part of the Chhattisgarh and lies at 21°16' N latitude and 81°36' E longitude with an altitude of 298.6 m above the mean sea level.

3.2 Climate

The climate of this region is dry, sub-humid to semi-arid. The average annual rainfall ranges from 1200-1400 mm out of which 85 per cent is received from middle of June to end of September and very little during October and February. May is the hottest and December the coolest month at Raipur. The maximum temperature of this region may reach as high as 48°C and minimum as low as 6°C during December months. The atmospheric relative humidity is high from June to October. The highest temperature during the crop season was recorded between 27.2 to 35.6°C and the

minimum temperature was 10.3 to 24°C. The maximum and minimum relative humidity during the crop period was 95 and 24 per cent, respectively. The highest rainfall was recorded during July (277.9 mm) and the lowest in October (96.4 mm). The total rainfall during the crop period was 538.6 mm (from 16th July to 16th December, 2001).

The average weather data recorded during the crop growth period presented in Appendix-I.

3.3 Experimental soil characterization

The soil characterization of rainfed and irrigated site are presented in the following table

Table 3.1 : Physico chemical properties of the experimental soil

Soil characteristics	Rainfed			Irrigated		
	Soil depth (cm)			Soil depth (cm)		
	10	20	30	10	20	30
Available N (kg/ha)	174	170	167	188	179	167
Available P (kg/ha)	7.78	8.91	8.67	51.56	34.27	28.14
Available K (kg/ha)	288	246	307	240	237	252
pH	6.40	6.92	6.31	6.16	6.20	6.88
Organic carbon (%)	0.311	0.302	0.253	0.368	0.331	0.271
Sand (%)	29.60	32.00	37.20	34.00	32.80	32.40
Silt (%)	38.40	38.80	37.60	35.60	38.80	40.40
Clay (%)	32.00	29.20	25.20	30.40	28.40	27.20
Texture	Clay loam			Clay loam		
Local name	<i>Matasi</i>			<i>Matasi</i>		
International name	<i>Inceptisols</i>			<i>Inceptisols</i>		

For the soil characterization soil samples were collected from 0-10, 10-20, 20-30 cms with a soil augur before starting the experiment. The samples were air dried, grinded, sieved (2 mm sieve) and used for the above chemical analysis. The soil pH was estimated as per the method described by Piper, (1950) with soil water suspension in 1:2 ratio. Electrical conductivity was determined by the supernatant liquid of soil suspension prepared for pH determination by using solubridge (Richard, 1954). Organic carbon was estimated by Walkley and Black rapid titration method (Piper, 1950). The available nitrogen was determined by Alkaline permanganate method as described by Subbiah and Asija (1956). Available phosphorus was estimated by calorimetric method as described by Olsen *et al.* (1954). The available potassium was determined by flame photometer method as described by Chapman and Pratt (1961). Soil texture (sand, silt and clay per cent of soil) was determined by using International Pipette method (Piper, 1960).

3.4 Experimental details

The studies were conducted with two sites (irrigated and rainfed). The experiment was laid out using factorial randomized complete block design (RCBD) with four replications in both the sites. The layout plan and details of the experiment is depicted in Fig.3.1. The plot size was 7.0 x 5.0 m in both the sites.

A

Rep-I

Rep-II

Rep-III

Rep-IV

W

7m

Site	Rainfed (R) Irrigated (I)
Statistical Design	RCBD Factorial
Replication	Four (4)
Spacing between	
Replication	1 m
Plot	1 m
Plant to plant	20 x 20 cm
Row to row	20 x 20 cm
Gross plot area	5 x 7 m = 35m ²
Total experimental area	29 x 31 m = 899 m ²
Date of sowing	19 th July, 2001
Date of transplanting	17 th Aug., 2001
Date of harvesting	04 th Nov. to 13 th Dec., 2001
Treatments(5) (DHL's)	1. IR-68586-F ₂ -CA-32 2. IR-68586-F ₂ -CA-51 3. IR-68586-F ₂ -CA-54 4. IR-68586-F ₂ -CA-107 5. IR-62266-42-6-2

Fig. 3.1 : Layout plan of the experiment

3.5 Cultural practices

3.5.1 Raising the seedling

Raised nursery beds were prepared with 30 cm wide channel in between. The seeds were treated with organomercurial fungicide and sown in nursery bed by hand drilling method in row. The seeds were thoroughly mixed in the top 2 to 3 cm layer of the soil.

All possible care with respect to plant protection, weeding, irrigation and drainage were applied to the growing seedlings for obtaining good disease free healthy seedlings till attaining the required age for transplanting.

3.5.2 Field preparation for transplanting

The final preparation of the field was done by two criss cross tractor ploughings followed by harrowing. The soil surface was levelled. The field was divided into four replications and then field was laid out as per plan.

3.5.3 Fertilizer application

100:50:30 kg/ha N:P:K were applied in the form of urea, diammonium phosphate and murate of potash, respectively. The half dose of nitrogen was applied as basal dressing. Rest half nitrogen was applied in two splits at 30 and 50 days of transplanting. Whole amount of phosphorus and potassium was applied as basal dressing.

3.5.4 Transplanting

Twenty nine days old seedlings were transplanted in the field. Flexible wire ropes marked at specific intervals (20 x 20 cm) with the help of coloured cloth strips for maintaining the distance between plants and rows.

3.5.5 Weed management

The weed were removed from the plots manually as and when required. Four hand weeding were done at 15 days interval.

3.5.6 Water management

After transplanting the soil was kept saturated until planted seedlings get established in both the sites. In irrigated site 5 ± 2 cm standing water was maintained throughout the growing period after establishment of seedlings. In rainfed site the irrigation was not provided from seedling establishment until maturity.

3.5.7 Plant protection

Plant protection measures were adopted as and when needed during the crop period. Incidence of rice case worm, leaf rollers and stem borer were observed only in rainfed conditions. The necessary plant protection measures were applied to control the diseases and pests.

Reaction of varieties against insect pests and other diseases are presented in following table.

Table 3.2 : Incidence of insects under irrigated and rainfed conditions

Variety	Rainfed				Irrigated			
	Gall midge		Brown spot hopper		Gall midge		Brown spot hopper	
	Flowering	Maturity	Flowering	Maturity	Flowering	Maturity	Flowering	Maturity
CA 32	S	S	5	5	S	S	1	-
CA 51	S	S	2	3	S	S	-	-
CA 54	S	S	1	2	S	S	-	-
CA 107	S	S	1	1	S	S	-	-
IR 62266	S	S	5	5	S	S	-	-

Blast and bacterial leaf blight incidence were not observed

* For GM presence of single silvershoot/ plant was taken as criteria of susceptibility.

* Incidence of the blast was found more severe under rainfed condition.

S : Susceptible

1 : No damage

2 : Slight yellowing of few plants
bum

3 : Leaves partially yellow but no hopper

5 : Leaves with pronounced yellowing and stunting or wilting of about 10 to 25 per cent of the plants with hopper burn.

3.6 Observations

3.6.1 Soil hydrology

3.6.1.1 Ponding water depth

The depth of ponded water on the soil surface were monitored every other day using a standard ruler or slant meter. A flat, bricks were inserted at the surface level of soil. The surface of bricks was taken as a consistent reference point for measurements with a ruler or meter stick. The ponding water depth was measured and expressed in centimeters

3.6.1.2 Depth of water table

Depth of the water table were monitored using 120 cm long perforated, cloth encased PVC pipes in the plots. Depth of water table was measured in every other day after water was disappeared from the soil

surface. The depth of water table was measured and expressed in centimeters.

3.6.1.3 Volumetric soil moisture

Volumetric soil moisture content were measured during drought period by collecting duplicate soil samples from soil depths of 0-8, 8-16, 16-24 and 24-32. The soil was taken by the volumetric core sampler. The fresh weight of the soil was noted and the soil was dried in an oven at 100°C upto the constant weight. The volumetric soil moisture was determined as follows

$$\text{Vol. soil moisture (\%)} = \frac{\text{Fresh wt} - \text{dry wt}}{\text{Dry weight}} \times 100 \times \text{Bulk density}$$

where,

$$\text{Bulk density} = \frac{\text{Mass}}{\text{Volume of core sampler}}$$

$$\text{Vol. of core sampler} = \pi r^2 h$$

$$= \frac{22}{7} \times (3.75)^2 \times 6.9$$

$$= 304.62$$

3.6.2 Dry matter production and its partitioning into various plant parts

Above ground dry matter was estimated at three stages i.e. panicle initiation, flowering and maturity. Eight hills were destructively harvested for the estimation of dry matter production and its partitioning into various

plant parts. Green leaves, dry leaves, stem and panicle were separated and was kept for dry matter estimation in hot air oven at 80°C. The dry matter was recorded when constant dry weight was observed. Care was taken that the area sampled is representative of plot and the harvested area is at least three rows of plants and away from the border and previously harvested areas in the plot. The dry matter was expressed in gram m⁻².

3.6.3 Tiller number

The number of tiller were counted from the dry matter sampling hills (eight) at tillering, flowering and mature stages. The tiller number was expressed as number m⁻².

3.6.4 Plant height

Plant height was measured from the base of the plant to the tip of the longest leaf. It was measured with a standard meter stick in three labelled hills at tillering and flowering stage. Plant height was recorded in conjunction with the periodic biomass sampling. The plant height was expressed in cms.

3.6.5 Phenology

3.6.5.1 Panicle initiation

For estimation of panicle initiation stage, plants were uprooted and main caulm was dissected from the base and was seen by naked eye. When a silky appearance was observed at the base, it was considered as panicle initiation stage.

3.6.5.2 Flowering stage

When stamens of spikelets came out and yellowish white structure was seen on spikelets of mother tillers, it was considered as flowering stage. The flowering stage was decided when nearly 90 per cent flowers were appeared.

3.6.5.3 Maturity stage

The maturity stage was determined when the stamens of spikelet are completely yellow and dried. This stage was also determined by grain hardness.

3.6.6 Photosynthesis, transpiration and canopy cooling

The net photosynthetic rate, leaf temperature and rate of transpiration were measured with the help of portable photosynthesis system (LI-COR LI-6400, USA) between 0930 hours to 1030 hours on clear sky day. Photosynthesis and related parameters were estimated in the five centre rows of the sub-plot. These observations were recorded in the flag leaf of the mother shoots or uppermost fully expanded leaf of the mother shoot from the irrigated and rainfed plots. The photosynthesis, transpiration and the leaf temperature was expressed as $\mu\text{mol m}^{-2}\text{s}^{-1}$, $\text{mmol m}^{-2}\text{s}^{-1}$ and $^{\circ}\text{C}$ respectively.

3.6.7 Leaf area index

Three hills were harvested for measurement of LAI. From these hills, three mother tillers were separated. All the green leaves present on the mother tillers were separated and was kept in a beaker to avoid the leaf rolling. The length and maximum width of the green leaves presented on the

mother tiller were measured and was kept for dry weight. All the green leaves from rest of the tillers were removed and was dried upto constant weight separately. A factor of 0.75 (at panicle initiation and flowering) and 0.67 (at maturity) was used (Gomez, 1972) to calculate the leaf area.

The leaf area was calculated as follows:

$$\text{Leaf area} = \frac{A \times W}{w}$$

where,

A = Area (length x width x factor)

W = Dry weight green leaves from all tillers including the mother tillers

w = Dry weight of three mother tillers green leaves

Leaf area index was calculated as follows (Watson, 1947).

$$\text{LAI} = \frac{\text{Leaf area (cm}^2\text{)}}{\text{Ground area (cm}^2\text{)}}$$

3.6.8 Leaf water status

Leaf water status was estimated by measuring leaf water potential by pressure chamber and relative water content.

The leaf water potential was measured with the help of a portable pressure chamber instrument (Model 1003 PMS, Instrument Company, USA) as described by Boyer (1967). The observations of water potential were recorded between 1 pm to 2 pm in uppermost fully expanded leaf of mother tiller. Three observations were recorded from each double haploid lines

under rainfed conditions. Leaves were removed from the plant and immediately placed in the chamber of the instrument by keeping the petiole outside the chamber. The chamber was locked carefully and the pressure was applied on the leaf at the rate of 0.1 bar per second using nitrogen gas, till a drop oozed out on the cut surface. Further raising of pressure was stopped and the water potential was recorded directly from the gauge. The pressure was then released and the leaf was removed from the chamber. The water potential was expressed in -bars.

Relative water content (RWC) were measured on the basis of oven dry weight. Leaves were removed from plot and placed in the preweighed air tight vial to reduce the evaporation losses. The vial along with the leaves were weighed for its fresh weight. After recording fresh weight leaf pieces were dipped in 30 ml distilled water for four hours. After four hours leaf pieces were removed from the vial and the water drops present on leaf surface were soaked with the help of blotting paper. The leaf pieces were weighed for its turgid weight. After recording the turgid weight, leaf pieces were kept in oven for drying till constant weight. Relative water content was calculated as follows.

$$\text{R.W.C.(\%)} = \frac{\text{Fresh wt} - \text{oven dry wt}}{\text{Turgid wt} - \text{oven dry wt}} \times 100$$

3.6.9 Crop responses to drought stress

Different lines were observed for signs of wilting, leaf rolling and leaf death. The magnitude and time at which these events observed were noted. Observations was recorded from all plots of rainfed site. Drought scores (leaf rolling and drying) was estimated as defined by IRRI (SES) standard evaluation system. Leaf rolling was estimated as follows:

Leaf rolling scale (0-9)

- 0 - Leaves healthy
- 1 - Leaves start to fold (shallow V-shape)
- 3 - Leaves folding (deep V-shape)
- 5 - Leaves fully cupped (U-shape)
- 7 - Leaf margin touching (O-shape)
- 9 - Leaves tightly rolled

Drought scale (0-9) based on leaf drying:

- 0 - No symptoms of leaf drying
- 1 - Slightly tip drying
- 3 - Tip drying extended upto $\frac{1}{4}$ length in most leaves
- 5 - One fourth to $\frac{1}{2}$ of all leaves fully dried
- 7 - More than $\frac{2}{3}$ of all leaves fully dried
- 9 - All plants apparently dead

3.6.10 Root dry weight

Root dry weight of the plants were determined by taking the root samples from the depth of 0-10, 10-20, 20-30 and 30-40 cm by using a core sampler. The diameter of core sampler was 10 cm. The shoot portion of the plants was cut off at the ground level. After that root core sampler was hammered down to the desired depth and the root samples were collected along with the soil. The soil was then washed off and the clean roots were collected. The clean roots were dried in an oven at 80°C till constant weight. Dry weight were recorded on an electronic balance. The root dry weight was expressed as gram m⁻².

3.6.11 Root / shoot ratio

Root shoot ratio was calculated as follows:

$$\text{Root shoot ratio (\%)} = \frac{\text{Root dry matter}}{\text{Shoot dry matter}} \times 100$$

A total of three hill from both the sites were considered for the root/shoot ratio. The root shoot ratio was obtained at panicle initiation, flowering and maturity stages. The roots were collected with the help of a core sampler. Root/ shoot ratio was expressed as per cent.

3.6.12 Flag leaf area

Upper most fully expanded leaf of the mother tiller was selected for the estimation of flag leaf area at flowering stage. The length and maximum

width of the flag leaves were recorded at flowering stage. A factor of 0.75 was used to calculate the flag leaf area. It was expressed as cm².

$$\text{Flag Leaf area} = \text{Length} \times \text{Width} \times K \text{ (Factor 0.75)}$$

3.6.13 Post flowering dry matter production

Post flowering dry matter production was estimated as follows:

Total dry matter at maturity - Total dry matter at flowering.

It was expressed as gram m⁻².

3.6.14 Apparent translocation rate

Apparent translocation rate from stem was estimated as follows:

$$\text{ATR} = \frac{\text{Stem dry matter at flowering} - \text{Stem dry matter at maturity}}{\text{Panicle dry matter at maturity} - \text{Panicle dry matter at flowering}}$$

3.6.15 Yield and its attributes

Hundred hills in the center of the plot were sampled for grain yield at maturity stage. Harvesting was done when the grain was deemed mature and grain texture is solid alongwith senescent leaves. Panicles were threshed and the grains were cleaned. Grain were sundried and weighed. A sample were collected to determine the grain moisture content. Reported grain weight was corrected to 14 per cent moisture content.

Grain yield attributes were estimated from the eight hills harvested at maturity. All the panicle from eight hills were threshed. The filled and unfilled grains were separated and counted. The weight of the filled and unfilled grains were recorded, separately.

The yield attributes were calculated by using the following formulas

$$\text{i) Unfilled grains (\%)} = \frac{\text{Unfilled grains}}{\text{Filled grains} + \text{Unfilled grains}} \times 100$$

$$\text{ii) Test weight (g)} = \frac{\text{Filled grains weight}}{\text{Filled grain number}} \times 1000$$

$$\text{iii) Grain per panicle (No.)} = \frac{\text{No. of filled grains}}{\text{Panicle number}}$$

3.7 Statistical analysis

Statistical analysis was done as the method described by the Gomez and Gomez (1983).

Results

CHAPTER - IV

RESULTS

4.1 Soil hydrology

4.1.1 Ponding water depth during crop growth under rainfed conditions

The average ponding water depth have been presented in Table 4.1 and Fig. 4.1 (a). The result shows that highest water depth was recorded at 38 days after sowing and decreases thereafter up to 77 days after sowing. The average ponding water depth recorded lowest (0.41 cm) at 77 days after sowing. No ponding water was present on soil surface after 77 days after sowing.

4.1.2 Water table depth during crop growth under rainfed conditions

The average water table depth have been presented in Table 4.2 and Fig. 4.1(b). The result shows that water table fluctuates up to 84 days after sowing. The lowest (2.93 cm) water table depth recorded at 84 days after sowing. After 84 days a constant decrease in water table was observed because of no rains. After 95 DAS water table was always below one meter depth.

4.1.3 Volumetric soil moisture (θ_v) content during crop growth under rainfed conditions

The volumetric soil moisture content in drying soil have been presented in Table 4.3 and Fig.4.1(c). The result showed that moisture

Table 4.1 : Ponding water depth (cm) at various stages under rainfed conditions

Plot No.	Ponding water depth (cm)				
	DAS				
	38	44	46	50	77
1	7.6	6.2	5.6	0.5	0.2
2	8.9	7.5	6.3	1.7	0.1
3	7.2	6.3	5.3	0.2	0.0
4	8.2	7.3	5.6	0.1	0.1
5	6.9	6.3	6.2	1.5	0.9
6	7.8	6.5	5.8	1.8	1.1
7	8.9	7.3	6.3	2.5	0.4
8	7.3	7.0	6.1	0.4	0.1
9	8.5	8.0	7.3	0.3	0.0
10	8.8	8.1	7.5	0.1	0.0
11	9.2	8.5	7.9	1.3	0.0
12	9.6	8.5	8.2	3.0	2.0
Average	8.24	7.29	6.51	1.12	0.41

Table 4.3 : Average volumetric soil moisture (θ_v) at various stages in different depth under rainfed conditions

Depth	Days after sowing (DAS)										
	57	66	72	82	91	96	104	110	117		
0-8	36.110	26.894	34.456	35.209	28.812	25.998	23.063	19.670	13.071		
8-16	38.990	30.623	35.567	35.638	30.444	27.975	24.335	21.294	16.792		
16-24	40.628	33.267	36.867	37.162	31.803	29.095	25.505	22.864	19.259		
24-32	43.671	34.419	38.214	37.267	32.863	31.780	27.228	24.233	21.269		
Average	39.849	31.300	36.276	36.319	30.980	28.712	25.032	22.015	17.590		
SE(m) \pm	0.7018	0.4575	0.2108	0.1998	0.2983	0.3135	0.563	0.239	0.2926		
CD at 5%	2.04	1.33	0.61	0.58	0.87	0.91	1.63	0.69	0.85		

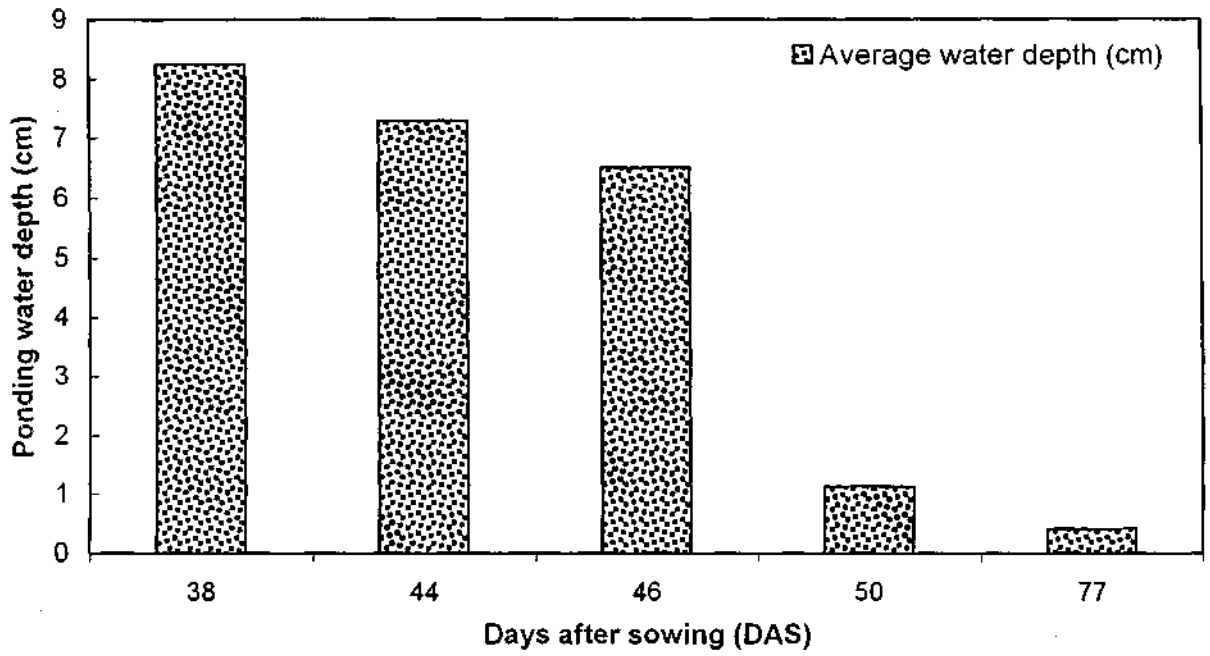


Fig. 4.1(a) : Ponding water depth (cm) at various stages under rainfed conditions

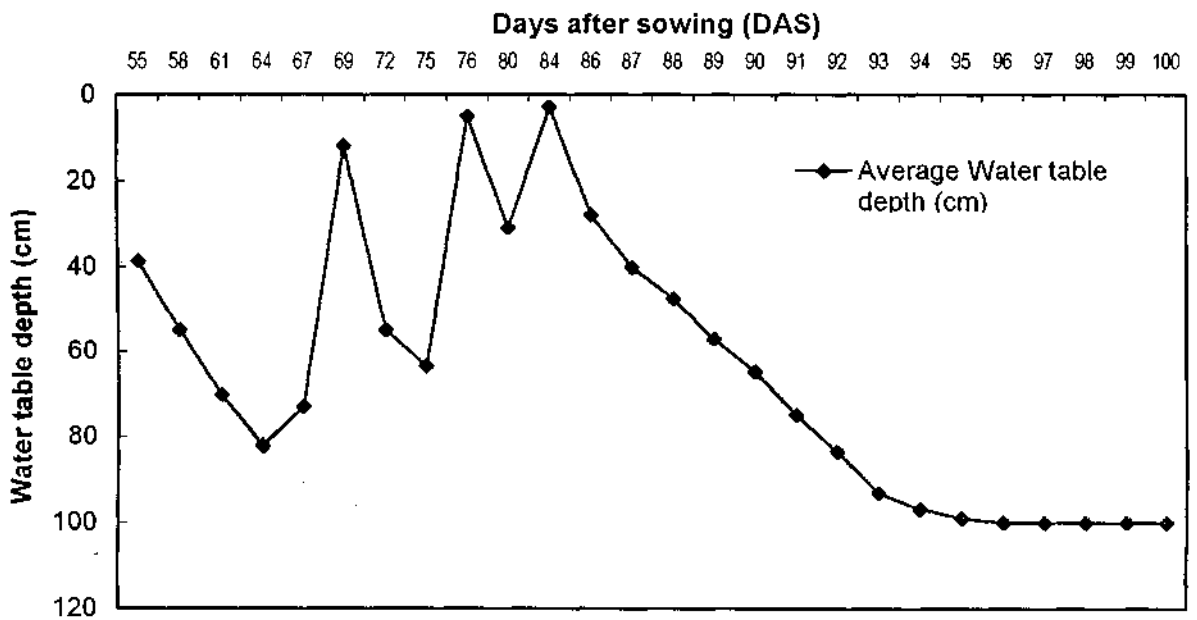


Fig. 4.1(b) : Water table depth from soil surface(cm) at various stages under rainfed conditions

