EFFECT OF REPRODUCTIVE STAGE DROUGHT ON RICE PHYSIOLOGY

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

by

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EFFECT OF REPRODUCTIVE STAGE DROUGHT ON RICE PHYSIOLOGY

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Dedicated

to

my Beloved Parents

Smt. S. Kujur

Shri D. Kujur

CERTIFICATE – I

This is to certify that the thesis entitled **"EFFECT OF REPRODUCTIVE STAGE DROUGHT ON RICE PHYSIOLOGY"** 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 ROBINSON SUDHIR KUJUR** 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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Member	: Shri A. L. Rai

CERTIFICATE - II

This is to certify that the thesis entitled **"EFFECT OF REPRODUCTIVE STAGE DROUGHT ON RICE PHYSIOLOGY"** submitted by **Shri ROBINSON SUDHIR KUJUR** 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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Introduction

CHAPTER-I

INTRODUCTION

Rice is a major staple food crop in the world, supplying one third of the world's population with more than 50 per cent of there calories and nearly half of their proteins. Drought is commonly considered the most severe limitation to the productivity of rice in rainfed areas. A prolonged dry spell can take place at both the vegetative and reproductive stages. Drought at the reproductive stage is believed to be more detrimental to the grain yield, but severe drought during early vegetative stage can also cause significant crop damage. In Chhattisgarh state rice is grown in about 3.9 million hectare. The 80 per cent of the total grown area is rainfed. Being rainfed crop, drought may occur at any stage of crop growth in general and reproductive stage in particular leading to partial or total crop failure.

Under above condition identification of drought resistance varieties and the traits responsible for drought tolerance becomes very important to sustain the productivity in the region. Two approaches can be followed to improve drought resistance in rice. One approach is to select directly for yield under drought conditions or select indirectly using physiological or morphological characteristics associated drought resistance or combination of both of these strategies. Selection for drought resistance with the direct use of grain yield under drought as a selection index may be inefficient when practices on limited samples. Among the several traits which can be associated with drought adaptation in rice, leaf water potential is one of the important indicator of plant water status (Jongdee 1998). Water potential is determined by the interaction of several process like uptake, transport and loss of water from the canopy. Plant size and water conductance can also be associated with spikelet sterility and yield reduction under drought.

Drought at reproductive stage can delay flowering. Genotype with a longer delay in flowering tended to experience more drought stress because they flowered and filled the grains when available soil water is lower (Pantuwan 2001). Therefore, varieties with lesser delay in flowering under drought can stabilize the yield. Production of higher biomass is often fundamental to higher yield, so the photosynthetic activity of cell, leaves, plants and whole crop has attained much attention. Photosynthetic capacity during and after drought stress was reported as important index of drought resistance (Townley-Smith and Hurd 1979). The ability of plants to continue relatively higher rate of photosynthetic activity under drought can contribute significantly to the yield. The current studies will also elucidate the relationship among leaf water potential, photosynthetic and membrane stability under drought conditions.

Membrane stability has also been associated with drought stress resistance in various crops. Lower membrane stability has also been reported in susceptible genotypes of wheat. (Sairam *et al.* 1999). The membrane stability can therefore contributes to the drought resistance in rice. Under water deficit conditions, biomass production is a function of extractable soil moisture and is related to the rooting pattern of the varieties. Therefore, severity of drought and its effect on crop growth and grain yield is strongly determined by the rooting pattern of the varieties (Puckridge and O'Toole, 1981).

The productivity of rice not only depends on total accumulation of dry matter but its effective partitioning to economic parts. This may be especially important in drought prone environments, where current photosynthesis is restricted due to drought. At reproductive stage, enhanced capacity to allocate dry matter from various plant parts to grain can plays an important role in yield stability (Kumar *et al.*, 2000).

The above morpho-physiological traits that confer drought resistant may be used as indirect selection criteria to improve grain yield under drought. However these traits should be evaluated for their contributions to adaptation under reproductive stage drought in rice. Keeping the above considerations in view the studies were conducted with following objectives:

1. To monitor and interpret plant response to progress of drought.
2. To examine the contribution of stored assimilates to yield stability under drought conditions.
3. To study changes in dry matter production and partitioning patterns under drought compared with well watered controls.
4. To examine the leaf water status, photosynthetic efficiency, membrane stability and root characteristics of different rice varieties.
5. To identify the traits, contributes to reproductive stage drought resistance in rice.

Review of Literature

CHAPTER-II

REVIEW OF LITERATURE

Water deficits or water stress refers to situations in which plant water potential and turgor is reduced enough to interfere with normal functioning of the plant. The exact water potential at which this occurs depends on the kind of plant, the stage of development and the process under consideration. For example cell enlargement usually begins to decrease at a water potential of only -0.2 to -0.4 Mpa, but stomatal closure does not begin until the water potential falls to - 0.8 to - 1.0 Mpa in some plants and much lower in others. (Hsiao, 1973).