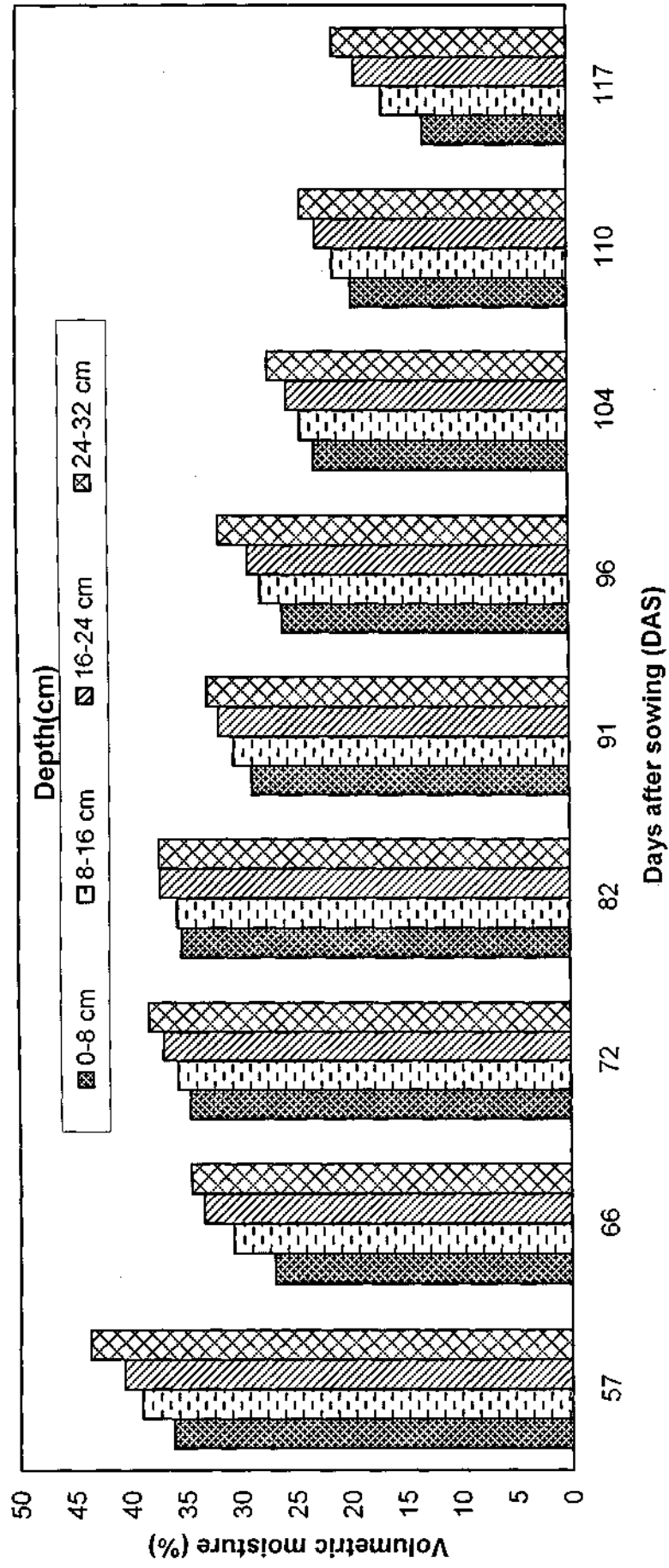


Fig. 4.1(c) : Volumetric soil moisture (%) at various stages under rainfed conditions

content decreases from 57 DAS to 66 DAS in all the soil depths. At 72 and 82 DAS soil moisture was recorded higher compare to 66 DAS due to rains during this period. Constant decrease in soil moisture content was observed from 82 DAS onwards. At 117 DAS soil moisture was recorded 13 per cent in top 8 cm soil layer and 21 per cent from 24-32 cm soil depth.

4.2 Leaf rolling and dessication at different DAS in various double haploid lines under **rainfed** conditions

Results related to leaf rolling and dessication have been presented in Table 4.4 and Fig.4.2 (a,b). Leaf rolling started from 93 DAS. CA-107 and CA-54 start rolling its leaf earlier than other lines. No rolling was observed in CA-32 and CA-51 upto 100 DAS. At 121 DAS rolling was recorded highest in CA-107 and IR 62266 compare to other lines. The lowest average rolling was observed in CA-32.

Average leaf drought score increases from 88 to 121 days after sowing. Leaf desiccation was recorded highest in CA-51 at all the stages of measurements. The leaf drought score was recorded lowest in CA-54 at all the stages.

4.3 Dry matter production and its partitioning into various plant parts under irrigated and rainfed conditions at panicle initiation stage

The results on dry matter production and its partitioning into different plant parts have been presented in Table 4.5 and from Fig. 4.3 to 4.8. The result showed that total dry matter production reduced significantly in rainfed site compare to irrigated site. The reduction in dry matter under rainfed site

Table 4.4 : Leaf rolling (scale 0-9) and desiccation (scale 0-9) at various stages under rainfed conditions

Variety	Leaf rolling (DAS)					Desiccation (DAS)					
	93	100	106	112	121	88	93	100	106	112	121
IR-68586-F ₂ -CA-32	0.00	0.00	0.50	2.25	4.75	2.00	3.00	3.50	5.00	5.75	6.25
IR-68586-F ₂ -CA-51	0.00	0.00	1.50	2.00	5.25	3.50	3.50	5.25	5.75	6.75	7.00
IR-68586-F ₂ -CA-54	1.00	1.00	2.75	3.50	6.50	1.00	2.50	2.75	2.75	3.00	4.25
IR-68586-F ₂ -CA-107	1.00	1.00	3.25	4.25	8.00	1.00	1.75	2.50	3.00	4.00	5.00
IR-62266-42-6-2	0.00	0.50	1.00	6.00	7.75	2.50	3.00	3.25	3.25	5.00	6.00
Average	0.40	0.50	1.80	3.60	6.45	2.00	2.75	3.45	3.95	4.90	5.70
SEm	0.11	0.12	0.25	0.53	0.54	0.39	0.41	0.26	0.20	0.16	0.24
CD(5%)	0.35	0.40	0.78	1.65	1.68	1.23	NS	0.81	0.64	0.51	0.76

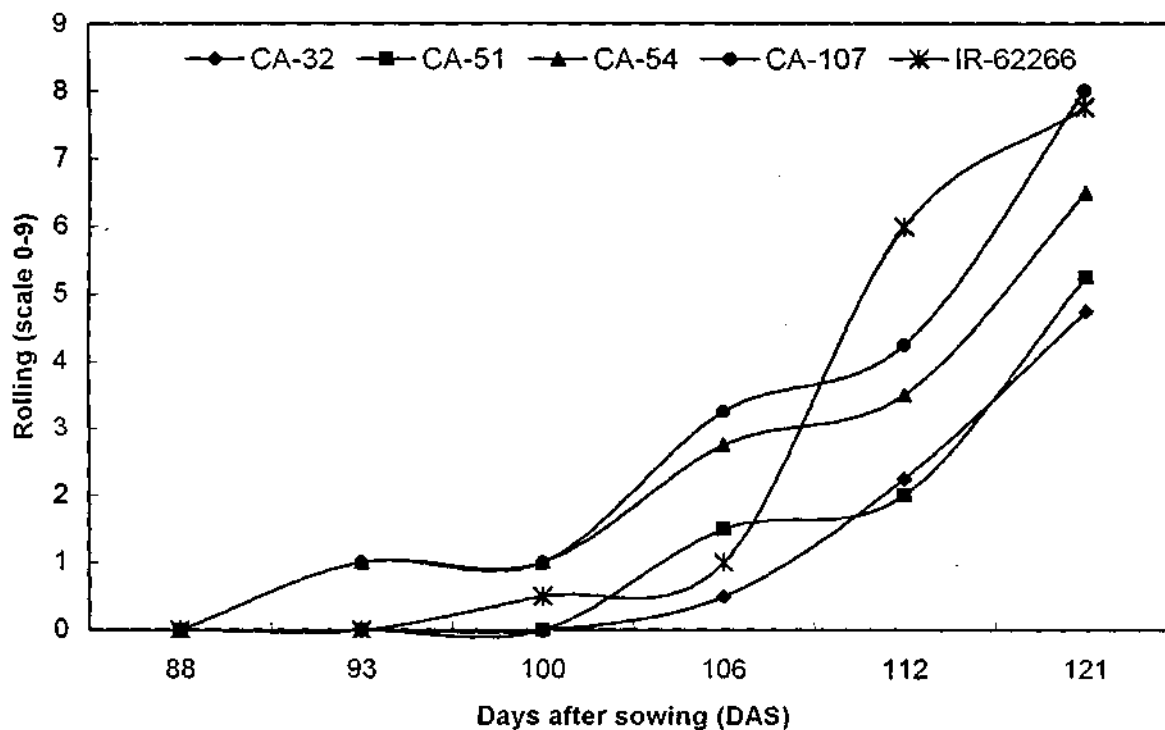


Fig. 4.2(a) : Leaf rolling at various stages in different double haploid lines under rainfed conditions

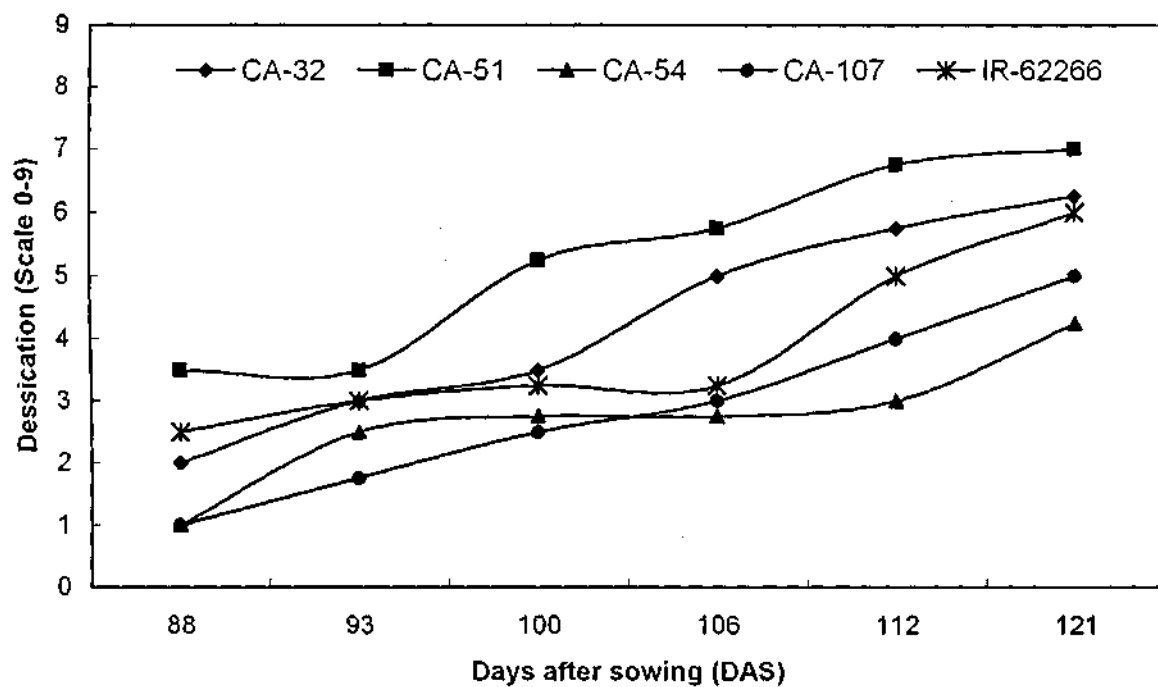


Fig. 4.2(b) : Leaf desiccation at various stages in different double haploid lines under rainfed conditions

Table 4.5 : Dry matter production and its partitioning into various plant parts under irrigated and rainfed conditions at panicle initiation stage

Site	Green leaf dry matter (g m ⁻²)	Dry leaf dry matter (g m ⁻²)	Stem dry matter (g m ⁻²)	Total dry matter (g m ⁻²)
Irrigated	100.60	2.53	83.93	186.97
Rainfed	60.43	3.14	54.72	118.30
SE(m) ±	4.17	0.25	4.12	8.26
CD at 5%	12.11	NS	11.96	23.95
Variety				
IR-68586-F ₂ -CA-32	56.49	2.55	65.90	124.94
IR-68586-F ₂ -CA-51	104.66	4.11	86.57	195.10
IR-68586-F ₂ -CA-54	73.84	2.76	54.25	130.85
IR-68586-F ₂ -CA-107	51.79	1.97	41.85	95.62
IR-62266-42-6-2	115.81	2.80	98.05	216.66
SE(m) ±	6.60	0.40	6.52	13.06
CD at 5%	19.15	1.16	18.92	37.87
Site x variety				
Irrigated x IR-68586-F ₂ -CA-32	73.16	1.93	82.44	157.54
Irrigated x IR-68586-F ₂ -CA-51	148.04	4.98	124.14	276.66
Irrigated x IR-68586-F ₂ -CA-54	81.21	1.68	53.96	136.85
Irrigated x IR-68586-F ₂ -CA-107	58.39	1.41	47.60	107.42
Irrigated x IR-62266-42-6-2	142.21	2.64	111.52	256.37
Rainfed x IR-68586-F ₂ -CA-32	39.81	3.16	49.37	92.35
Rainfed x IR-68586-F ₂ -CA-51	61.29	3.24	49.00	113.54
Rainfed x IR-68586-F ₂ -CA-54	66.48	2.83	54.54	124.85
Rainfed x IR-68586-F ₂ -CA-107	45.18	2.54	36.10	83.83
Rainfed x IR-62266-42-6-2	89.41	2.95	84.58	176.95
SE(m) ±	9.34	0.56	9.23	18.47
CD at 5%	27.08	1.64	26.75	53.56

increases, as plant grows older from panicle initiation stage to maturity stage. Varietal variation and interaction were observed statistically significant. The total dry matter production was highest in CA-51 and IR-62266 under irrigated and rainfed conditions respectively. The reduction in total dry matter under rainfed site was highest in CA-51 (58%) and lowest in CA-54 (8%) compare to irrigated site. The average dry matter was reduced by 36 per cent under rainfed condition compared to irrigate controls at panicle initiation stage.

Green leaf dry matter significantly reduced under rainfed conditions. Green leaf dry matter was highest in CA-51 and IR-62266 under irrigated and rainfed site respectively. The reduction in green leaf area under rainfed site ranges from 18 to 58 per cent among different lines. Significant differences were not observed for dead leaf dry matter between two sites. The dead leaf dry matter was observed highest in CA-51 under both water regimes. Stem dry matter was highest in CA-51 under irrigated site. Stem dry matter decreases significantly under rainfed site compare to irrigated site. The reduction in stem dry matter under rainfed site was recorded highest (60%) in CA-51. Significant variation was not observed for stem dry matter in CA-54 between two sites.

4.4 Dry matter production and its partitioning into various plant parts at flowering

The results on dry matter production and its partitioning into different plant parts have been presented in Table 4.6 and from Fig. 4.3 to 4.8. *The*

Table 4.6 : Dry matter production and its partitioning into various plant parts under irrigated and rainfed conditions at flowering stage

Site	Green leaf dry matter (g m ⁻²)	Dry leaf dry matter (g m ⁻²)	Stem dry matter (g m ⁻²)	Panicle dry matter (g m ⁻²)	Total dry matter (g m ⁻²)
Irrigated	135.78	28.98	330.31	130.11	625.70
Rainfed	70.37	43.92	186.04	66.42	366.77
SE(m) ±	4.38	2.25	12.06	9.26	20.72
CD at 5%	12.71	6.05	34.97	26.87	60.06
Variety					
IR-68586-F ₂ -CA-32	75.16	15.28	195.30	38.19	323.94
IR-68586-F ₂ -CA-51	94.85	49.12	222.74	80.22	446.88
IR-68586-F ₂ -CA-54	98.24	42.88	297.53	121.62	560.28
IR-68586-F ₂ -CA-107	109.12	26.00	244.64	97.67	477.45
IR-62266-42-6-2	138.01	48.96	330.68	153.63	672.62
SE(m) ±	6.93	3.56	19.07	14.65	32.76
CD at 5%	20.09	10.32	55.31	42.49	94.97
Site x variety					
Irrigated x IR-68586-F ₂ -CA-32	103.68	11.66	230.62	46.58	392.56
Irrigated x IR-68586-F ₂ -CA-51	131.22	39.54	288.85	108.64	568.27
Irrigated x IR-68586-F ₂ -CA-54	130.25	38.24	416.48	173.25	758.22
Irrigated x IR-68586-F ₂ -CA-107	142.64	18.72	320.29	128.21	609.87
Irrigated x IR-62266-42-6-2	171.10	36.73	395.33	193.89	799.56
Rainfed x IR-68586-F ₂ -CA-32	46.64	18.89	159.97	29.81	255.33
Rainfed x IR-68586-F ₂ -CA-51	58.47	58.71	156.62	51.81	325.49
Rainfed x IR-68586-F ₂ -CA-54	66.23	47.52	178.58	70.00	362.33
Rainfed x IR-68586-F ₂ -CA-107	75.60	33.29	169.00	65.14	345.04
Rainfed x IR-62266-42-6-2	104.91	61.20	266.04	113.37	545.68
SE(m) ±	9.80	5.03	26.98	20.72	46.33
CD at 5%	NS	NS	78.21	NS	34.31

result showed that total dry matter production reduced significantly under rainfed site as compare to irrigated site. Varietal variation and its interaction were observed statistically significant while the green leaf, dead leaf, panicle dry matter production among two sites was observed statistical non-significant. The total dry matter production was highest in IR-62266 and CA-54 under irrigated and rainfed conditions respectively. The reduction in total dry matter under rainfed site was highest in CA-54 (52%) and lowest in IR-62266 (31.75%). The average dry matter was reduced by 41 per cent under rainfed condition compare to irrigated condition.

Green leaf dry matter significantly reduced under rainfed conditions. Green leaf dry matter was highest in CA-107 and IR-62266 under irrigated and rainfed sites respectively. The average green leaf dry matter was reduced by 48 per cent under rainfed condition as compare to irrigated controls. Significant differences were not observed in dead leaf dry matter among two sites. The dead leaf dry matter was observed highest in CA-51 under irrigated and rainfed conditions. Stem dry matter decreases significantly under rainfed site compare to irrigated site. Stem dry matter was highest in CA-54 under irrigated condition. The reduction in stem dry matter was also highest (57%) in CA-54 under rainfed condition.

The average panicle dry matter was reduced by 49 per cent under rainfed site as compare to irrigated site. Varietal variation for panicle dry matter was observed significant. At flowering stage the highest panicle dry

matter was produced by IR-62266, while the reduction in panicle dry matter under rainfed site was observed highest in CA-54.

4.5 Dry matter production and its partitioning into various plant parts at maturity stage

The results on dry matter production and its partitioning into different plant parts have been presented in Table 4.7 and from Fig. 4.3 to 4.8. The results showed that total dry matter production reduced significantly in rainfed site compare to irrigated site. Varietal variations were observed statistically significant however the interaction was non significant. The total dry matter production was observed highest in IR-62266 under both the sites. The reduction in total dry matter under rainfed site was highest in CA-32 (67%) and lowest in CA-54 (54%) followed by IR-62266. The average dry matter was reduced by 53 per cent under rainfed condition compared to irrigate controls.

Green leaf dry matter significantly reduced under rainfed condition. Green leaf dry matter was highest in CA-54 under irrigated site while it was observed maximum in IR-62266 under rainfed site. Green leaf dry matter was reduced by 61 per cent under rainfed site compare to irrigated site. The average production of dead leaf dry matter was higher in irrigated site as compare to rainfed site. Dry leaf dry matter was highest in IR-62266 and CA-54 under irrigated and rainfed site respectively. The reduction in dead leaf dry matter under rainfed site ranges from 4 to 51 per cent. Stem accumulates higher dry matter under irrigated conditions as compare to

Table 4.7 : Dry matter production and its partitioning into various plant parts under irrigated and rainfed conditions at maturity

Site	Green leaf dry matter (g m ⁻²)	Dry leaf dry matter (g m ⁻²)	Stem dry matter (g m ⁻²)	Panicle dry matter (g m ⁻²)	Total dry matter (g m ⁻²)
Irrigated	11.83	139.25	374.46	362.95	888.30
Rainfed	4.58	111.60	167.65	126.02	409.87
SE(m) ±	1.80	6.05	14.20	17.88	32.93
CD at 5%	5.22	17.55	41.20	51.83	95.48
Variety					
IR-68586-F ₂ -CA-32	2.10	81.02	250.42	82.24	415.79
IR-68586-F ₂ -CA-51	14.14	121.49	237.18	155.32	528.15
IR-68586-F ₂ -CA-54	16.03	124.18	273.00	208.13	621.36
IR-68586-F ₂ -CA-107	2.92	117.80	253.85	376.93	751.02
IR-62266-42-6-2	5.83	182.64	340.81	399.82	929.11
SE(m) ±	2.85	9.57	22.46	28.27	52.07
CD at 5%	8.26	27.75	65.12	81.96	150.97
Site x variety					
Irrigated x IR-68586-F ₂ -CA-32	3.85	108.99	387.97	128.25	629.08
Irrigated x IR-68586-F ₂ -CA-51	24.06	124.54	327.62	232.71	708.93
Irrigated x IR-68586-F ₂ -CA-54	27.00	133.18	363.45	279.70	803.35
Irrigated x IR-68586-F ₂ -CA-107	0.00	133.93	346.58	599.73	1079.25
Irrigated x IR-62266-42-6-2	4.23	195.62	446.68	574.37	1220.91
Rainfed x IR-68586-F ₂ -CA-32	0.35	53.04	112.87	36.23	202.50
Rainfed x IR-68586-F ₂ -CA-51	4.23	118.45	146.75	77.93	347.37
Rainfed x IR-68586-F ₂ -CA-54	5.06	1155.18	182.56	136.56	439.37
Rainfed x IR-68586-F ₂ -CA-107	5.85	101.66	161.12	154.14	422.79
Rainfed x IR-62266-42-6-2	7.43	169.66	234.93	225.27	637.31
SE(m) ±	4.03	13.54	31.76	39.98	73.64
CD at 5%	11.68	NS	NS	115.91	NS

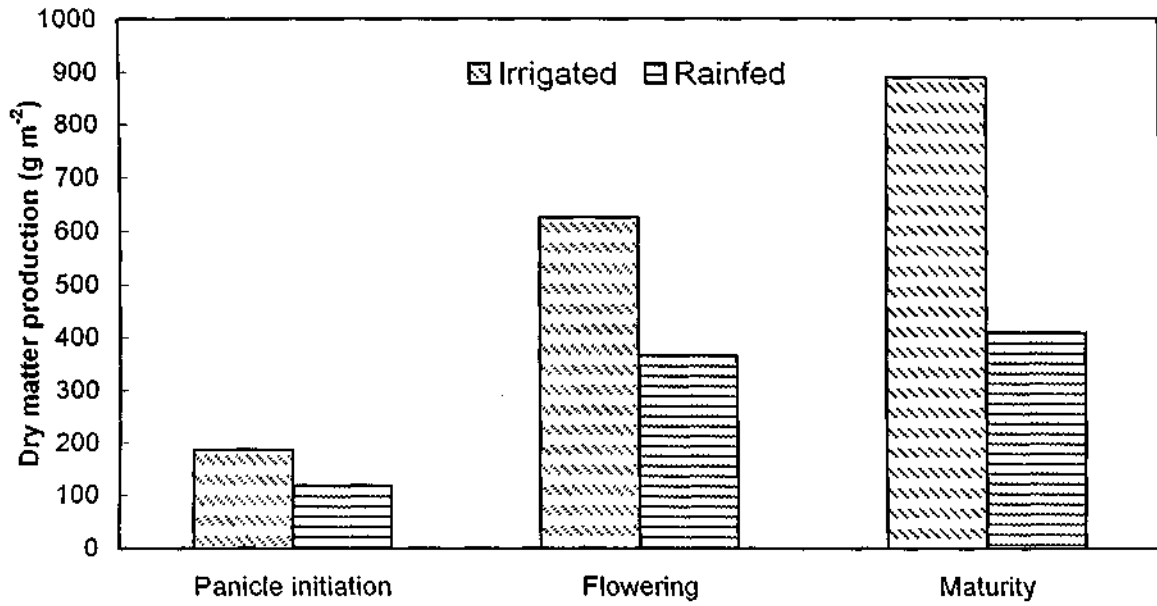


Fig. 4.3 (a) : Total average dry matter production under irrigated and rainfed conditions

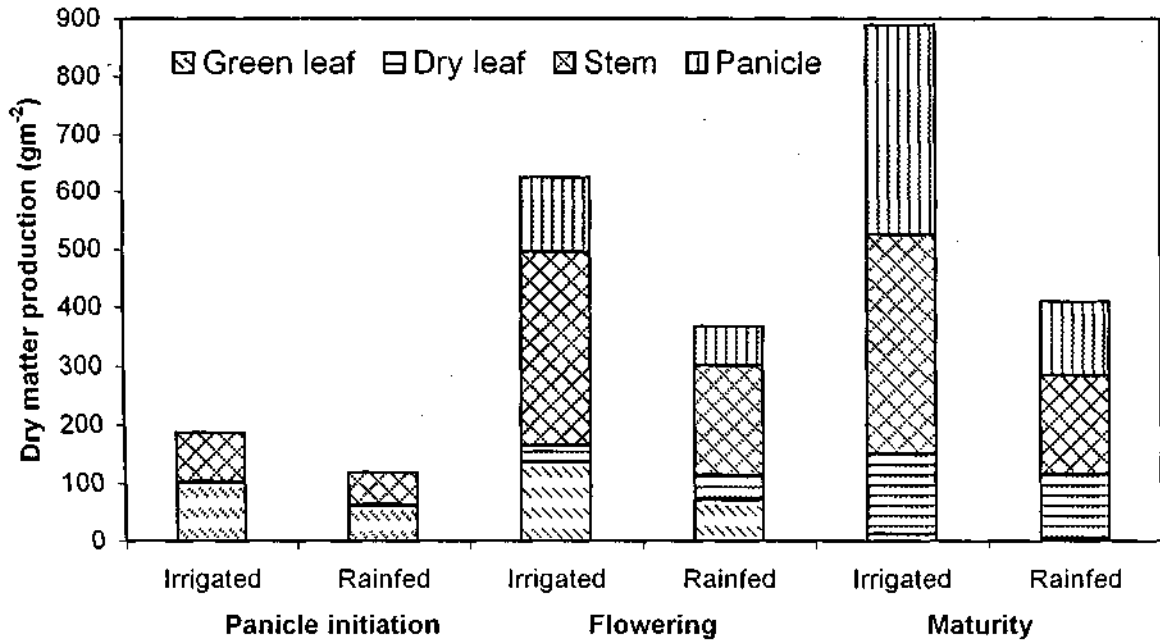


Fig. 4.3(b) : Average dry matter partitioning into various plant parts under irrigated and rainfed conditions

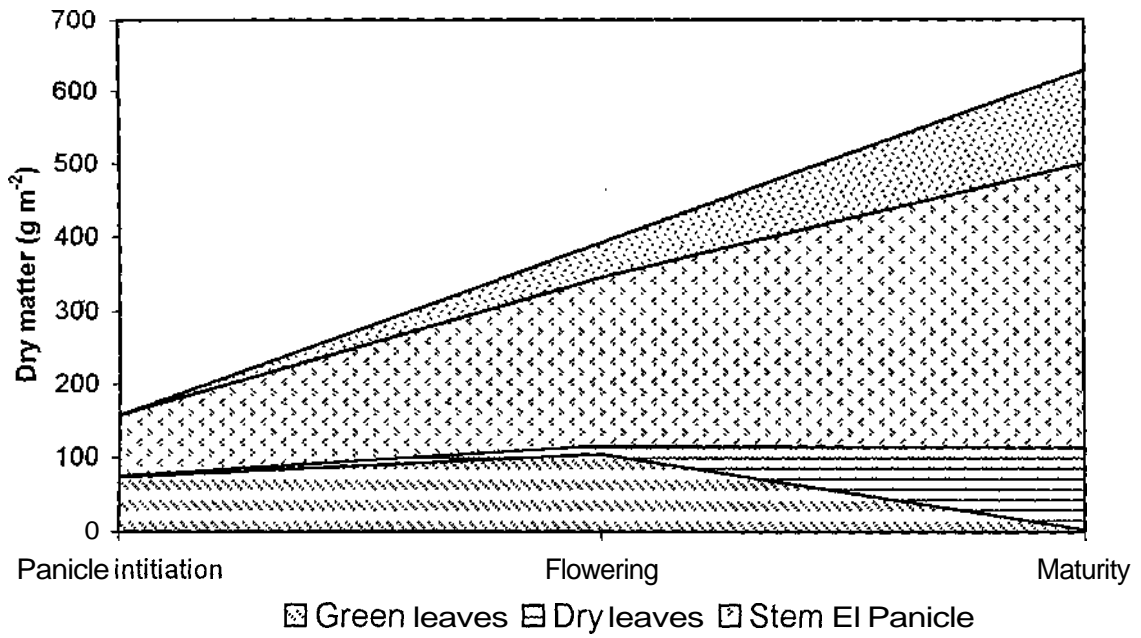


Fig. 4.4(a) : Dry matter partitioning in CA-32 under irrigated conditions at various stages

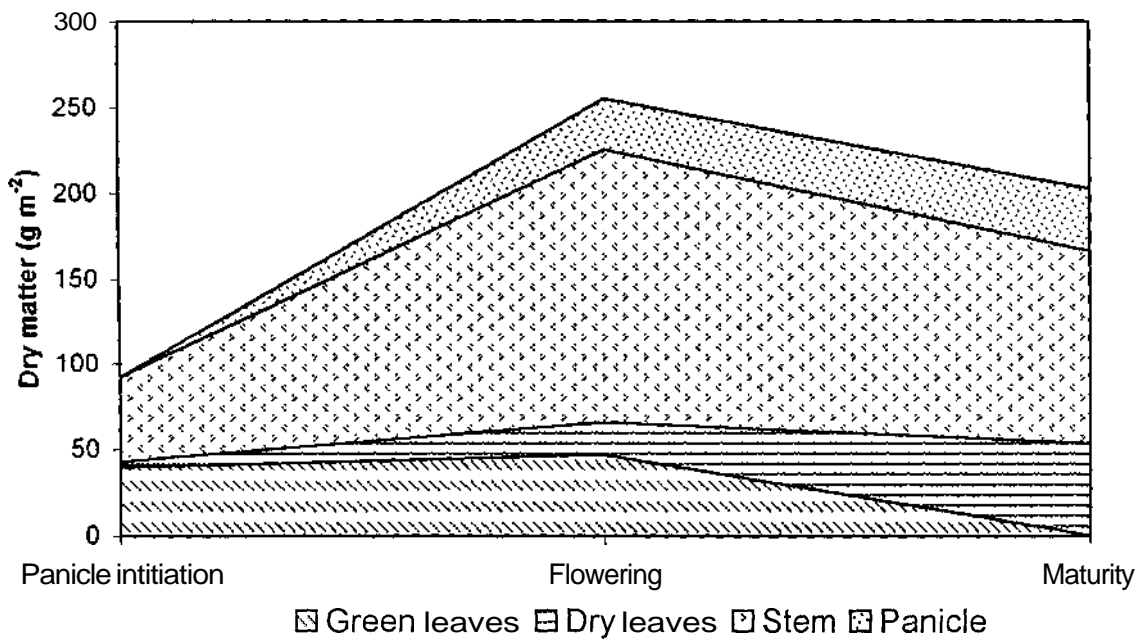


Fig. 4.4(b): Dry matter partitioning in CA-32 under rainfed conditions at various stages

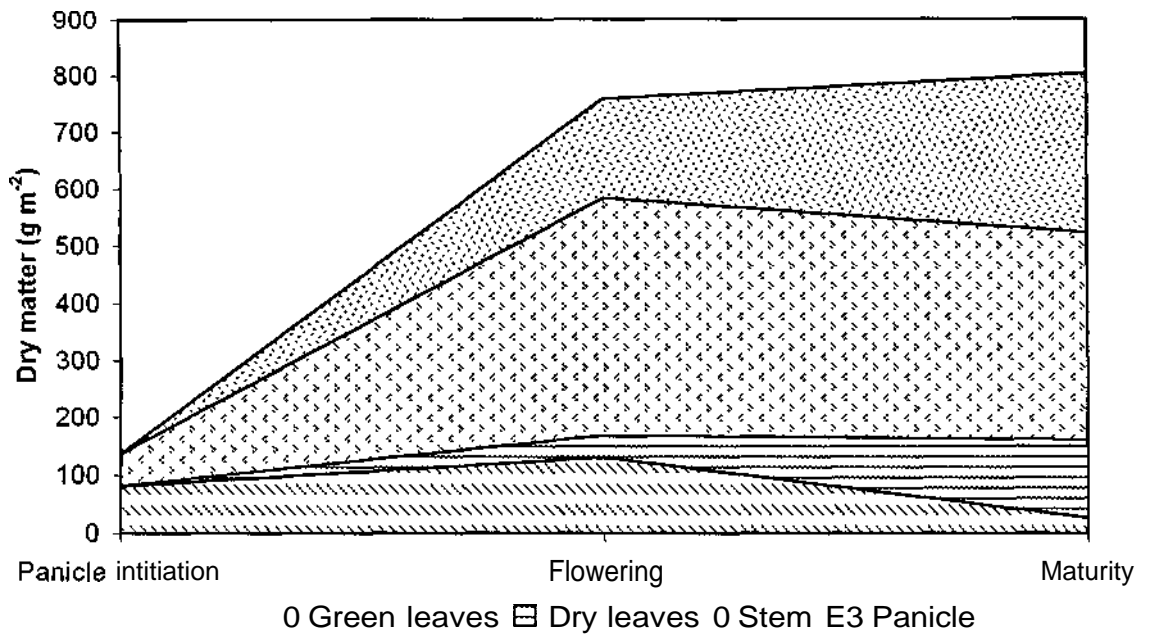


Fig.4.5a : Dry matter partitioning in CA-51 under irrigated conditions at various stages

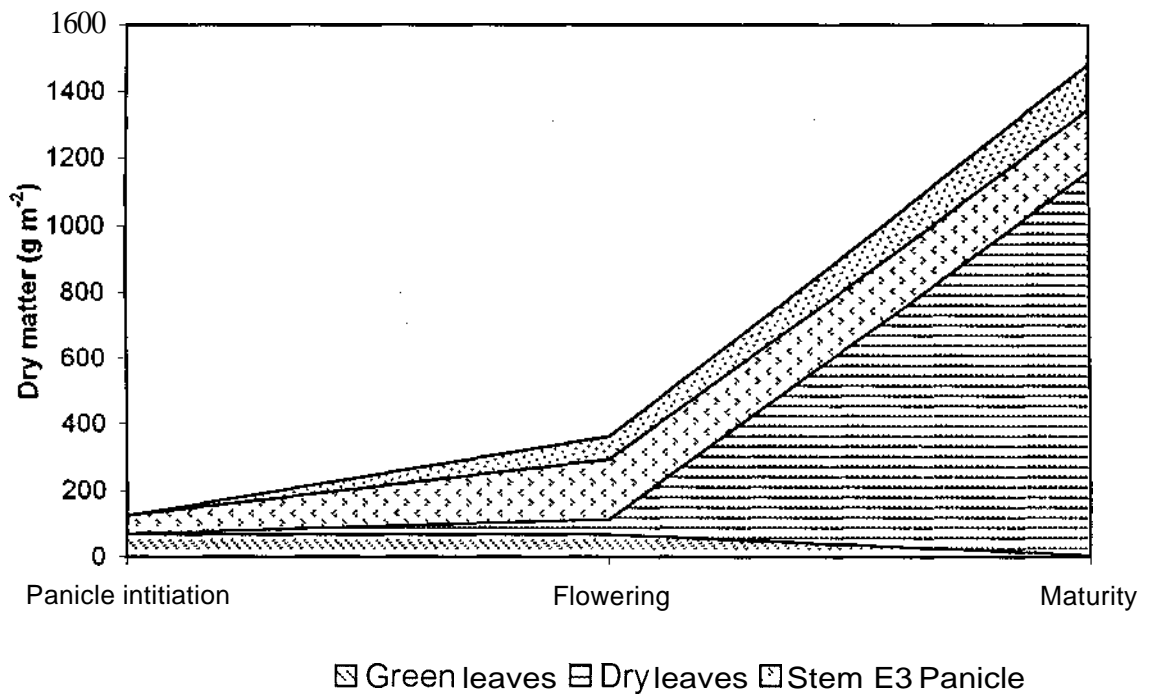
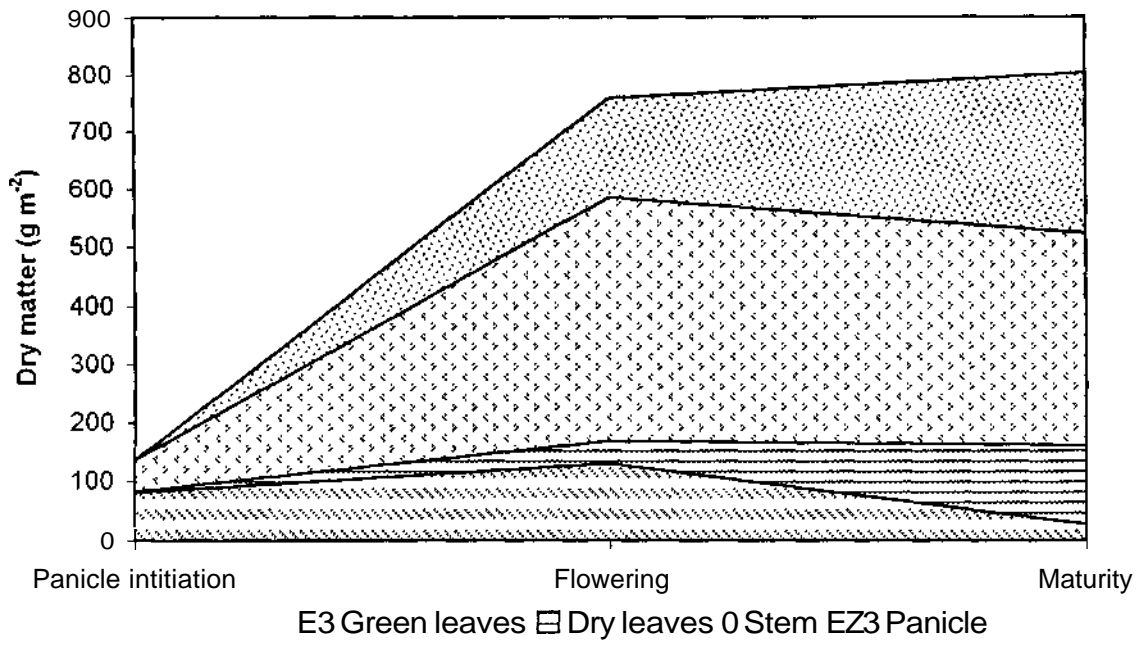
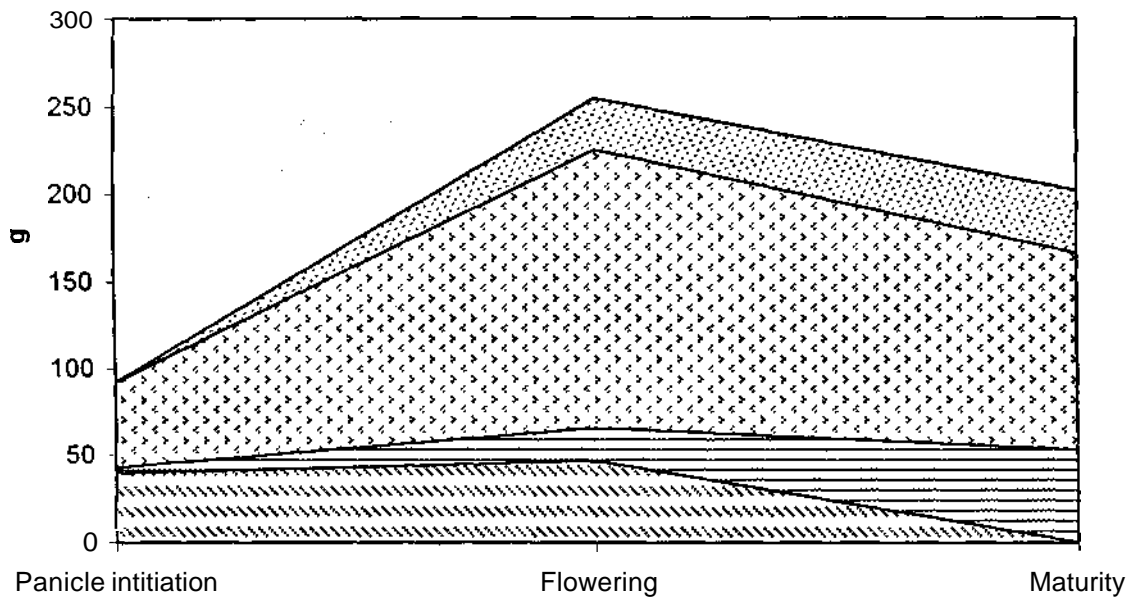


Fig.4.5b: Dry matter partitioning in CA-51 under rainfed conditions at various stages



E3 Green leaves □ Dry leaves 0 Stem E3 Panicle
Fig. 4.6(a) : Dry matter partitioning in CA-54 under irrigated conditions at various stages



E1 Green leaves □ Dry leaves 0 Stem E3 Panicle
Fig.4.6(b) : Dry matter partitioning in CA-54 under rainfed conditions at various stages

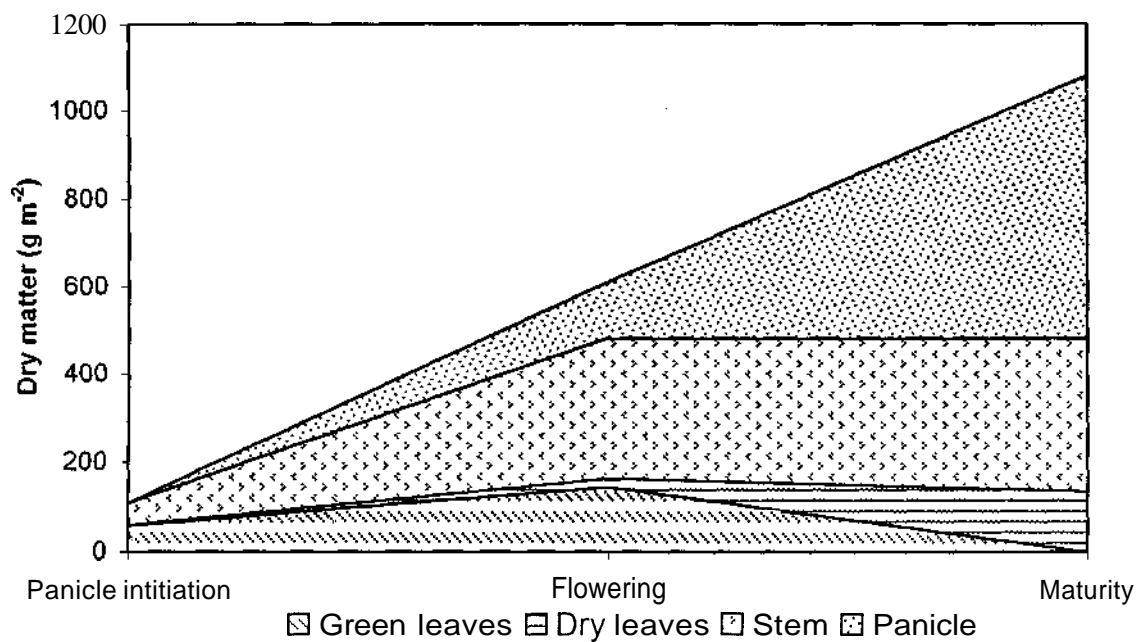


Fig.4.7(a) : Dry matter partitioning in CA-107 under irrigated conditions at various stages

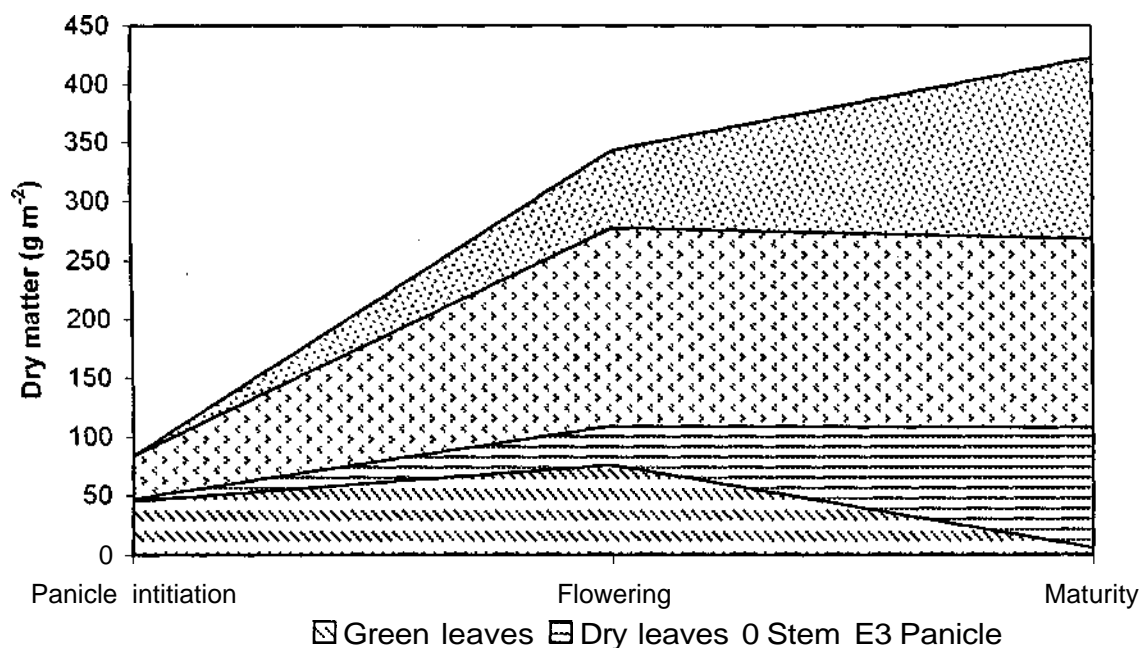


Fig. 4.7(b) : Dry matter partitioning in CA-107 under rainfed conditions at various stages

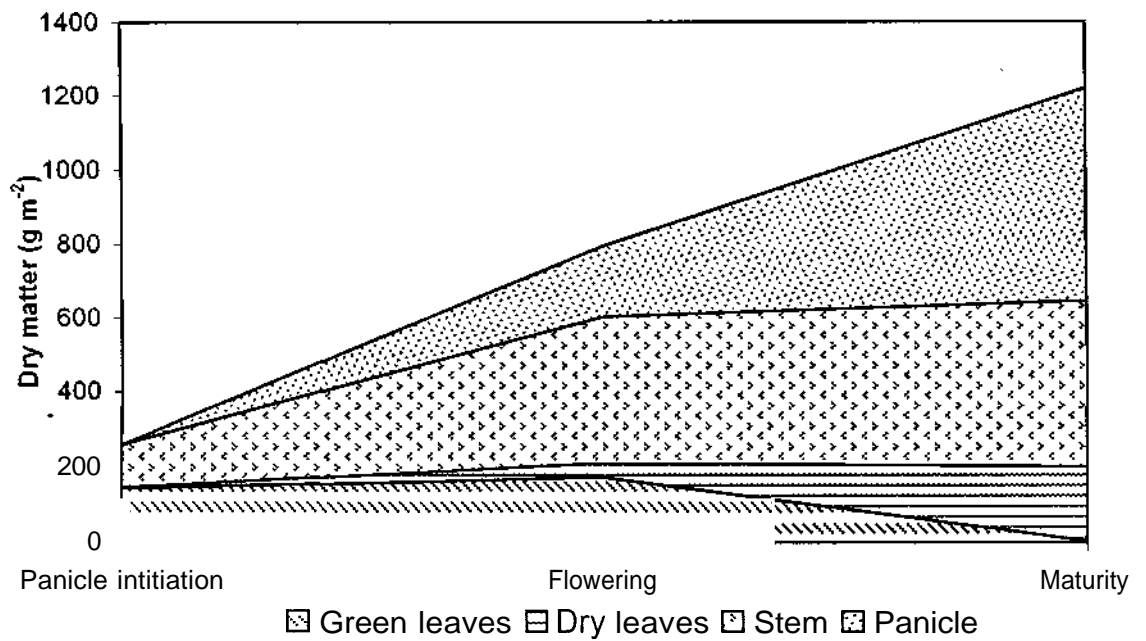


Fig. 4.8(a): Dry matter partitioning in IR-62266 under irrigated conditions at various stages

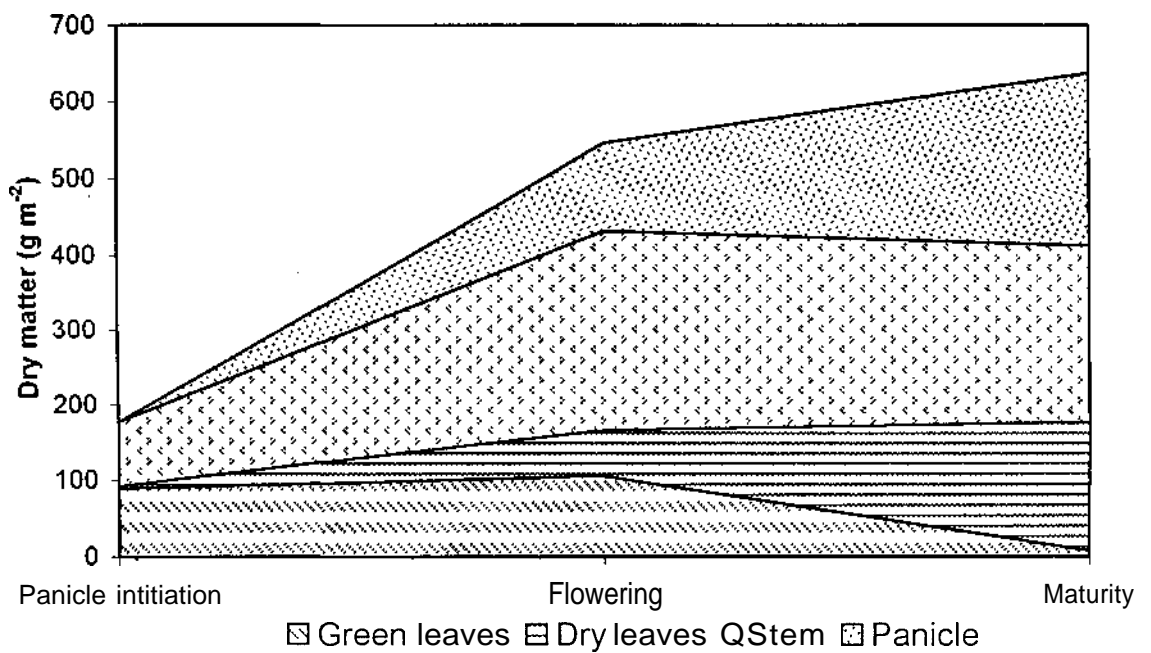


Fig.4.8(b) : Dry matter partitioning in IR-62266 under rainfed conditions at various stages

a

rainfed site. IR-62266 and CA-54 accumulate higher stem dry matter under irrigated and rainfed conditions respectively. The average reduction in stem dry matter was 55 per cent under rainfed site compare to irrigated site.

Panicle dry matter reduced significantly in rainfed site compare to irrigated site. Varietal variation and interaction were also observed statistically significant. The panicle dry matter production was highest in IR-62266 and CA-107 under irrigated and rainfed condition respectively. The reduction in panicle dry matter under rainfed site was highest in CA-107 (74%) and lowest in CA-54 (51%). The average panicle dry matter was reduced by 65 per cent under rainfed as compare to irrigated site. The dry matter stability under rainfed condition was observed higher in CA-54 and IR-62266 as compare to other lines.

4.6 Plant height at panicle initiation and flowering under irrigated and rainfed conditions

The results related to plant height at panicle initiation and flowering stage have been presented in Table 4.8 and Fig. 4.9(a, b). At panicle initiation stage plant height significantly reduced due to water shortage in rainfed site. Under irrigated conditions maximum plant height was recorded in CA-51 and lowest in CA-54. The plant height was reduced by 17 per cent and 26 per cent at panicle initiation and flowering stage respectively. The reduction in plant height (28%) was recorded maximum in IR-62266.

Under both the irrigated and rainfed conditions maximum plant height was recorded in CA-107 and lowest in CA32 respectively at flowering stage.

Table 4.8 : Plant height at panicle initiation and flowering stage under irrigated and rainfed conditions in different double haploid lines

Site	Plant height (cm)	
	PI	FL
Irrigated	67.80	101.86
Rainfed	55.67	75.26
SE(m) _±	1.14	1.15
CD at 5%	3.33	3.33
Variety		
IR-68586-F ₂ -CA-32	58.57	79.36
IR-68586-F ₂ -CA-51	73.59	87.76
IR-68586-F ₂ -CA-54	58.37	89.13
IR-68586-F ₂ -CA-107	58.92	100.00
IR-62266-42-6-2	59.25	87.80
SE(m) _±	1.81	1.82
CD at 5%	5.26	5.27
Site x variety		
Irrigated x IR-68586-F ₂ -CA-32	62.94	86.82
Irrigated x IR-68586-F ₂ -CA-51	81.83	103.17
Irrigated x IR-68586-F ₂ -CA-54	62.34	104.04
Irrigated x IR-68586-F ₂ -CA-107	62.64	114.15
Irrigated x IR-62266-42-6-2	69.28	101.10
Rainfed x IR-68586-F ₂ -CA-32	54.21	71.90
Rainfed x IR-68586-F ₂ -CA-51	65.35	72.34
Rainfed x IR-68586-F ₂ -CA-54	54.41	74.22
Rainfed x IR-68586-F ₂ -CA-107	55.20	85.86
Rainfed x IR-62266-42-6-2	49.21	
SE(m) _±	2.56	2.57
CD at 5%	7.44	7.45

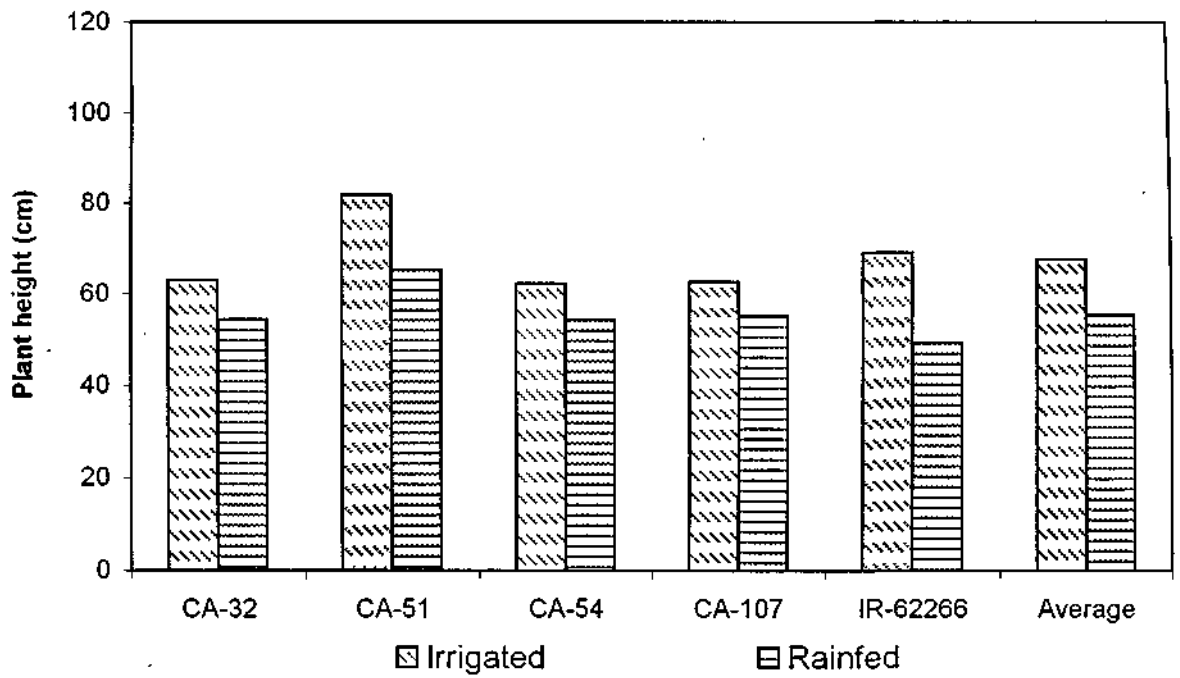


Fig. 4.9(a) : Plant height (cm) at panicle initiation under irrigated and rainfed conditions of different double haploid lines

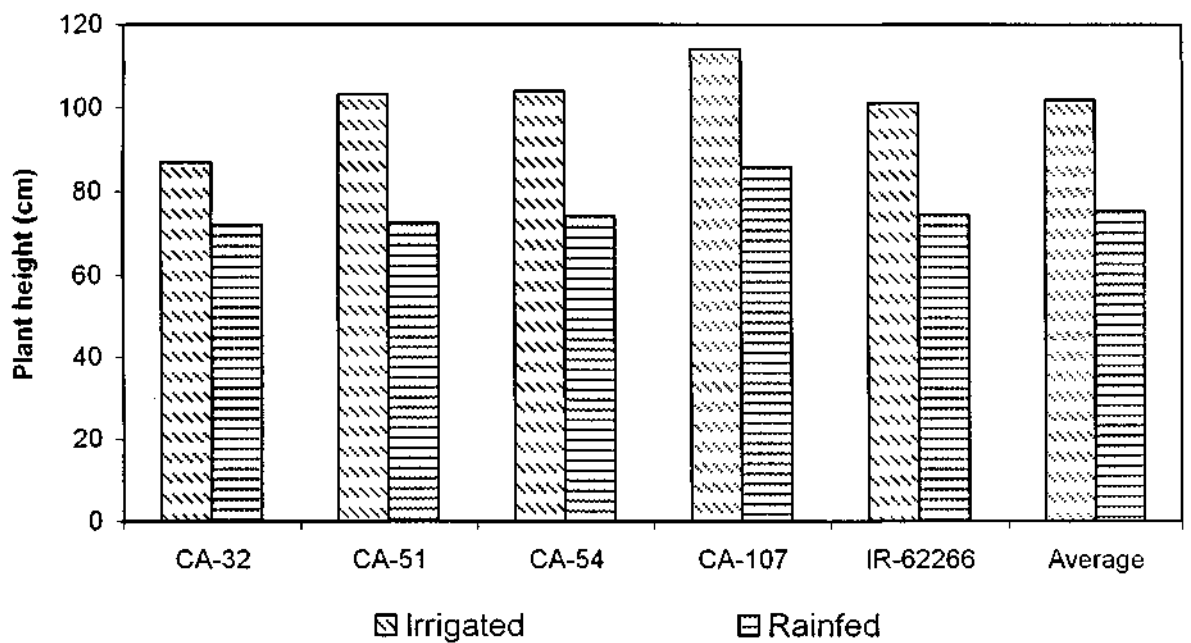


Fig. 4.9(b) : Plant height (cm) at flowering under irrigated and rainfed conditions of different double haploid lines

The highest reduction in plant height (29 %) was recorded in CA-51 at flowering stage and lowest in CA-32.

4.7 Phenology under irrigated and **rainfed** conditions

The data on phenology have been presented in Table 4.9 and Fig.4.10. The result revealed that average time taken to attain panicle initiation stage among irrigated and rainfed site was not statistically different. The varietal variation and interaction was also non significant however the maturity among two sites and interaction was observed significant. Under irrigated conditions CA-54 flower after 108 days while CA-32 take only 92 days to flower in both the sites. Flowering was delayed by 14 days in CA-51 under rainfed site compare to irrigated site. CA-54 and IR-62266 flowers 7 and 3 days earlier in rainfed site compare to irrigated site. The average duration for flowering was non significant among sites.

4.8 Relative water content under rainfed conditions

The relative water content under rainfed have been presented in Table 4.10 and Fig. 4.11(a,b). The result showed that the average relative water content was 90 per cent at 83 DAS while it was 71 per cent at 118 days after sowing. At 83 days after sowing the relative water content was recorded highest in CA-107 and IR-62266. The result showed that CA-107 and IR-62266 maintain high relative water content at all the stage of measurements.

Table 4.9 : Phenology under irrigated and rainfed conditions into various double haploid lines

Site	Phenology		
	Panicle initiation (days)	Flowering 90% (days)	Maturity (Days)
Irrigated	72.40	99.45	144.85
Rainfed	73.80	100.90	131.40
SE(m)+	0.00	1.92	1.25
CD at 5%	NS	NS	3.64
Variety			
IR-68586-F2-CA-32	70.00	92.00	135.12
IR-68586-F2-CA-51	73.50	103.12	140.87
IR-68586-F2-CA-54	75.00	105.00	140.75
IR-68586-F2-CA-107	73.00	101.75	136.62
IR-62266-42-6-2	74.00	99.00	137.26
SE(m)+	0.00	3.04	1.98
CD at 5%	NS	8.83	NS
Site x variety			
Irrigated x IR-68586-F2-CA-32	70.00	92.00	147.00
Irrigated x IR-68586-F2-CA-51	74.00	96.00	146.50
Irrigated x IR-68586-F2-CA-54	75.00	108.50	147.25
Irrigated x IR-68586-F2-CA-107	70.00	100.00	141.75
Irrigated x IR-62266-42-6-2	73.00	100.75	141.75
Rainfed x IR-68586-F2-CA-32	70.00	92.00	123.25
Rainfed x IR-68586-F2-CA-51	73.00	110.25	135.25
Rainfed x IR-68586-F2-CA-54	75.00	101.50	134.25
Rainfed x IR-68586-F2-CA-107	76.00	103.50	131.50
Rainfed x IR-62266-42-6-2	75.00	97.25	132.75
SE(m)+	0.00	4.30	2.80
CD at 5%	NS	NS	8.14

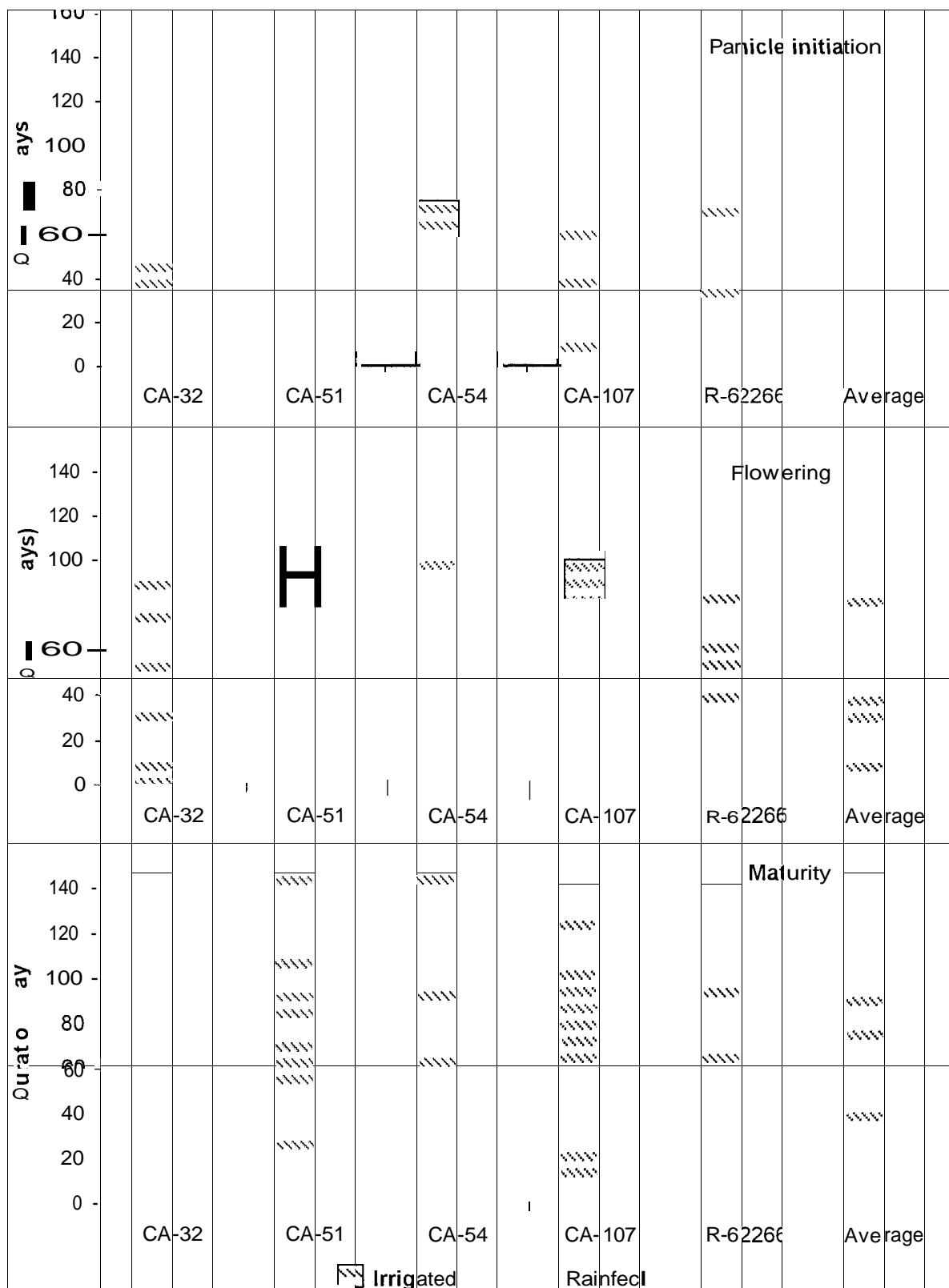


Fig.4.10 : Duration for panicle initiation, flowering (90%) and maturity under irrigated and rainfed conditions

Table 4.10 : Relative water content in various double haploid lines under rainfed conditions

Variety	Relative water content (%)					
	Days after sowing					
	83	97	104	111	118	Average
IR-68586-F2-CA-32	88.40	82.96	78.21	75.50	67.63	78.54
IR-68586-F2-CA-51	89.14	85.94	81.65	73.85	68.21	79.75
IR-68586-F2-CA-54	88.10	82.70	78.18	73.67	66.81	77.89
IR-68586-F ₂ -CA-107	93.38	86.08	84.29	81.97	79.60	85.06
IR-62266-42-6-2	93.18	88.24	83.25	78.42	76.48	83.91
Mean	90.44	85.18	81.12	76.68	71.74	
SE(m) _±	1.04	1.07	1.25	1.23	1.18	
CD at 5%	3.41	3.49	4.08	4.00	3.84	

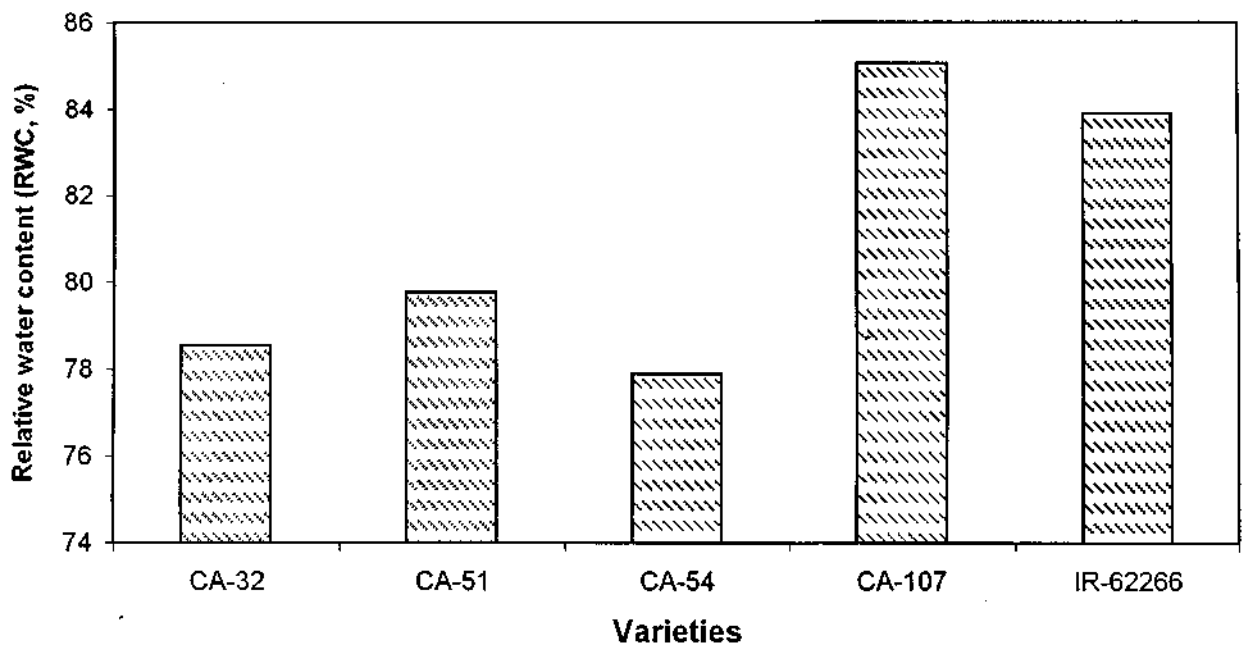


Fig. 4.11(a) : Average RWC in different double haploid lines under rainfed conditions

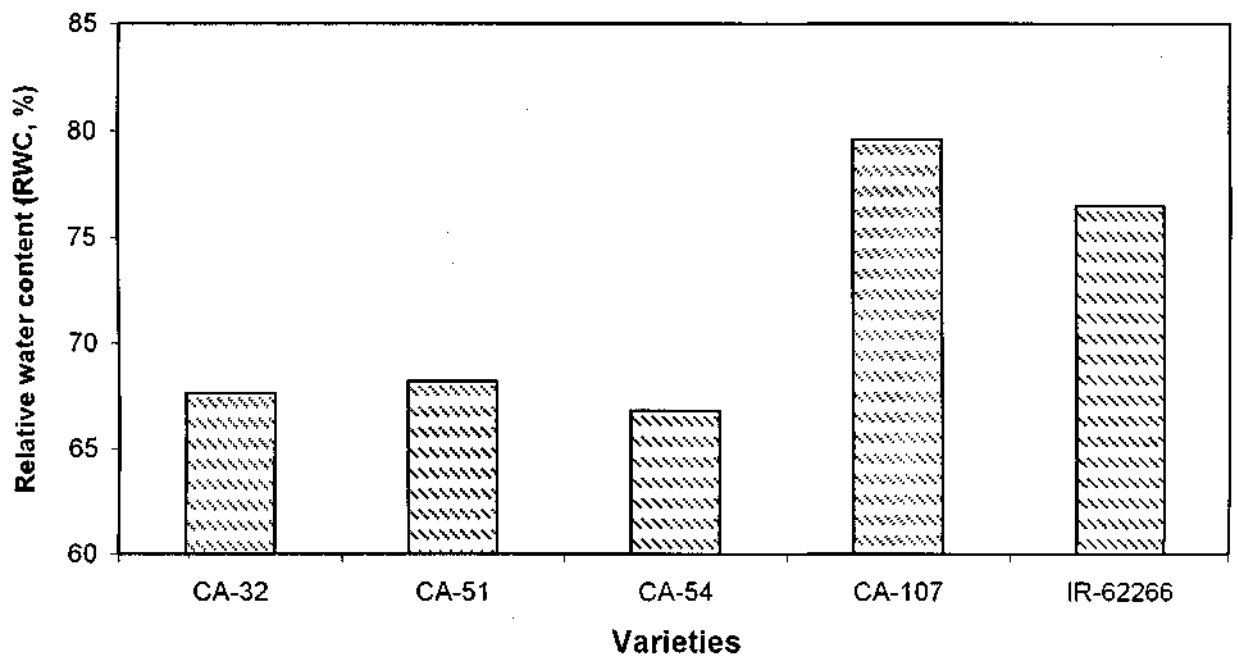


Fig. 4.11(b) : RWC of different lines after 118 DAS under rainfed conditions

4.9 Leaf water potential (-bar) under rainfed condition.

The leaf water potential under rainfed has been presented in Table 4.11 and Fig. 4.12(a,b). The result on leaf water potential showed that water potential continuously decreases from 83 days after sowing to 118 days after sowing. Like relative water content water potential was also recorded higher in CA-107 and IR62266 compare to other lines at all the stages of measurements. The average leaf water potential was recorded lowest -21.86 bars in CA-32 while it was highest (-16.93) in CA-107.

4.10 Root dry weight under irrigated and rainfed condition at panicle initiation, flowering and maturity stage

The results on root dry weight have been presented in Table 4.12 and Fig. 4.13. Average root dry weight was recorded significantly lower in rainfed site at panicle initiation stage compare to irrigated site. The varietal variation and interaction was also significant. At panicle initiation stage under irrigated condition root dry matter was observed significantly higher in CA-51 (43.19g m⁻²) and lowest in CA-32 (15.87 g m⁻²). Under rainfed condition root dry matter of CA-54 and CA-107 increases (26.37 and 27.81g m⁻²) compare to irrigated site. Rest of three lines decreases their root dry matter under rainfed condition. The reduction of root dry matter under rainfed site at flowering stage was higher in CA-32 (37%) and CA-51 (36%) compare to other three lines. The average reduction in root dry matter at flowering stage was 22 per cent under rainfed site as compare to irrigated site. At maturity stage root dry matter was recorded highest in CA-32 under

Table 4.11 : Leaf water potential (-bar) under rainfed conditions

Variety	Leaf water potential (-bar)						
	Days after sowing						
	83	90	97	104	111	118	Average
IR-68586-F ₂ -CA-32	9.523	11.433	19.517	24.693	30.483	35.550	21.866
IR-68586-F ₂ -CA-51	8.897	11.183	19.550	34.357	30.230	36.343	21.760
IR-68586-F ₂ -CA-54	8.830	10.797	18.650	23.507	29.573	34.547	20.984
IR-68586-F ₂ -CA-107	7.480	9.153	14.707	19.360	23.517	27.370	16.931
IR-62266-42-6-2	7.647	9.470	14.847	18.820	23.830	28.233	17.307
Mean	8.475	10.407	17.454	22.347	27.526	32.408	
SE(m) _±	0.361	0.333	0.332	0.415	0.425	0.408	
CD at 5%	1.18	1.08	1.08	1.36	1.38	1.33	

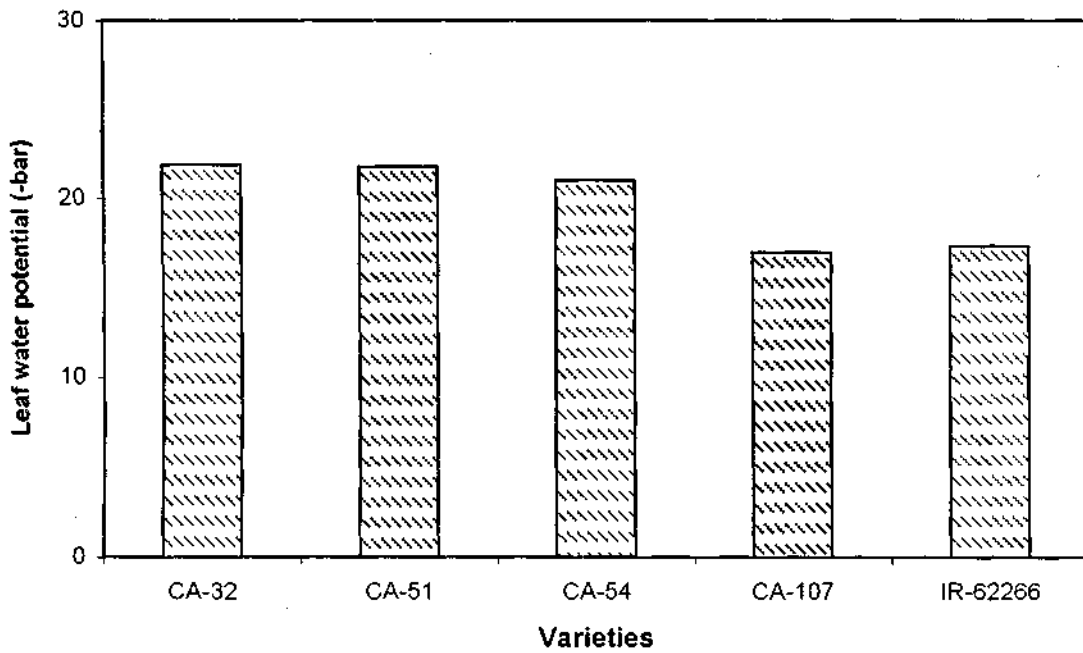


Fig. 4.12(a) : Average leaf water potential in different double haploid lines under rainfed conditions

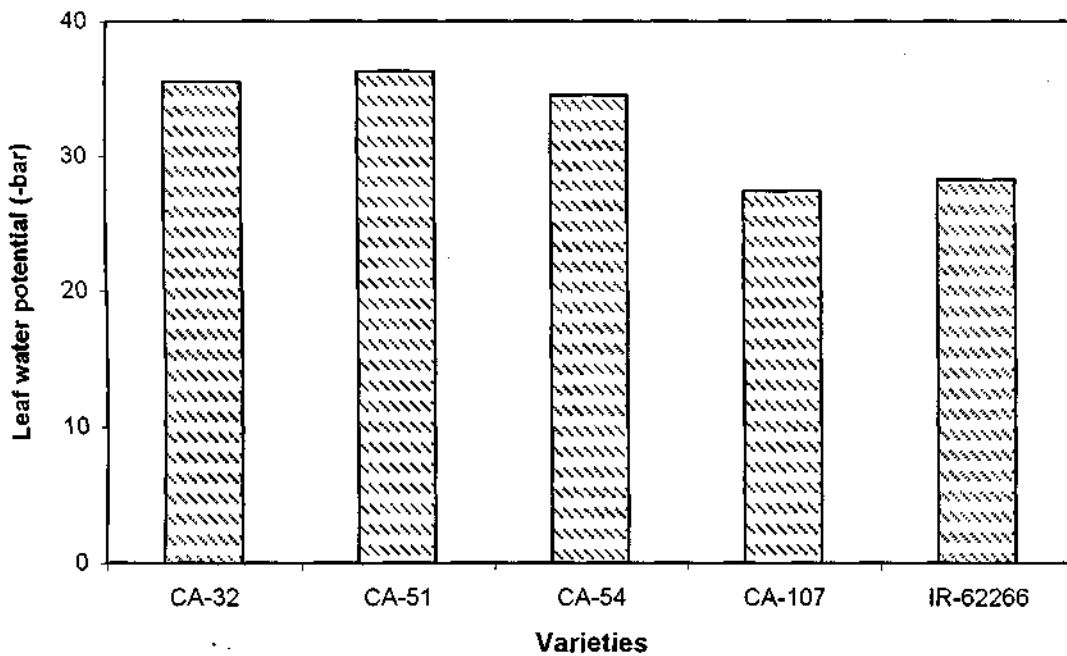


Fig. 4.12(b) : Leaf water potential after 118 DAS in different double haploid lines under rainfed conditions

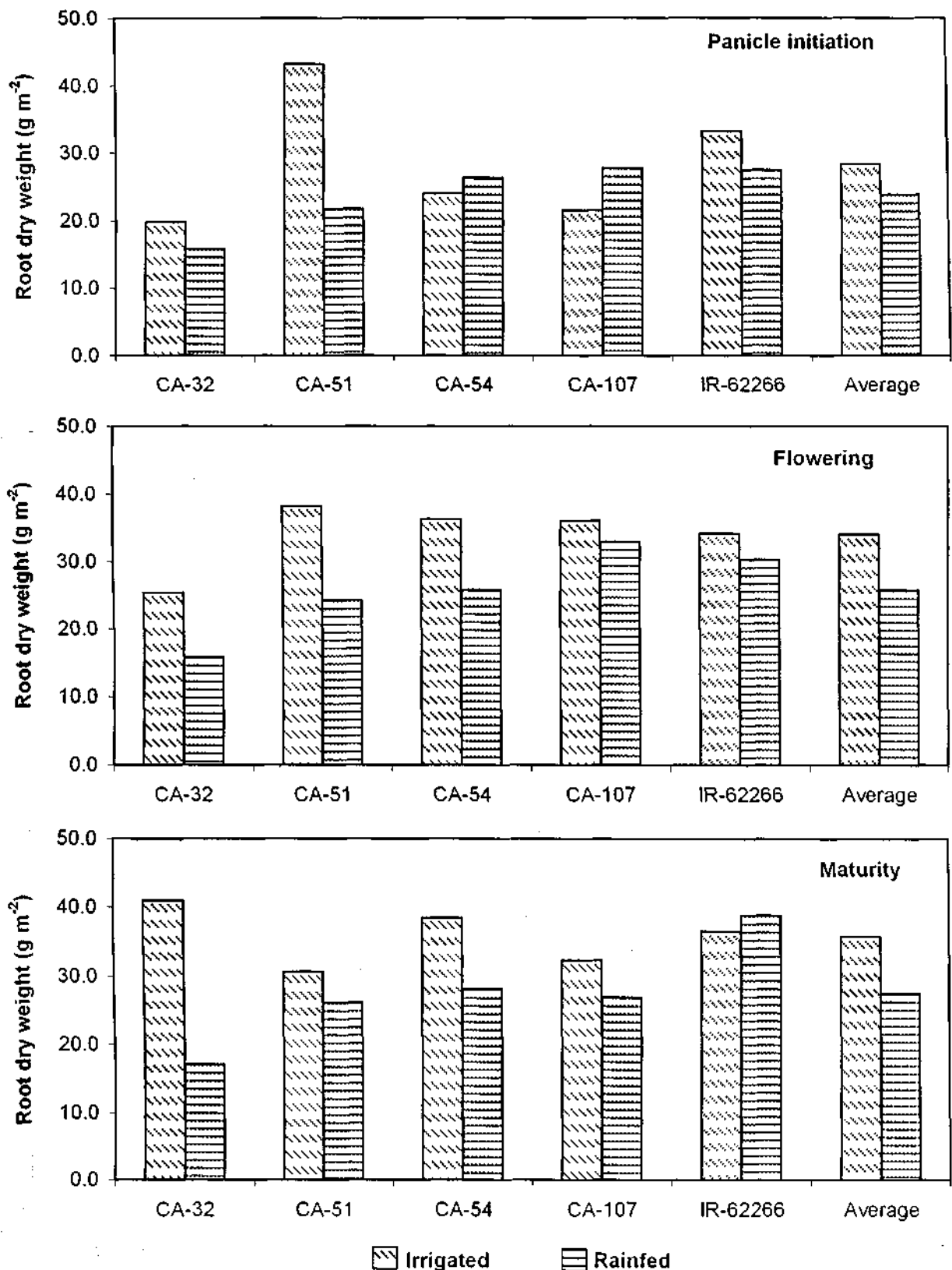


Fig. 4.13 : Root dry weight (g m^{-2}) under irrigated and rainfed condition at panicle initiation, flowering and maturity stage among different double haploid lines

irrigated condition. The reduction in root dry matter was also higher in CA-32 under rainfed site. No decrease in root dry matter was observed in IR-62266 while other lines decrease the root dry matter under rainfed site.

4.11 Root/shoot ratio (%) under irrigated and rainfed condition at panicle initiation, flowering and maturity stages

The results on root/shoot ratio have been presented in Table 4.13 and Fig. 4.14. The result reveals that root/shoot ratio increases under rainfed site compare to irrigated site at all the three stages. Under irrigated condition root/shoot ratio recorded highest in CA-107 and CA-51 at panicle initiation and flowering stage respectively. Under rainfed conditions CA-107 showed highest root/shoot ratio at panicle initiation and flowering stages compare to other lines. IR-62266 recorded lowest root/shoot ratio under rainfed site at all the stages.

4.12 Leaf area index at various stages under irrigated and rainfed conditions

The results related to leaf area index have been presented in Table 4.14 and Fig.4.15. The results showed that leaf area index under both the sites were highest at flowering stage and decrease thereafter as the plants grow older. At panicle initiation and flowering stage IR-62266 produces significantly higher LAI under irrigated condition compare to other lines. The reduction in leaf area index due to water shortage under rainfed condition was highest (55%) and lowest (8%) in CA-51 and CA-54 respectively at panicle initiation stage.

Table 4.13 : Root /shoot ratio among different double haploid lines under irrigated and rainfed conditions at panicle initiation, flowering and maturity stage

Site	Root shoot ratio (%)		
	Panicle initiation	Flowering	Maturity
Irrigated	16.29	5.70	4.41
Rainfed	21.64	7.31	7.14
SE(m) +	0.83	0.42	0.27
CD at 5%	2.42	1.23	0.79
Variety			
IR-68586-F2-CA-32	19.96	6.47	7.53
IR-68586-F2-CA-51	17.41	7.27	6.11
IR-68586-F2-CA-54	19.72	6.02	5.78
IR-68586-F ₂ -CA-107	28.05	7.74	4.90
IR-62266-42-6-2	14.68	5.02	4.55
SE(m) ±	1.32	0.67	0.43
CD at 5%	3.82	NS	1.24
Site x variety			
Irrigated x IR-68586-F ₂ -CA-32	12.60	6.38	6.62
Irrigated x IR-68586-F ₂ -CA-51	15.51	6.92	4.45
Irrigated x IR-68586-F ₂ -CA-54	18.17	4.90	4.85
Irrigated x IR-68586-F ₂ -CA-107	22.05	5.96	3.07
IrrigatedxIR-62266-42-6-2	13.10	4.35	3.05
Rainfed x IR-68586-F ₂ -CA-32	17.32	6.56	8.44
Rainfed x IR-68586-F ₂ -CA-51	19.30	7.63	7.76
Rainfed x IR-68586-F ₂ -CA-54	21.28	7.14	6.71
Rainfed x IR-68586-F ₂ -CA-107	34.05	9.53	6.73
Rainfed x IR-62266-42-6-2	16.26	5.68	6.04
SE(m) +	1.86	0.94	0.61
CD at 5%	NS	NS	NS

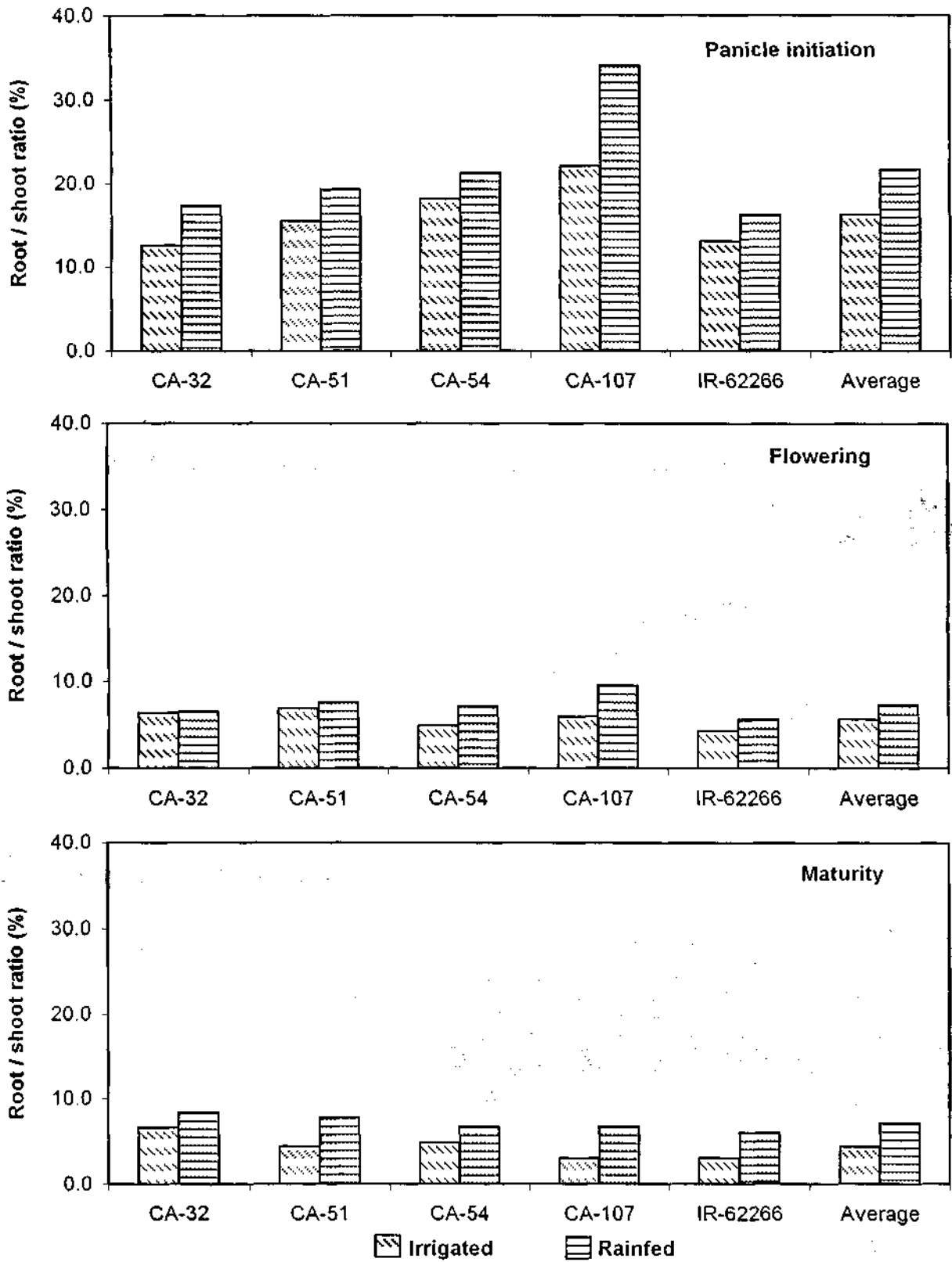


Fig. 4.14 : Root / shoot ratio (%) under irrigated and rainfed condition at panicle initiation, flowering and maturity stage among different double haploid lines

Table 4.14 : Leaf area index at panicle initiation, flowering and maturity under irrigated and rainfed conditions into various double haploid lines

Site	Leaf area index		
	Panicle initiation	Flowering	Maturity
Irrigated	1.95	2.13	0.17
-Rainfed	1.25	1.15	0.00
SE(m) +	0.10	0.07	0.02
CD at 5%	0.28	0.22	0.07
Variety			
IR-68586-F ₂ -CA-32	1.13	1.18	0.04
IR-68586-F ₂ -CA-51	1.97	1.37	0.16
IR-68586-F ₂ -CA-54	1.42	1.62	0.19
IR-68586-F ₂ -CA-107	0.94	1.64	0.00
IR-62266-42-6-2	2.55	2.40	0.03
SE(m) +	0.15	0.12	0.04
CD at 5%	0.45	0.36	0.11
Site x variety			
Irrigated x IR-68586-F ₂ -CA-32	1.42	1.63	0.08
Irrigated x IR-68586-F ₂ -CA-51	2.72	1.87	0.32
Irrigated x IR-68586-F ₂ -CA-54	1.49	2.06	0.38
Irrigated x IR-68586-F ₂ -CA-107	1.09	2.15	0.00
Irrigated x IR-62266-42-6-2	3.05	2.96	0.06
Rainfed x IR-68586-F ₂ -CA-32	0.83	0.74	0.00
Rainfed x IR-68586-F ₂ -CA-51	1.22	0.87	0.00
Rainfed x IR-68586-F ₂ -CA-54	1.36	1.19	0.00
Rainfed x IR-68586-F ₂ -CA-107	0.79	1.13	0.00
Rainfed x IR-62266-42-6-2	2.06	1.84	0.00
SE(m) +	0.22	0.17	0.05
CD at 5%	0.63	NS.	0.15

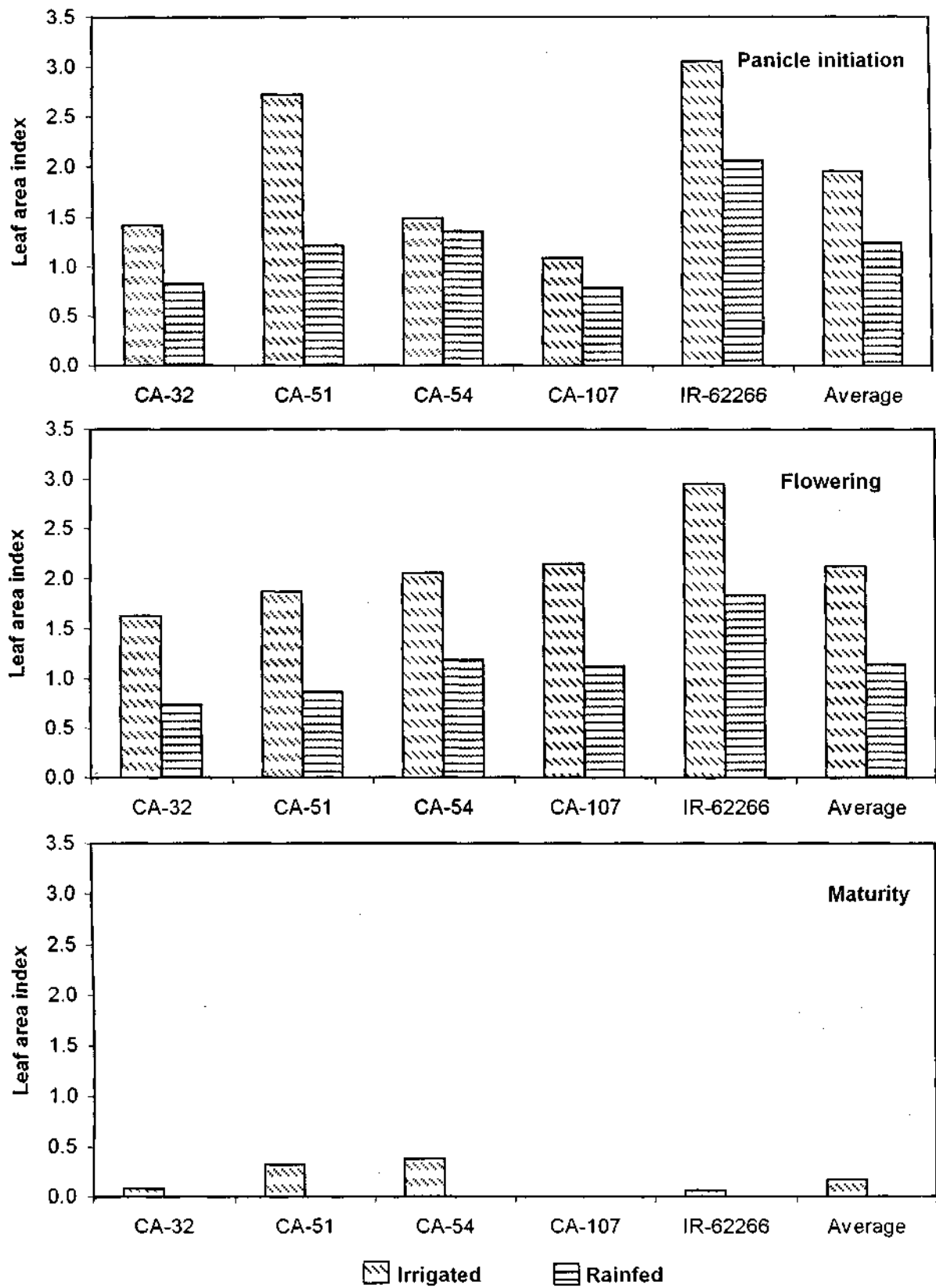


Fig. 4.15 : Leaf area index under irrigated and rainfed conditions at panicle initiation, flowering and maturity stage among different double haploid lines

At flowering stage leaf area index was recorded highest (2.96 and 1.84) in IR-62266 under irrigated and rainfed site respectively. The reduction in LAI at flowering stage under rainfed condition was observed lowest (37%) in IR-62266. The average reduction in leaf area index under rainfed site was 46 per cent. At maturity CA-51 and CA-54 produces higher leaf area index compare to other three lines. Under rainfed site at maturity LAI was recorded zero in all the lines.

4.13 Flag leaf area under irrigated and rainfed conditions

The results related to flag leaf area have been presented in Table 4.15 and Fig.4.16. The results showed that flag leaf area was significantly reduced under rainfed site compare to irrigated site. Varietal variation and interaction was also recorded significant. Average flag leaf reduced by 33 per cent under rainfed site compare to irrigate site. The flag leaf area was recorded significantly higher (55.93 cm²) and lower (20.97cm²) in CA-107 and CA-32 respectively. The reduction in leaf area under rainfed condition ranges from 21 to 39 per cent at flowering stage among different lines. The highest (39%) reduction in leaf area recorded in CA-51.

4.14 Tiller number under irrigated and rainfed conditions

The results related to tillers number have been presented in Table 4.16 and Fig. 4.17. The results showed that tiller number reduced significantly in rainfed site compare to irrigated site. Varietal variation and interaction were observed statistically significant at all the stages. At panicle initiation stage

Table 4.15 : Flag leaf area at flowering stage under irrigated and rainfed conditions into various double haploid lines

Site	Flag leaf area (cm ²)
Irrigated	39.778
Rainfed	26.391
SE(m) <u>±</u>	1.080
CD at 5%	3.130
Variety	
IR-68586-F ₂ -CA-32	18.711
IR-68586-F ₂ -CA-51	38.035
IR-68586-F ₂ -CA-54	31.746
IR-68586-F ₂ -CA-107	46.005
IR-62266-42-6-2	30.746
SE(m) <u>±</u>	1.708
CD at 5%	4.950
Site x variety	
Irrigated x IR-68586-F ₂ -CA-32	20.977
Irrigated x IR-68586-F ₂ -CA-51	47.480
Irrigated x IR-68586-F ₂ -CA-54	36.273
Irrigated x IR-68586-F ₂ -CA-107	55.932
Irrigated x IR-62266-42-6-2	38.227
Rainfed x IR-68586-F ₂ -CA-32	16.445
Rainfed x IR-68586-F ₂ -CA-51	28.590
Rainfed x IR-68586-F ₂ -CA-54	27.575
Rainfed x IR-68586-F ₂ -CA-107	36.080
Rainfed x IR-62266-42-6-2	23.265
SE(m) <u>±</u>	2.416
CD at 5%	7.000

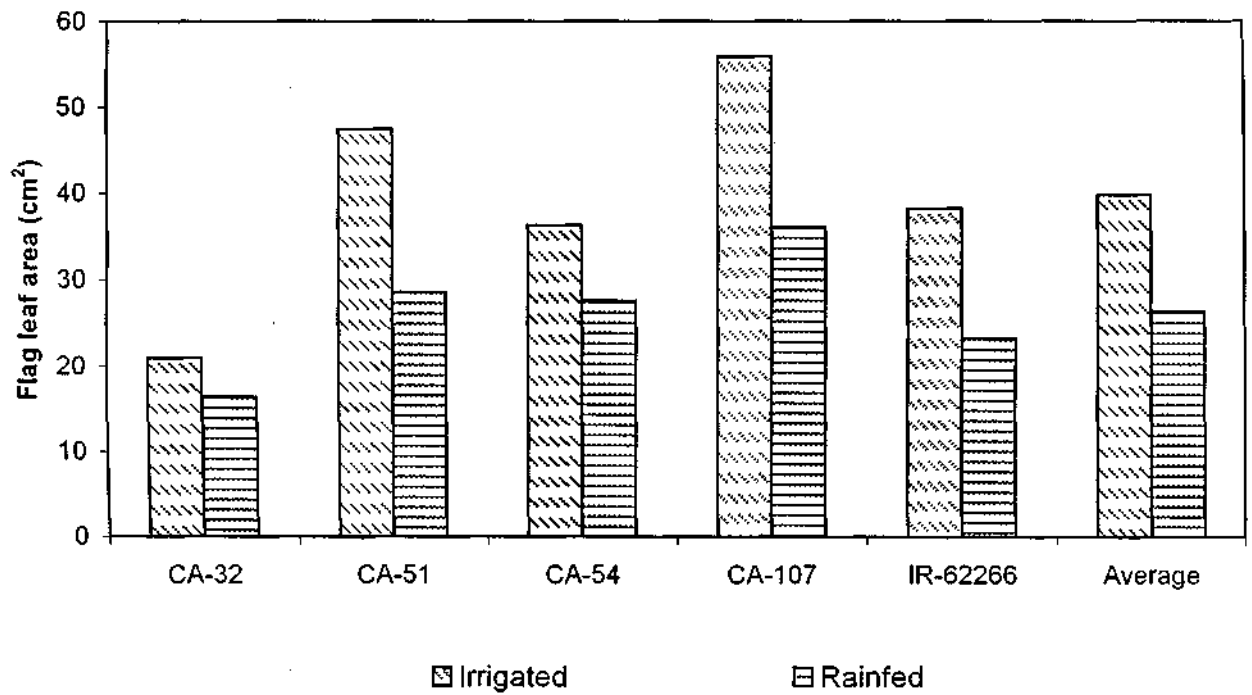


Fig. 4.16 : Flag leaf area under irrigated and rainfed conditions at flowering stage of different double haploid lines

Table 4.16 : Tillers (m⁻²) under irrigated and rainfed conditions into various double haploid lines

Site	Tillers (meter ⁻²)		
	Panicle initiation	Flowering	Maturity
Irrigated	372.91	316.25	302.75
Rainfed	328.74	256.66	240.00
SE(m)+	17.88	14.19	10.39
CD at 5%	51.84	43.22	30.12
Variety			
CA-32	376.04	304.16	306.25
CA-51	284.37	253.12	231.87
CA-54	334.37	290.62	265.62
CA-107	231.23	218.75	213.75
IR-62266	528.12	365.62	339.37
SE(m) _±	28.27	23.57	16.43
CD at 5%	81.97	68.35	47.63
Site x variety			
Irrigated x CA-32	441.66	393.75	388.75
Irrigated x CA-51	318.75	258.33	256.25
Irrigated x CA-54	337.50	322.91	287.50
Irrigated x CA-107	254.16	235.41	226.25
Irrigated x IR-62266	512.50	370.83	355.00
Rainfed x CA-32	310.41	214.58	223.75
Rainfed x CA-51	520.00	247.91	207.50
Rainfed x CA-54	331.25	258.33	243.75
Rainfed x CA-107	208.30	202.08	201.25
Rainfed x IR-62266	543.74	360.41	323.75
SE(m)+	39.99	33.34	23.23
CD at 5%	NS	96.66	67.36

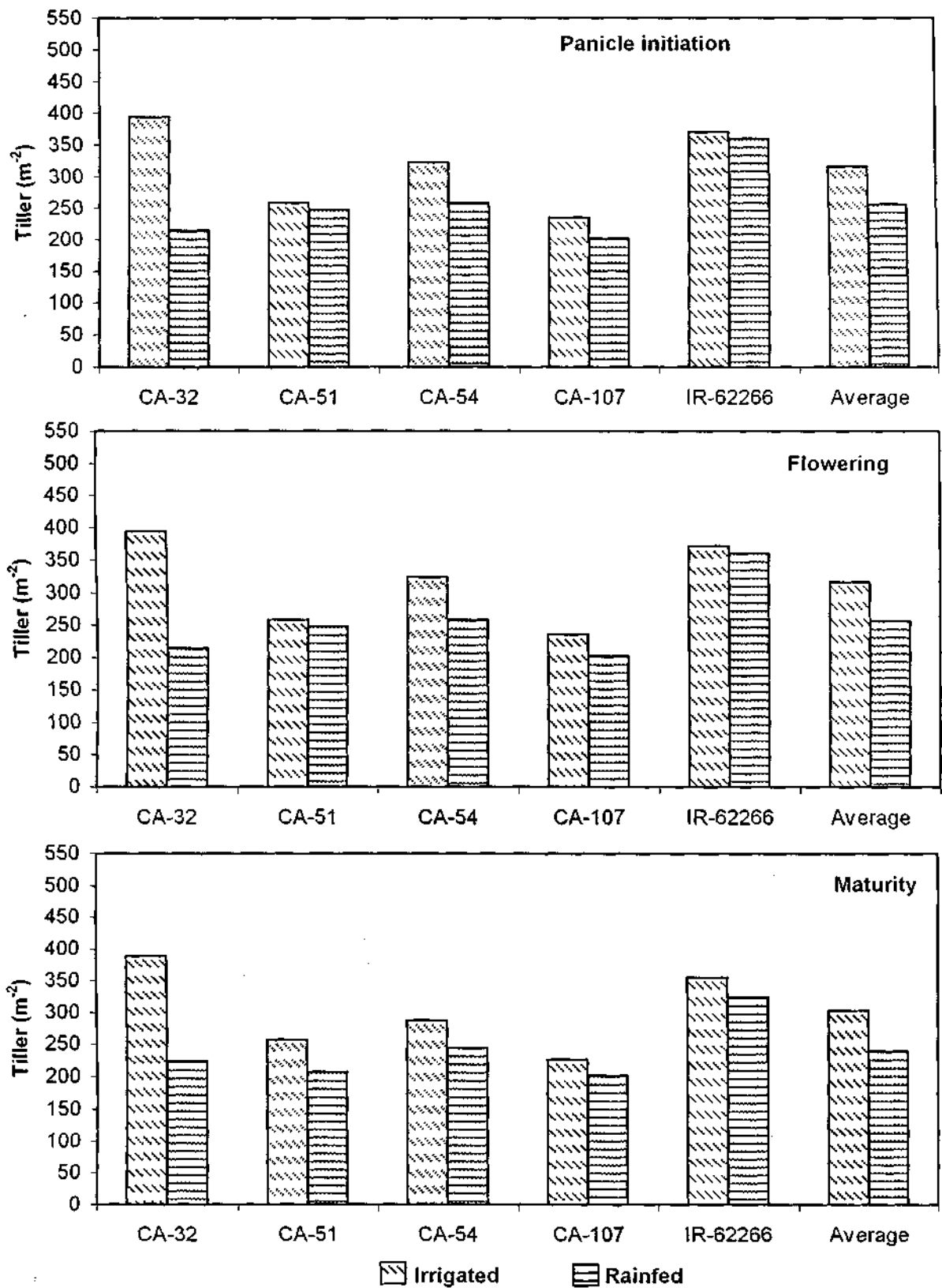


Fig. 4.17 : Tiller (m⁻²) under irrigated and rainfed conditions at panicle initiation, flowering and maturity stage among different double haploid lines

tiller number was reduced by 11 per cent under rainfed site compare to irrigated site. At panicle initiation stage tiller number was observed maximum in IR-62266 under both sites. Reduction in tiller number under rainfed site was recorded highest in CA-32 at all three stages compared to other lines. It was observed that CA-51 produces more tillers under rainfed site as compare to irrigated site at panicle initiation stage. Reduction in tiller number was observed lowest in IR-62266 (2 and 8%) at flowering and maturity stages respectively under rainfed site.

4.15 Photosynthetic rate under irrigated and rainfed conditions

The results related to photosynthetic rate at four stages have been presented in Table 4.17 and Fig. 4.18. At 90 DAS the photosynthetic rate was recorded almost equal among CA-32, CA-54 and CA-107 under irrigated conditions. IR-62266 photosynthesizes significantly at higher rate compare to other lines at 90 DAS under irrigated condition. The photosynthetic rate was significantly reduced in rainfed site compare to irrigated site at all the stages of measurement. The reduction in photosynthesis under rainfed site was recorded lowest in CA-107 at 90 days after sowing. From 97 DAS to 111DAS the reduction in photosynthetic rate was recorded highest in CA-32. It was found that CA-107 and IR-62266 photosynthesize at a faster rate under rainfed condition particularly at 104 and 111 days after sowing. At 111 days after sowing, average photosynthetic rate decline by 62 per cent under rainfed site compare to irrigated site.

Table 4.17 : Photosynthetic rate under irrigated and rainfed conditions

Site	Photosynthesis ($\mu \text{ mol m}^{-2} \text{ s}^{-1}$)			
	Days after sowing			
	90	97	104	111
Irrigated	23.272	18.346	20.800	15.001
Rainfed	18.697	11.867	10.727	5.675
SE(m)+	0.2068	0.1424	0.1392	0.0494
CD at 5%	0.593	0.408	0.399	0.141
Variety				
IR-68586-F2-CA-32	20.300	12.041	13.324	7.561
IR-68586-F2-CA-51	20.950	15.667	15.930	9.130
IR-68586-F2-CA-54	20.152	15.027	14.023	10.600
IR-68586-F2-CA-107	20.740	15.541	18.650	12.866
IR-62266-42-6-2	22.780	17.258	16.890	11.533
SE(m) <u>±</u>	0.3270	0.2252	0.2201	0.0781
CD at 5%	0.937	0.645	0.631	0.223
Site x variety				
Irrigated x IR-68586-F2-CA-32	22.200	17.038	20.780	13.126
Irrigated x IR-68586-F2-CA-51	23.280	18.820	20.760	13.302
Irrigated x IR-68586-F2-CA-54	22.200	17.560	18.580	15.326
Irrigated x IR-68586-F2-CA-107	22.180	18.264	22.680	17.742
Irrigated x IR-62266-42-6-2	26.500	20.050	21.200	15.510
Rainfed x IR-68586-F2-CA-32	18.400	7.044	5.868	1.996
Rainfed x IR-68586-F2-CA-51	18.620	12.514	11.100	4.958
Rainfed x IR-68586-F2-CA-54	18.104	12.494	9.466	5.874
Rainfed x IR-68586-F2-CA-107	19.300	12.818	14.620	7.990
Rainfed x IR-62266-42-6-2	19.060	14.466	12.580	7.556
SE(m)+	0.4624	0.3185	0.3113	0.1104
CD at 5%	1.326	0.913	0.892	0.316

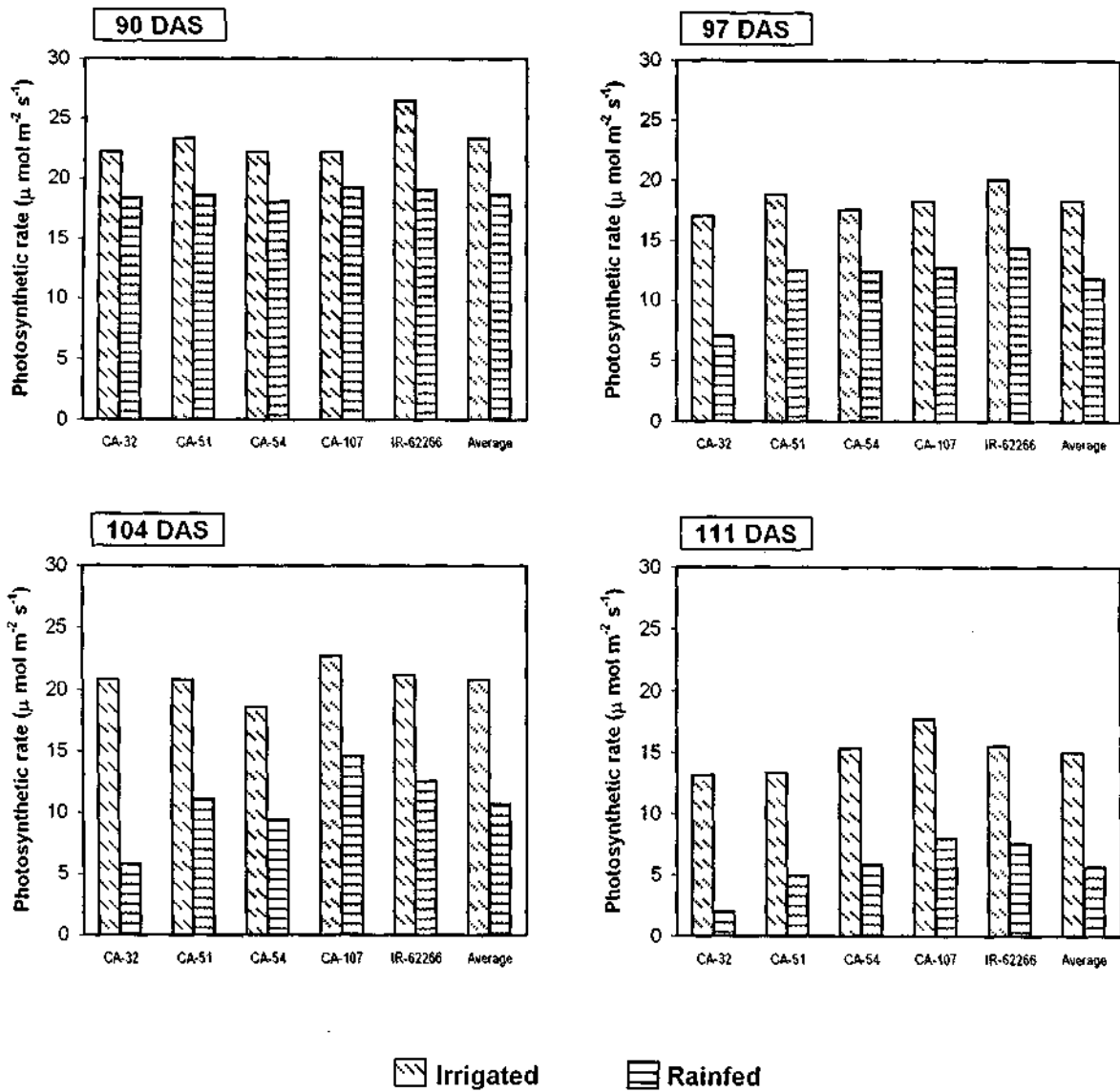


Fig.4.18 : Photosynthetic rate under irrigated and rainfed conditions at 90, 97, 104 and 111 DAS in different double haploid lines

4.16 Transpiration rate under irrigated and rainfed conditions

The results related to transpiration have been presented in Table 4.18 and Fig. 4.19. The transpiration rate was measured from 90 DAS to 111 DAS at four stages. Average transpiration rate was significantly reduced in rainfed site compare to irrigated site at all the stages of measurements. At 90 DAS the average reduction in transpiration rates was lowest (17.38%) while it was highest (69.13%) at 111 DAS. The reduction in transpiration under rainfed site was recorded lowest (8.51%) in CA-107 at 90 DAS. From 97 days after sowing to 111 days after sowing the reduction in transpiration rate was recorded highest in CA-32. CA-107 and IR-62266 transpire at a faster rate under rainfed condition particularly at 111 days after sowing compare to other lines.

4.17 Canopy cooling under irrigated and rainfed conditions

The results related to leaf temperatures have been presented in Table 4.19 and Fig.4.20. The result showed that the canopy-air temperature difference was not observed significant between irrigated and rainfed site at 90 DAS, however at 97,104 and 111 DAS the canopy temperature was recorded higher than air under rainfed site compare to irrigated site. Canopy temperature was lower than air temperature under irrigated condition at 90 and 97 DAS. The increase in canopy temperature under rainfed conditions was recorded lowest in CA-54 at 104 and 111 days after sowing. The increase in canopy temperature was recorded higher in CA-51 at 104 DAS,

Table 4.18 : Transpiration rate under irrigated and rainfed conditions

Site	Transpiration rate ($\text{mmol m}^{-2} \text{s}^{-1}$)			
	Days after sowing			
	90	97	104	111
Irrigated	7.269	7.580	6.801	5.084
Rainfed	6.005	4.591	3.932	1.569
SE(m) \pm	0.095	0.068	0.054	0.029
CD at 5%	0.271	0.193	0.155	0.084
Variety				
IR-68586-F2-CA-32	4.596	5.217	3.906	2.211
IR-68586-F2-CA-51	7.464	6.570	5.534	3.089
IR-68586-F2-CA-54	6.913	5.869	5.965	3.369
IR-68586-F2-CA-107	6.514	6.201	5.726	3.385
IR-62266-42-6-2	7.671	6.571	5.702	4.578
SE(m)+	0.1495	0.1067	0.0856	0.0463
CD at 5%	0.428	0.306	0.245	0.132
Site x variety				
Irrigated x IR-68586-F2-CA-32	5.430	7.414	5.666	4.204
Irrigated x IR-68586-F2-CA-51	8.222	7.590	7.358	4.986
Irrigated x IR-68586-F2-CA-54	7.738	6.436	7.044	4.880
Irrigated x IR-68586-F2-CA-107	6.832	7.780	6.796	4.704
Irrigated x IR-62266-42-6-2	8.124	8.680	7.140	6.646
Rainfed x IR-68586-F2-CA-32	3.762	3.020	2.146	0.218
Rainfed x IR-68586-F2-CA-51	6.706	5.550	3.710	1.192
Rainfed x IR-68586-F2-CA-54	6.088	5.302	4.886	1.858
Rainfed x IR-68586-F2-CA-107	6.250	4.622	4.656	2.066
Rainfed x IR-62266-42-6-2	7.218	4.462	4.264	2.510
SE(m)+	0.2114	0.1509	0.121	0.0655
CD at 5%	0.606	0.432	0.347	0.187

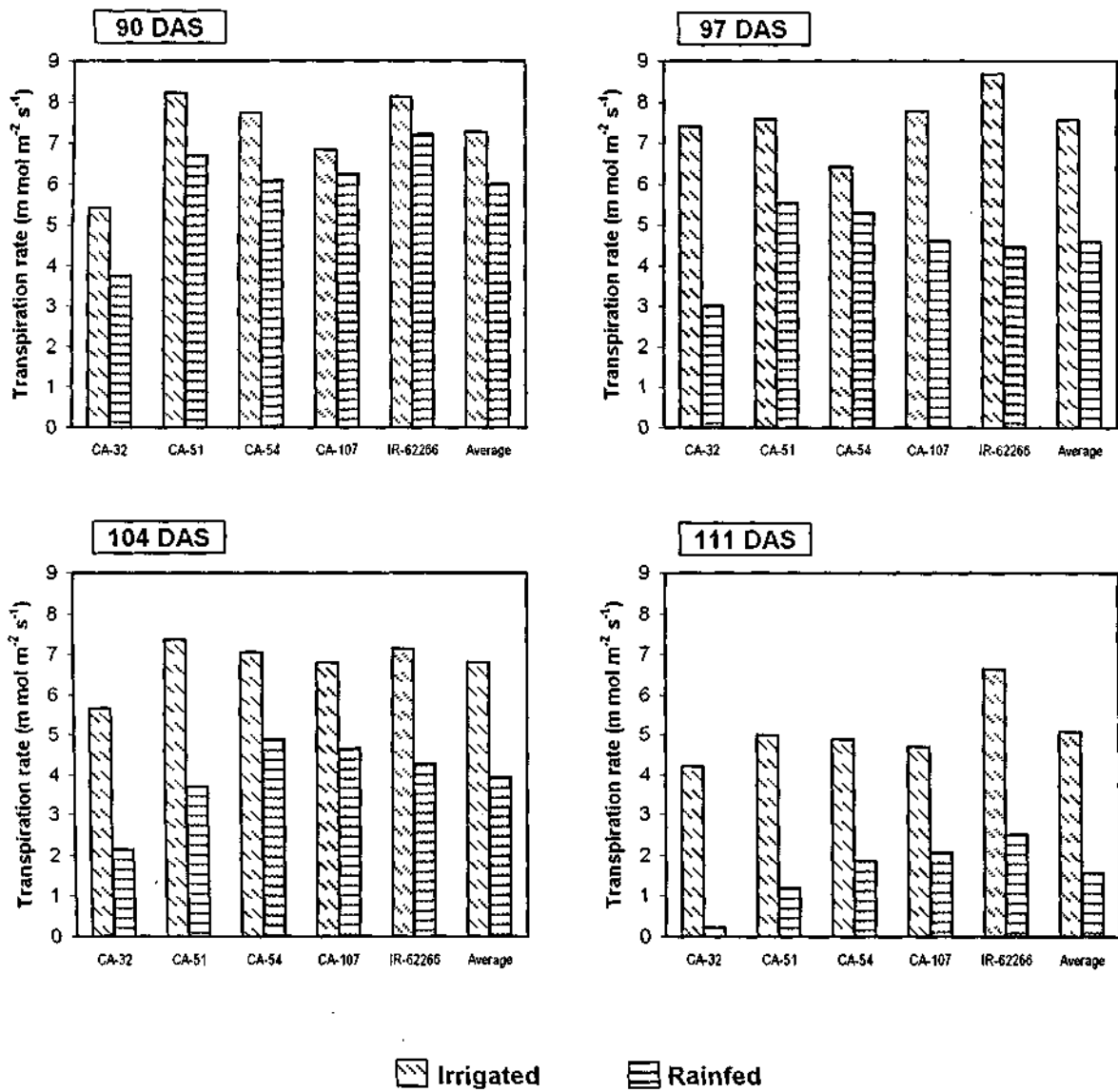


Fig. 4.19 : Transpiration rate under irrigated and rainfed conditions at 90, 97, 104 and 111 DAS in different double haploid lines

Table 4.19 : Canopy cooling under irrigated and rainfed conditions

Site	Canopy cooling (°C) (L-A difference)			
	Days after sowing			
	90	97	104	111
Irrigated	-0.402	-0.808	0.243	0.323
Rainfed	-0.454	0.576	1.406	1.673
SE(m) +	0.0194	0.2309	0.0339	0.0442
CD at 5%	NS	0.662	0.097	0.126
Variety				
IR-68586-F2-CA-32	0.113	0.223	0.298	1.628
IR-68586-F2-CA-51	-0.491	-0.095	1.278	0.867
IR-68586-F2-CA-54	-0.453	-0.431	0.740	0.577
IR-68586-F2-CA-107	-0.646	-0.327	1.051	1.174
IR-62266-42-6-2	-0.663	0.050	0.755	0.743
SE(m) +	0.0307	0.3651	0.0536	0.0698
CD at 5%	0.088	NS	0.153	0.200
Site x variety				
Irrigated x IR-68586-F2-CA-32	-0.110	-0.234	-0.136	1.000
Irrigated x IR-68586-F2-CA-51	-0.132	-0.694	0.372	0.102
Irrigated x IR-68586-F2-CA-54	-0.772	-0.780	0.840	0.122
Irrigated x IR-68586-F2-CA-107	-0.502	-0.664	0.050	0.790
Irrigated x IR-62266-42-6-2	-0.492	-1.666	0.090	-0.400
Rainfed x IR-68586-F2-CA-32	0.336	0.680	0.732	2.256
Rainfed x IR-68586-F2-CA-51	-0.850	0.504	2.184	1.632
Rainfed x IR-68586-F2-CA-54	-0.132	-0.082	0.640	1.032
Rainfed x IR-68586-F2-CA-107	-0.790	0.010	2.052	1.558
Rainfed x IR-62266-42-6-2	-0.834	1.766	1.420	1.886
SE(m) +	0.0434	0.5163	0.0757	0.0988
CD at 5%	0.124	NS	0.217	0.283

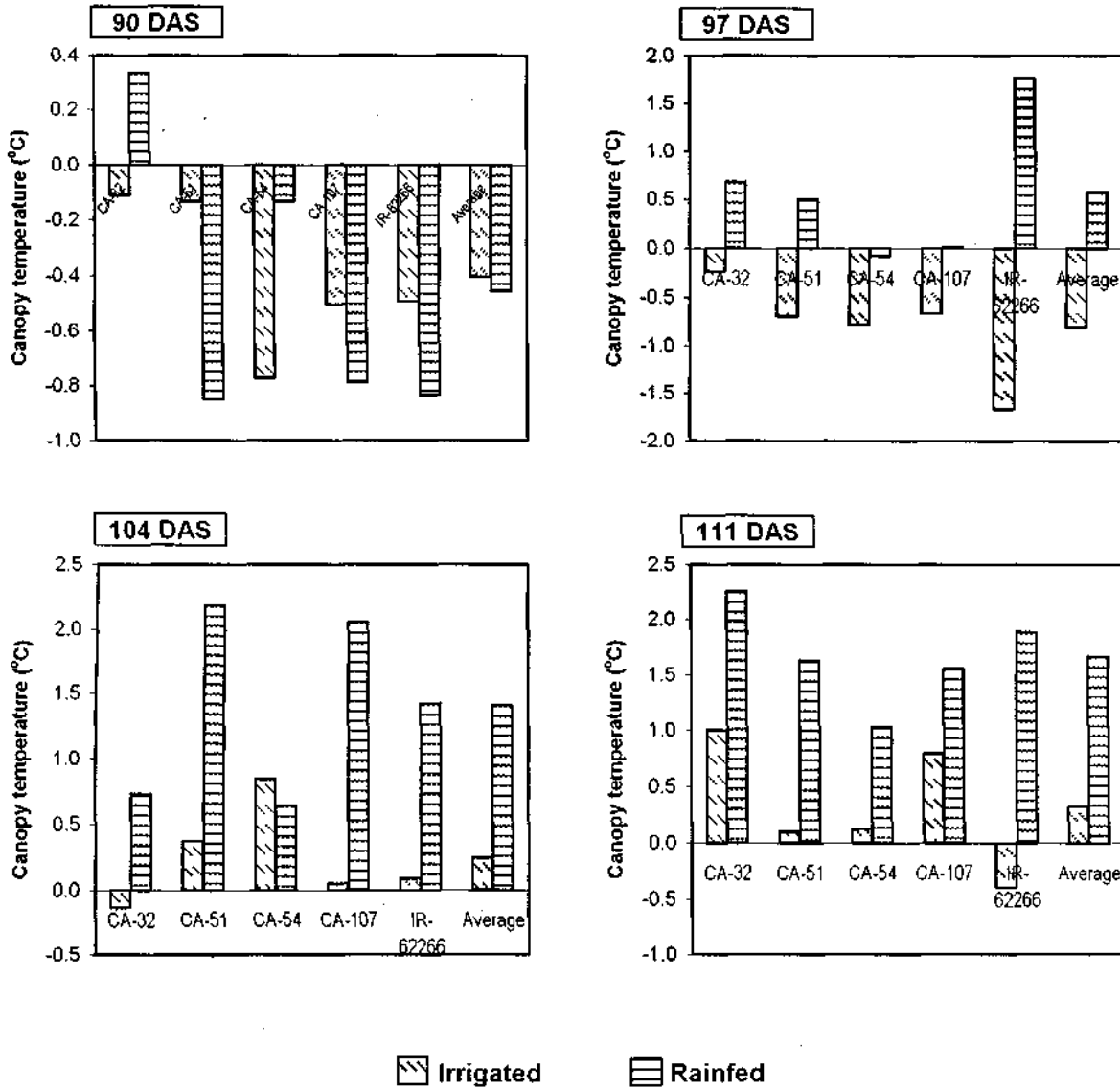


Fig.4.20 : Canopy temperature under irrigated and rainfed conditions at 90, 97, 104 and 111 DAS in different double haploid lines

however it was highest in CA-32 at 111 days after sowing compare to the other lines under rainfed condition.

4.18 Post flowering dry matter production and apparent translocation rate from stem under irrigated and rainfed conditions

The results on post flowering dry matter production and apparent translocation rate from stem have been presented in Table 4.20 and Fig. 4.21 (a,b). The result showed that the post flowering dry matter production significantly decrease (82%) under rainfed site compare to irrigated site. The average of both sites post flowering dry matter was recorded significantly highest and lowest in CA-107 (273.57g m⁻²) and CA-54 (61.08 g m⁻²) respectively. No increase in dry matter was recorded after flowing in CA-32 under rainfed conditions. The post flowering dry matter production was higher in CA-107 and IR-62266 (77.75 and 91.62 g m⁻²) under rainfed condition compare to other lines.

Apparent translocation rate from stem was not significantly different among sites. The results showed that all lines except CA-54 do not translocate dry matter from stem under irrigated conditions. The average translocation rate of dry matter increases from stem under rainfed condition. The highest stem translocation rate was observed in IR-62266 and lowest in CA-32 under rainfed condition.

Table 4.20 : Post flowering dry matter production (PFDM) and apparent translocation rate (ATR) from stem under irrigated and rainfed conditions

Site	Post flowering dry matter production (g m ⁻²)	Stem apparent translocation rate
Irrigated	262.60	-0.185
- Rainfed	43.10	0.313
SE(m)±	28.69	0.50
CD at 5%	83.25	NS
Variety		
IR-68586-F2-CA-32	91.88	-1.250
IR-68586-F2-CA-51	81.27	-0.190
IR-68586-F2-CA-54	61.08	0.280
IR-68586-F2-CA-107	273.57	-0.030
IR-62266-42-6-2	256.48	0.040
SE(m)+	45.36	0.79
CD at 5%	131.63	NS
Site x variety		
Irrigated x IR-68586-F2-CA-32	236.52	-1.920
Irrigated x IR-68586-F2-CA-51	140.66	-0.316
Irrigated x IR-68586-F2-CA-54	45.12	0.577
Irrigated x IR-68586-F2-CA-107	469.37	-0.047
Irrigated x IR-62266-42-6-2	421.35	-0.137
Rainfed x IR-68586-F2-CA-32	-52.74	0.700
Rainfed x IR-68586-F2-CA-51	21.87	-0.370
Rainfed x IR-68586-F2-CA-54	77.04	-0.050
Rainfed x IR-68586-F2-CA-107	77.75	0.080
Rainfed x IR-62266-42-6-2	91.62	0.332
SE(m)+	64.15	1.120
CD at 5%	186.16	NS

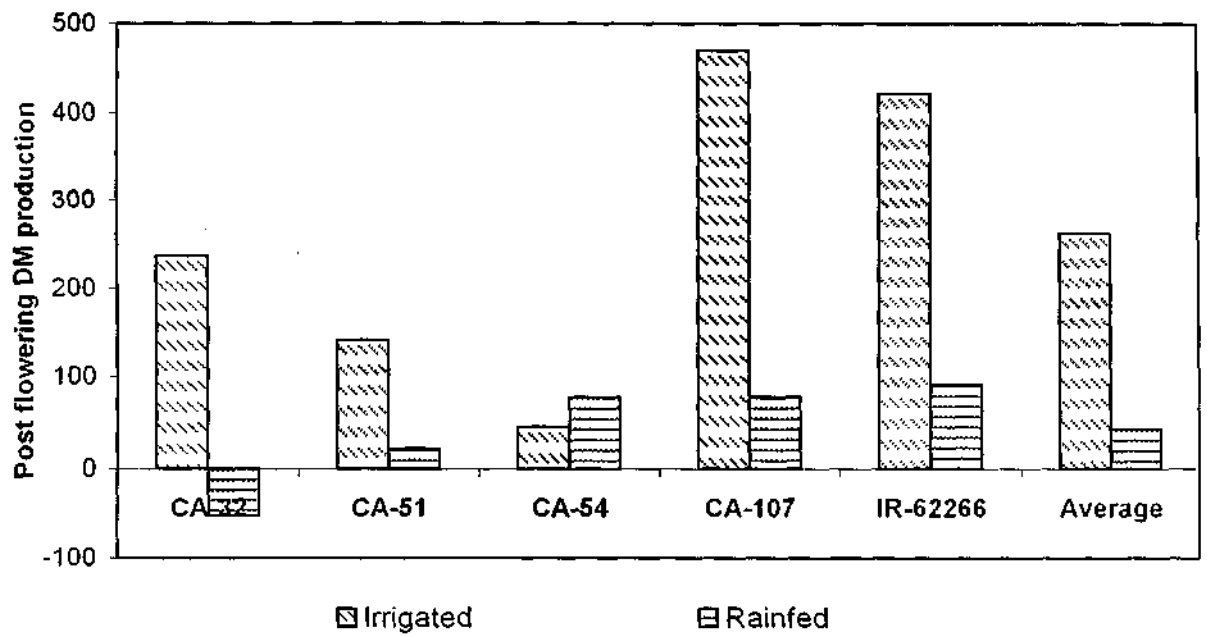


Fig. 4.21(a) : Post flowering dry matter production under irrigated and rainfed condition of different double haploid lines

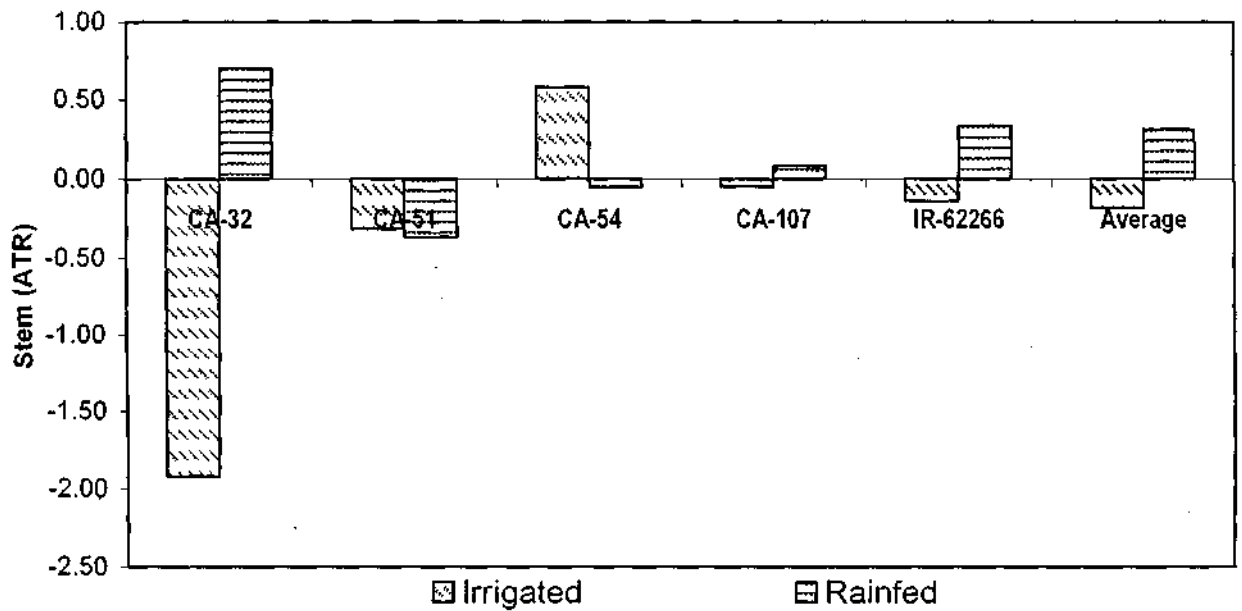


Fig. 4.21(b) : Apparent translocation rate from stem under irrigated and rainfed condition of different double haploid lines

4.19 Grain yield and its components under irrigated and rainfed conditions

The results related to grain yield and its components have been presented in Table 4.21 and Fig.4.22 (a to d). The results showed that grain yield reduced significantly in rainfed site compare to irrigated site. Varietal variation and interaction was also observed statistically significant. The grain yield was highest in CA-107, which was at par with IR-62266 under irrigated condition. The lowest grain yield under irrigated condition was produced by CA-32 (0.367 t ha⁻¹). Under rainfed conditions highest and lowest yield was recorded in IR-62266 and CA-32 respectively.

Number of filled grain per panicle and per cent unfilled grain between two sites was significant. The varietal variation and interaction was also recorded significantly different. Filled grain per panicle reduced under rainfed site while unfilled grain per cent increase under rainfed site compare to irrigated site. The decrease in filled grain number per panicle was highest and lowest CA-107 and CA-32 respectively. Under irrigated site unfilled grains were recorded significantly lower in CA-107 and IR-62266 compare to other varieties. Test weight was recorded highest and equal among CA-54, CA-107 and IR-62266 while lowest (18.23 g) in CA-32 in irrigated site. The reduction in test weight under rainfed site was highest in CA-51 (35.20 %) and lowest in CA-32 (1.83 %) respectively.

Table 4.21 : Grain yield and its attributes under irrigated and rainfed conditions in various double haploid lines

Site	Grain yield (t ha ⁻¹)	Filled grain panicle ⁻¹ (No)	Unfilled grain (%)	Test weight (g)
Irrigated	1.934	52.583	54.277	20.797
Rainfed	0.400	19.603	70.655	16.286
SE(m) _±	0.070	2.804	2.745	0.538
CD at 5%	0.202	8.130	7.957	1.559
Variety				
IR-68586-F ₂ -CA-32	0.225	3.645	88.151	18.070
IR-68586-F ₂ -CA-51	0.625	28.429	67.750	15.928
IR-68586-F ₂ -CA-54	0.775	30.150	60.954	19.469
IR-68586-F ₂ -CA-107	2.012	76.386	46.722	19.442
IR-62266-42-6-2	2.196	41.858	48.752	19.799
SE(m) _±	0.110	4.434	4.340	0.851
CD at 5%	0.320	12.854	12.581	2.466
Site x variety				
Irrigated x IR-68586-F ₂ -CA-32	0.367	2.910	84.800	18.237
Irrigated x IR-68586-F ₂ -CA-51	1.075	39.088	61.403	19.390
Irrigated x IR-68586-F ₂ -CA-54	1.112	37.912	56.770	22.165
Irrigated x IR-68586-F ₂ -CA-107	3.560	123.045	27.015	22.063
Irrigated x IR-62266-42-6-2	3.553	59.963	34.695	22.130
Rainfed x IR-68586-F ₂ -CA-32	0.083	4.380	91.503	17.902
Rainfed x IR-68586-F ₂ -CA-51	0.175	17.770	74.098	12.465
Rainfed x IR-68586-F ₂ -CA-54	0.437	22.387	65.138	16.773
Rainfed x IR-68586-F ₂ -CA-107	0.465	29.728	66.430	16.822
Rainfed x IR-62266-42-6-2	0.840	23.753	62.810	17.468
SE(m) _±	0.156	6.271	6.138	1.203
CD at 5%	0.452	18.179	17.793	3.487

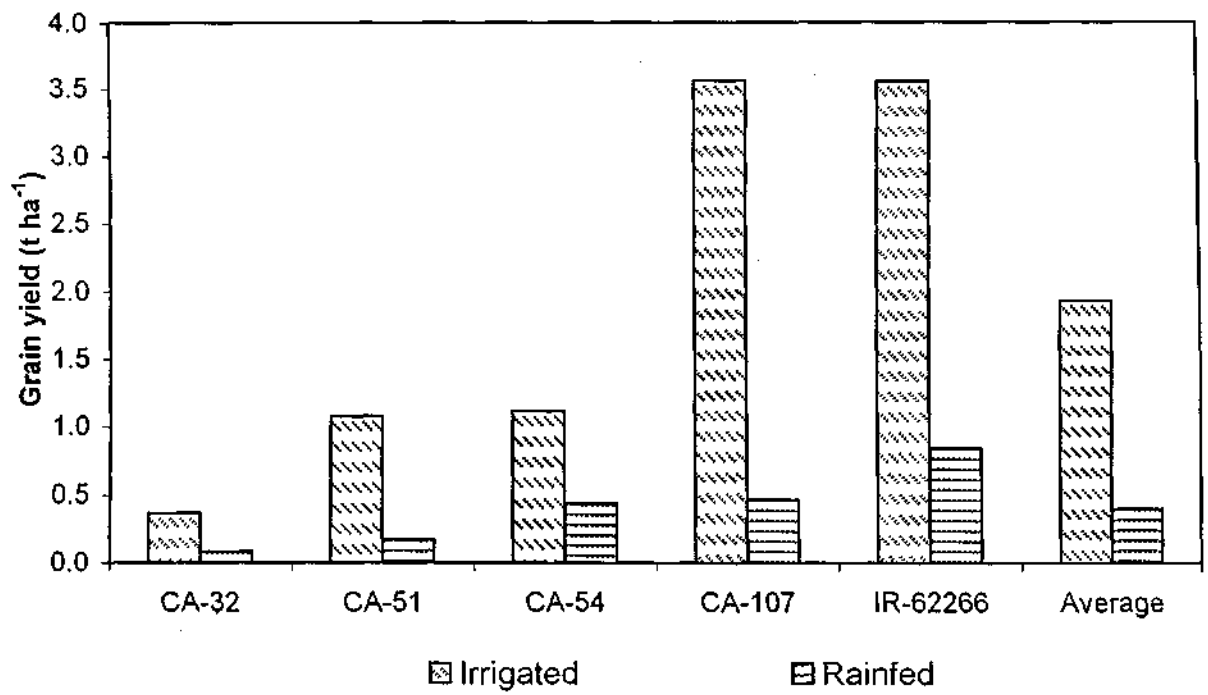


Fig. 4.22(a) : Grain yield under irrigated and rainfed conditions of different double haploid lines

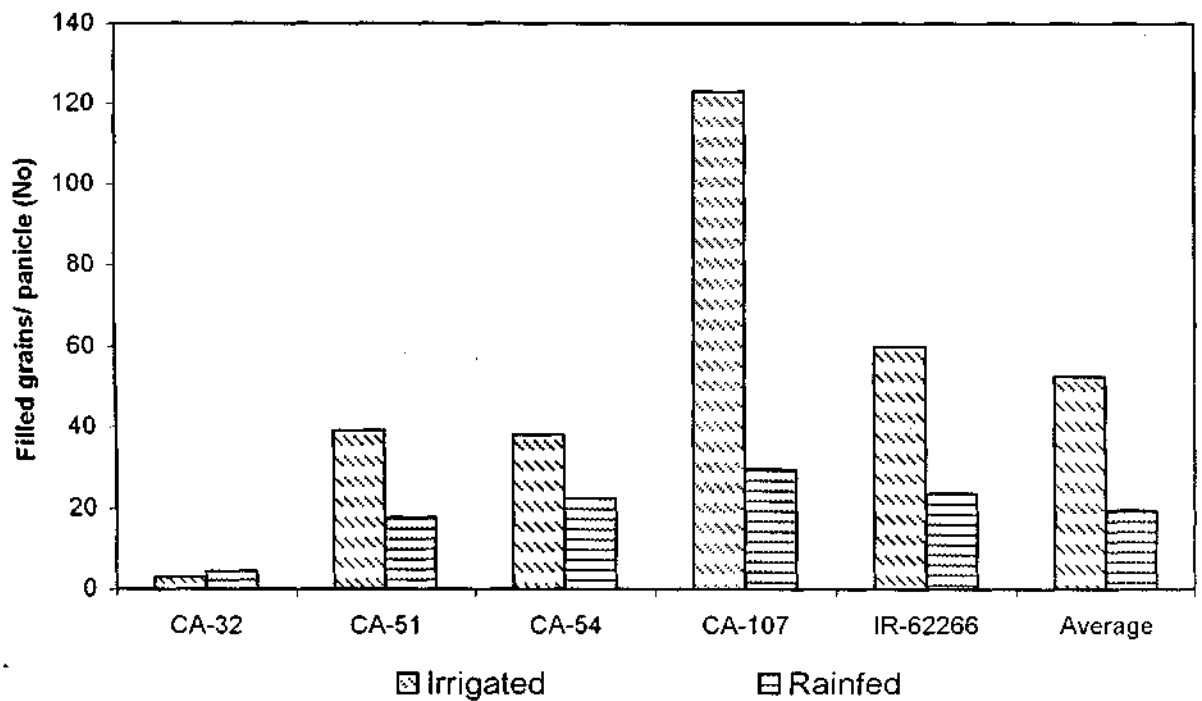


Fig. 4.22(b) : Filled grain per panicle under irrigated and rainfed conditions of different double haploid lines

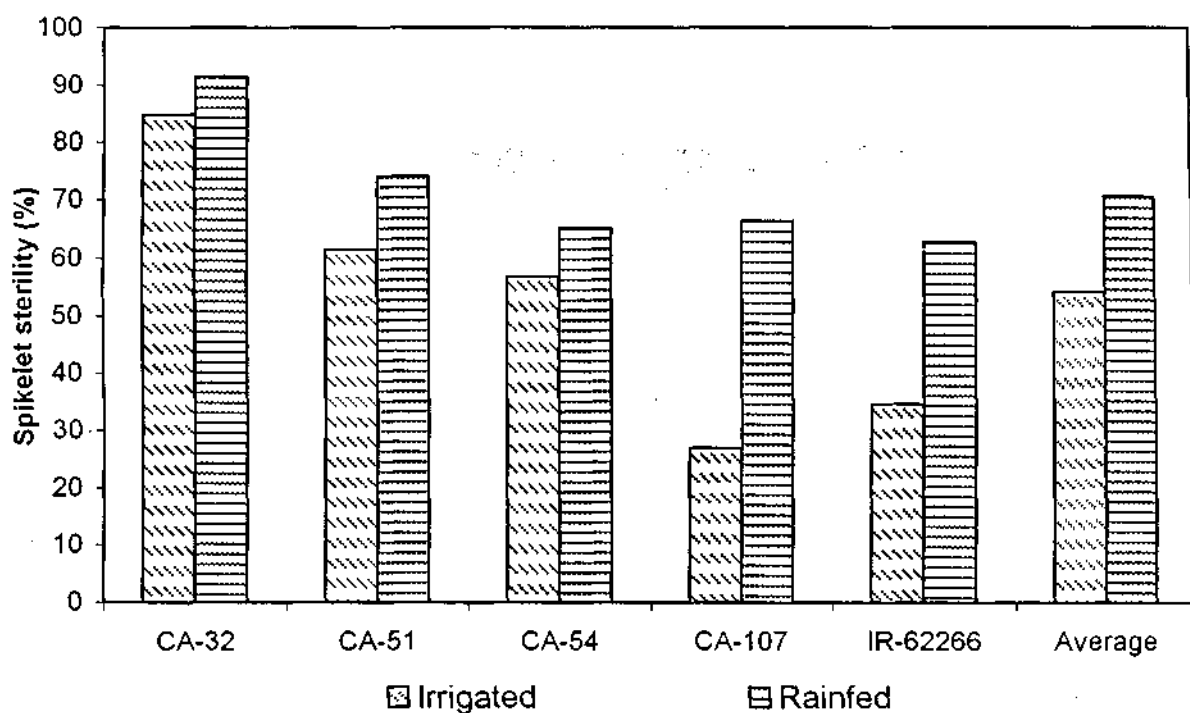


Fig. 4.22(c) : Per cent spikelet sterility (%) under irrigated and rainfed conditions of different double haploid lines

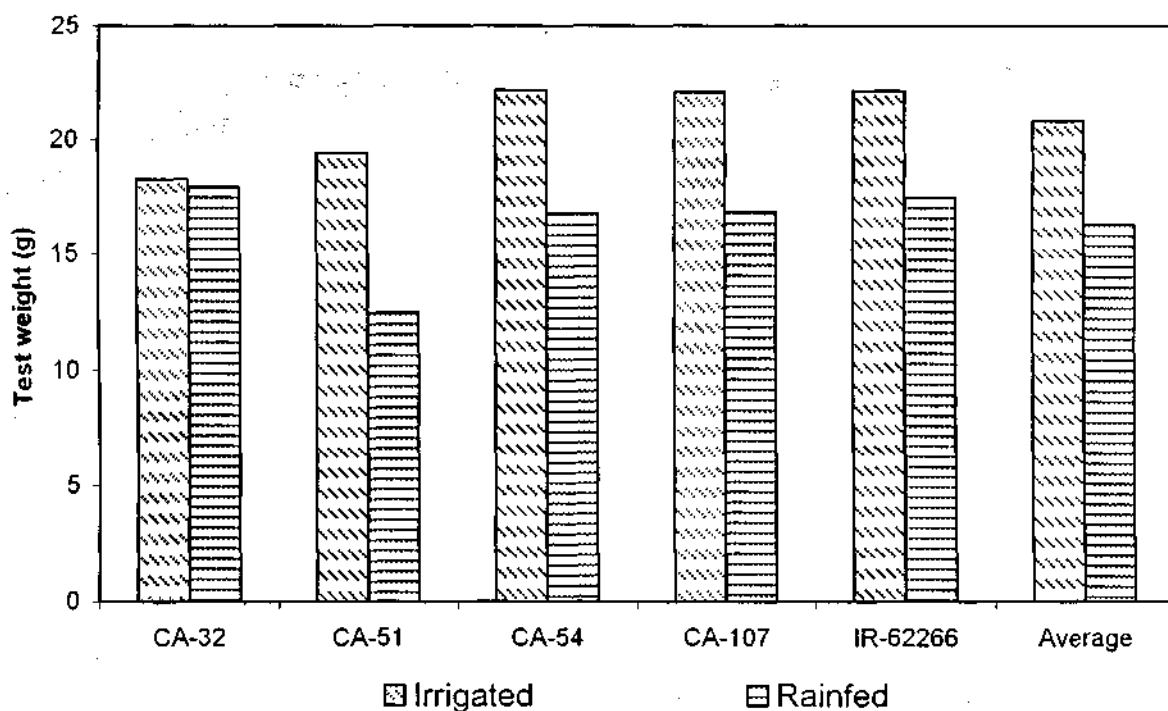


Fig. 4.22(d) : Test weight under irrigated and rainfed conditions of different double haploid lines

Discussion

CHAPTER - V

DISCUSSION

The present study entitled "Identification of morpho-physiological traits responsible for drought tolerance in rice" were conducted during kharif season-2001 with the objective to assess and identify the role of various morpho-physiological traits in drought tolerance behaviour of different double haploid lines. Studies were conducted in irrigated and rainfed conditions to observed the effect of water limiting conditions on phenology, dry matter production ability and its partitioning into various plant parts, photosynthetic stability, transpiration efficiency, canopy cooling, role of flag leaf and stem in yield building capacity, root characteristics, root/shoot ratio and plant water status. The studies were also aimed to identify the role of various traits in yield stability among different double haploid lines. The studies shows that total dry matter increase progressively from sowing till maturity in both irrigated and rainfed sites. The increase in dry matter from panicle initiation to maturity was recorded significantly higher in irrigated site as compare to rainfed site. (Fig. 4.3). The average dry matter production reduced by 36, 41 and 53 per cent at panicle initiation, flowering and maturity stage respectively. Lilley and Fukai (1994a) also observed 56 per cent reduction in dry matter due to water deficit compare to irrigated conditions. Significant variations in dry matter reduction under rainfed site

were observed among different lines. The dry matter production stability was highest in CA-54 at panicle initiation stage, however IR-62266 was stable at flowering and maturity stages. The dry matter production stability in IR-62266 can be related with photosynthetic stability under rainfed conditions. Thome (1966) reported that the ability of plants to continue relatively higher rate of photosynthetic activity under drought, contributes to dry matter stability. The dry matter in CA-32 was lower at maturity compare to irrigated site. Such a reduction in dry matter from flowering to maturity can be related with low photosynthesis and high respiratory loss under water limiting conditions. The dry matter stability under rainfed site can also be linked with root characteristics. The reduction in root dry matter at flowering under rainfed site was maximum in CA-32. Such a high reduction in root dry matter can leads to low water and nutrient uptake which ultimately reduces the dry matter. In water deficit situation, biomass production is a function of extractable soil water and this is related to the rooting pattern of cultivars (Puckridge and O'Toole, 1981).

The productivity of rice not only depends on accumulation of total amount of dry matter but its effective partitioning to economic part is a key to stabilize the yield particularly under water limiting environments (Kumar *et al.*, 2000). The result indicates that IR-62266 maintains higher dry matter partitioning in green leaves at flowering. This provides the higher photosynthetic surface to this line. Lower dry matter partitioning in CA-32 and CA-51 to green leaves at flowering under rainfed site can limit the

current photosynthesis for building grain yield. The increase in panicle dry matter from flowering to maturity was observed lowest in CA-32 under rainfed conditions. This can be related with low current photosynthesis along with low dry matter partitioning from other plant parts to panicle.

The photosynthetic activity of cell, tissue, leaves and canopy have received considerable attention. In current studies IR-62266 photosynthesize at a faster rate under irrigated condition particularly at 90 and 97 DAS. The higher photosynthesis in this variety under irrigated condition can be linked to higher dry matter and grain yield. Photosynthetic rate significantly reduces under rainfed site. The varietal variation were observed among lines in photosynthesis stability under rainfed conditions. It was found that IR-62266 and CA-107 photosynthesize at a faster rate compare to other lines. Such a higher rate of photosynthesis under water limiting conditions can be associated with maintenance of higher turgor due to the higher water potential of leaves (Uprety and Sirohi,1985). The capacity of plants to photosynthesize during and after stress was strongly associated with drought resistance (Townley-Smith and Hurds, 1979). Sairam *et al.* (1990) also reported the tolerant genotypes generally had higher photosynthesis than the susceptible genotypes.

Transpiration rate under irrigated condition was highest in IR-62266 at all the stages. Such a higher transpiration rate can be linked to the high yield of IR-62266 under irrigated conditions. The transpiration rate under

rained site significantly decrease as drought progress from 90 to 111 days after sowing. Such a reduction in transpiration was associated with decreasing plant water status under water deficit conditions (Subramanian and Maheswari, 1990). The low transpiration was also associated with decreasing soil moisture as the stress progress (Choi *et al.*, 1999). The reduction in transpiration rate was recorded lowest in CA-54 particularly at 91 and 104 DAS in rainfed site. The higher reduction in transpiration rate of other varieties can be related with faster closing of stomata due to low leaf water potential (Hirasawa and Hardy, 1999).

Canopy temperature was higher in rainfed site compare to irrigated site among different double haploid lines. Canopy temperature was increased under rainfed site as drought progress. The higher canopy temperature under rainfed site can be related with lower transpiration rates in drying soil. The result shows increase in canopy temperature was highest in CA-32 at 111 DAS. This was further related with transpiration rate. CA-32 showed maximum reduction in transpiration. The higher reduction in transpiration of CA-32 can be linked with poor root system mainly at flowering.

Drought tended to delay flowering and higher delay in flowering was associated with low grain yield, low harvest index and low percentage fertile panicles and filled grains (Pantuwan *et al.* 2000). In current studies flowering was delayed by 3 and 14 days under rainfed site compare to irrigated site in CA-107 and CA-51 respectively. The 14 days delay of flowering in CA-51

was related with low yield under rainfed conditions. It was found that CA-54 and IR-62266 flowered 7 and 2 days earlier respectively. Such early flowering in these lines can be associated with higher yield stability along with lower sterility. The results indicate that the 14 days delay in flowering under water limiting conditions is a function of low plant water status and higher delay can be related to drought susceptibility.

The plant height at flowering was observed highest in CA-107 under rainfed condition. The maintenance of height was related with higher leaf water status, which favours the shoot growth through cell enlargement and cell division (Boyer, 1968). Flag leaf area contributes significantly to gram yield in rice (Padmaja Rao, 1991). It was found that average flag leaf reduced in rainfed site as compare to irrigated site. The maximum flag leaf area was observed in IR-62266 under rainfed condition. Highest reduction in

flag leaf area was recorded in CA-51 alongwith highest yield reduction. Such result indicates that stability in flag leaf area under rainfed site contribute to yield. The high flag leaf area increase the grain yield and spikelet sterility in rice (Ghosh and Saran, 1990). The leaf area index was significantly higher in irrigated site as compare to rainfed site. The maximum reduction in leaf area index was observed in CA-51 while minimum in CA-54 at both the panicle initiation and flowering stages. The higher reduction in leaf area index of CA-51 can be associated with low plant water status, low canopy photosynthesis and lower yield. Leaf area index was recorded highest in IR-62266 at panicle initiation and flowering stages. The maintenance of high leaf

area index under rainfed condition contributes significantly to the higher canopy photosynthesis. Hsiao *et al.* (1976) reported that reduction in leaf area due to lower water potential appears to be the consequence of slowed cell enlargement.

Relative water content (RWC) and leaf water potential decrease as the drought progresses from 83 to 118 days after sowing under rainfed conditions. CA-107 and IR-62266 maintained relatively higher water status at all the stages of measurements as compared to other lines. Such maintenance of higher leaf water potential and relative water content helps in maintaining photosynthetic efficiency under water limiting conditions. Higher internal plant water status during the period of drought is the key to drought resistance, these results are in consistency with findings by Jongdee (1998). The mechanism controlling higher plant water status may involve higher water uptake and water conservation by the plant and also internal plant water conductance during drought stress (Pantun *et al.* 2000). Leaf water potential of leaves declines exponentially with decreasing soil water potential (Pal and Varade, 1980).

Tiller number significantly reduced in rainfed site compared to irrigated site. Reduction in tiller number under rainfed site was recorded highest in CA-32 at all the stages. The higher reduction of tiller in CA-32 can be associated with low plant water status. Reduction in tiller number observed

lowest in IR-62266 at flowering and maturity stages under water limiting condition.

Leaf rolling was observed as the drought progress under rainfed site. Leaf rolling is one of the visible physiological responses under water deficit condition. In current studies highest leaf rolling was observed in CA-107 and IR-62266 while lowest in CA-32 under rainfed conditions. The higher rolling in CA-107 and IR-62266 can be linked with larger leaf area in rainfed conditions. The leaf rolling helps these line to conserved water by exposing less leaf surface to the environment. Similar results were reported by Singh and Singh, (2000). CA-32 shows low leaf rolling score due to its smaller leaf. The less rolling in CA-32 can be linked with higher water loss from its leaves which ultimately reflects in low leaf water potential.

Biomass production under rainfed condition is a function of extractable soil water and can be related to the rooting pattern of the double haploid lines. The result on root dry weight shows that CA-54 increases its root dry weight under rainfed conditions compare to irrigated condition at panicle initiation, however CA-107 shows higher root dry weight at flowering under rainfed conditions. Such an increase in root dry weight can be very helpful in water extraction from deeper soil layers in drying soil. The deep and thick roots which enables the plant to avoid the adverse effect of internal water deficit (Chang *et al.* 1972). Extractable soil water and water extraction rate were related with root length density and water extraction

were similarly ranked among lines (Lilley and Fukai, 1994). Puckridge and O'Toole (1981) reported mat crop growth and grain yield under water limiting conditions strongly influenced by water extraction capability of roots.

Root/shoot ratio increases under rainfed site compare to irrigated site at all the stages. CA-107 shows highest root/shoot ratio at panicle initiation and flowering stage compare to other lines under rainfed conditions. Such an increase in root/shoot ratio can be linked with maintenance of leaf water status under drying soil. IR-62266 shows lowest root/shoot ratio under rainfed condition compared to other lines. IR-62266 have the capacity to osmotically adjust under water deficit conditions (Sarkarung and Pantuwan, 1999). The results showed that instead of higher root/shoot ratio, IR-62266 maintain the higher plant water status and photosynthetic stability by good osmotic adjustment capacity.

The results shows that post flowering dry matter reduced significantly under rainfed site. The post flowering dry matter production is a indicator of current photosynthesis after flowering. It is evident that reduction in current photosynthesis under rainfed site was responsible for low post flowering dry matter production. Under irrigated condition the post flowering dry matter production was significant higher CA-107 and IR-62266. Such a higher post flowering dry matter production was responsible for higher yield of these lines under irrigated conditions. Significant variation were observed under rainfed condition. It was observed that CA-32 donot produce any dry matter

after flowering under rainfed conditions, rather it decreases its dry matter from flowering to maturity. The decrease in dry matter can be associated with highest reduction in current photosynthesis of CA-32 under rainfed conditions. IR-62266 produce highest dry matter after flowering under rainfed conditions. The higher post flowering dry matter production in IR-62266 can be associated with higher photosynthetic rate.

It was observed that the contribution of stem reserves to yield increases under rainfed condition compare to irrigated conditions. Such a higher apparent translocation rate under rainfed conditions is due to reduction in current photosynthates and plants depends more on reserved carbohydrates. The highest apparent translocation rate was observed in IR-62266. The photosynthetic stability by maintaing higher leaf water status along with higher apparent translocation rate was responsible for better performance of IR-62266 under water limiting conditions.

The result on grain yield showed that CA-107 and IR-62266 produces highest grain yield under irrigated conditions. Higher photosynthetic rate along with higher transpiration rate in these lines helps in achieving maximum grain yield under irrigated conditions. Yield was reduced by 79 per cent under rainfed site compared to irrigated site. The rainfed site suffered due to drought at the flowering and grain filling stages which leads to high yield reduction. Nayak *et al.* (1974) reported that drought during flowering stage cause severe reduction in grain yield.

The result showed that higher grain yield of CA-107 and IR-62266 under rainfed site can be related with maintenance of high leaf water status, less delay in flowering, photosynthetic stability and high transpiration rate through more water uptake. The lower yield of CA-51 under water limiting condition can be associated two weeks delay in flowering, low post flowering dry matter production, low photosynthetic stability, low transpiration and low root/shoot ratio.

It can be concluded that different morpho-physiological traits like less delay in flowering, maintenance of higher water status, increase in root dry matter and root/shoot ratio, canopy cooling, photosynthesis stability, higher transpiration rates through high water uptake from soil contributes significantly to yield stability under water limiting condition. These traits can be incorporated into the superior agronomic lines to improve the yield of rice under water limiting conditions. It was also found that different lines adopt different mechanisms to survive and produce under water limiting environments.

*Summary, Conclusion &
Suggestions for Future Work*

CHAPTER - VI

SUMMARY, CONCLUSION AND SUGGESTION FOR FUTURE WORK

The studies entitled "Identification of morpho-physiological traits responsible for drought tolerance in rice" were conducted at Instructional Farm of Indira Gandhi Agricultural University, Raipur (C.G.) during kharif season of 2001. Two sites (irrigated and rainfed) were used for studies. The major objective of the studies was to evaluate the contribution of different morpho-physiological traits in yield stability under water limiting environments. Following are the main finding of the studies.

1. Rainfed site suffered due to water shortage during flowering and grain filling stages.
2. Water table depth under rainfed site was always below one meter depth after 95 days after sowing.
3. Dry matter production significantly reduces under rainfed site compare to irrigated sites. CA-54 showed maximum dry matter stability at panicle initiation stage while IR-62266 was stable in dry matter production at flowering and maturity under rainfed site.
4. Under irrigated conditions IR-62266 showed high rate of photosynthesis compare to other varieties. Photosynthetic rate significantly reduces under rainfed site. IR-62266 and CA-107 showed higher photosynthetic rate

under rainfed conditions. The stability of photosynthetic rate under rainfed site was related with maintenance of higher turgor through high plant water status.

5. Transpiration rate decreases significantly under rainfed site. The higher transpiration rate in CA-107 was related with higher root/shoot ratio under rainfed site.
6. Canopy temperature was recorded higher than ambient temperature in rainfed site. Such a rise in canopy temp was observed higher in CA-32 and CA-51. The increase in canopy temperature was related with the drought susceptibility.
7. Flowering was delayed in some lines under rainfed site compare to irrigated site. The highest delay (14) days was observed in CA-51. The delay in flowering under water limiting condition was related with drought susceptibility.
8. The maintenance of higher plant water status (as measured in terms of water potential and relative water content) under rainfed site was related with root characteristics, high osmotic adjustment capacity which ultimately reflects in yield stability.
9. Root/Shoot ratio increases under rainfed site compare to irrigated site at all the stages. The maintenance of high root/shoot area was related with maintenance of high water potential through higher water uptake.

The Following major conclusions can be drawn from the current studies:

1. Maintenance of photosynthetic stability under water limiting conditions contributes to dry matter and yield stability.
2. Higher root/shoot ratio can be related with higher water uptake, maintenance of higher plant water status and yield stability.
3. The contribution of stem reserves in building grain yield increases under drought compare to irrigated conditions.
4. Maintenance of higher plant water status was related to yield stability and drought tolerance behaviour.
5. Delay in flowering under water limiting environments was related with drought susceptibility.
6. The maintenance of cooler canopy in drying soil was also related with drought tolerance.

Suggestions

1. Rapid and repeatable screening technique should be developed for screening the breeding lines for drought tolerance.
2. The contribution of various morpho-physiological traits in yield stability should be investigated in details.
3. Major quantitative trait loci should be identify for major traits and marker assisted breeding should be practices to improve the drought tolerance.

Abstract

IDENTIFICATION OF MORPHO-PHYSIOLOGICAL TRAITS RESPONSIBLE FOR DROUGHT TOLERANCE IN RICE

by


Anilkumar Zamsingh Yerne

ABSTRACT

The present studies entitled, "Identification of morpho-physiological traits responsible for drought tolerance in rice" was conducted at the Instructional Farm of IGAU, Raipur during kharif season of 2001. The objective of the studies was to identify the role of various morpho-physiological traits responsible for drought tolerance behaviour of different double haploid lines. Studies were conducted using two sites i.e. rainfed and irrigated. In rainfed site the irrigation was not provided from seedling establishment until maturity. The difference in phenology, dry matter production ability and its partitioning into various plant parts, photosynthetic rate, transpiration rate, canopy cooling, role of flag leaf and stem in yield building capacity, root characteristics, root/shoot ratio and plant water status were studied among irrigated and rainfed sites. The studies were also aimed to identify the role of various traits in yield stability among four double haploid lines and its parent.

Dry matter production capacity reduced under rainfed site as the drought progress from panicle initiation to maturity. The ability to maintain higher leaf water status and photosynthetic stability was related with stability in dry matter production under rainfed conditions. Rainfed site tended to delay the flowering. The higher delay in flowering due to drought under rainfed site was associated with higher yield reduction. It was noticed that low plant water status and higher delay can be related to drought susceptibility. Crop growth and grain yield under rainfed site was strongly influenced by root growth. The lines with good root system keeps the aerial parts well supplied with water. Such a regular flow of water was also reflects in higher transpiration rate. Less delay in flowering, maintenance of higher water status, increase in root dry matter and root/shoot ratio, canopy cooling, photosynthetic stability, higher transpiration rates and higher water extraction contribute significantly to stable yield under water limiting conditions and were related with drought tolerance.

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Appendices

Appendix -I : Weekly meteorological data during crop growth period (July 19th to December 15th, 2001)

Month & Year	Date	Week number	Temperature (°C)		Rainfall (mm)	Relative humidity (%)		Evaporation (mm day ⁻¹)	Sunshine (hr day ⁻¹)	Wind velocity (km hr ⁻¹)
			Maximum	Minimum		I	II			
July, 2001	16-22	29	27.2	24.1	66.9	93	88	1.7	0.0	11.5
	23-29	30	30.3	24.8	50.2	92	73	3.4	1.7	9.4
	30-05	31	31.7	25.3	4.2	92	71	3.7	2.8	5.5
August	06-12	32	31.4	25.4	34.2	95	75	4.5	5.2	5.5
	13-19	33	29.0	24.6	59.5	92	83	3.4	1.3	11.1
	20-26	34	29.9	24.7	120.2	95	87	3.5	1.9	6.7
September	27-02	35	30.9	24.8	10.9	88	69	4.4	5.6	8.2
	03-09	36	32.2	24.5	43.1	92	69	3.8	4.7	5.2
	10-16	37	33.2	24.2	11.3	93	67	4.1	6.7	4.0
October	17-23	38	33.6	24.4	0.2	93	57	4.5	7.6	2.9
	24-30	39	33.2	24.3	41.5	90	65	5.2	8.4	3.4
	01-07	40	31.0	24.5	52.3	93	24	4.0	3.3	5.6
November	08-14	41	32.6	23.9	34.5	93	60	4.5	8.3	3.0
	15-21	42	31.9	20.4	0.0	88	47	4.7	8.4	3.4
	22-28	43	32.0	18.1	0.0	92	40	3.8	9.0	1.6
December	29-04	44	32.3	18.5	9.6	90	40	3.8	9.2	2.2
	05-11	45	31.4	17.4	0.0	89	33	4.1	7.6	4.1
	12-18	46	30.3	18.4	0.0	88	50	3.3	5.4	3.5
December	19-25	47	30.4	13.7	0.0	89	32	3.5	9.0	2.1
	26-02	48	28.3	11.7	0.0	88	29	3.1	7.9	2.1
	03-09	49	29.7	10.3	0.0	89	24	3.1	8.7	1.5
	10-16	50	30.6	13.2	0.0	90	34	3	7.3	1.9