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 and decrease in cell enlargement and plant growth, decrease in photosynthesis, disturbance of many metabolic processes and finally death (Kramer, 1983).

Causes and development of water stress:

Water deficits developed during the periods, when water loss in transpiration exceeds absorption. This occurs to some extent every sunny morning in plants that are transpiring at normal rates, but it becomes more severe when transpiration becomes rapid on hot and sunny days, when absorption is limited by drying, cold or poorly aerated soil or when a combination of two situations occur.

When there is less moisture in the soil, the leaf and root water potential decreases. Initially the leaf water potential returns at night to a value equal to soil water potential but as the soil dries, the recovery becomes less and less. Day time wilting occurs when movement of water towards the roots in the drying soil becomes too slow to replace day time water loss. Permanent wilting occurs when the soil water potential decreases to the leaf water potential at which wilting occurs and leaves do not recover turgor at night. (Slatyer, 1957, 1967).

A brief review of research work about the effect of drought stress on rice physiology and various characteristics responsible for drought tolerance is summarized below :

2.1 Effect of drought-stress on growth characteristics:

Plant growth is reduced more often by water deficits than any other factor (Begg and Turner, 1976). Plant size is reduced by a decrease in cell enlargement (Boyer, 1968). The leaf enlargement can be reduced by only small degree of desiccation, generally long before stomatal aperture and CO2 assimilation is affected (Boyer, 1968). Sahu and Rao (1974) found that all the three rice plant, Tall-Indica PTB-10, Dwarf-Indica Jaya and Japonica-Indica ADT-27 were adversely affected by soil moisture stress at any growth phase and development. Stress during the vegetative phase reduced plant height, tiller number, less-functional leaves and delayed maturity.

Row and Venkateshwarle (1983) noticed a decrease in growth of rice cv. Rasi and IR-20 subjected to moisture stress at vegetative phase. Deka *et al.* (1998) studied the effect of water stress (0, -3, -5, -7.5 and -10 bars) on seed germination and seedling growth in ten upland rice cultivars. Per cent seed germination and seedling growth decreased with increasing water stress in all the cultivars but cv. Maibee 11 and Iharsal Ahu recorded better seedling growth in terms of radicle and plumule length under stress conditions than the other cultivars.

Lai *et al.* (1998) worked on growth variations to soil water deficits in lowland and upland genotypes of rice. It was found that plant height decreases due to water deficit and generally lowland genotypes were more sensitive than the upland ones. Lu *et al.* (1998) worked on two varieties of rice Shanyon-63 (Indica hybrid) and Ganjing-2 (Japonica normal cultivars). Soil water deficit treatments were given in the whole growth period and it was found that increasing soil water deficit progressives decrease in population growth rate in both cultivars.

Scartazza *et al.* (1998) studied, growth analysis and water use efficiency in rice plants subjected to drought during different developmental stages and found that drought causes major effect on growth. Chauhan *et al.* (1999) reported that rice cv. Browngora and Vandana were subjected to water stress at booting or anthesis stages. Water stress at both stages reduced plant height, leaf area and leaf temperature was observed higher than ambient.

Park *et al.* (1999) investigated the growth stages in the influence of soil moisture stress in the cultivars Japonica and Dongjinbyeo. The cultivars were subjected to soil moisture stress at five growth stages until the initial wilting point (about 10% soil moisture content) and was then irrigated again. The results showed that plant height at maturity was lower then irrigated control. Singh *et al.* (2000) conducted studies on root and shoot systems, on four upland rice (*Oryza sativa* L.) cultivars (Japonica, Indica. Avs and zero groups) grown under stressed (booting to harvest stage) and irrigated conditions. The result showed that the tiller number, shoot weight, shoot height and shoot diameter decreased due to stress. The reduction in shoot weight in Japonica (drought resistant) rice was less (5.3%), whereas the reduction was higher (10.1-24.2%) in Indica (drought susceptible) rice.

Wade *et al.* (2000) studied shoot growth and transpiration in response to drought and rewatering among eight diverse rice genotypes in three experiments. One under severe stress development after panicle initiation and two under slow and progressive stress development during tillering. On experiment 1, the effect of plant size before stress imposition was large and genotypic variation for response to drought and rewatering was small. During early drought phase in experiment 2 and 3 genotypes differed in relative amount of tiller and leaf area production compared with the well watered treatment.

2.2 Effect of drought-stress on photosynthesis:

Drought stress reduces photosynthesis by reduction in leaf area, closure of stomata and decrease in the efficiency of carbon fixation process. Production at higher biomass is often fundamental to higher yield, so the photosynthetic activity of cell, leaf, plants, and whole crop have received much attention. The reduction of photosynthetic under drought may be due to stomatal, non stomatal or both depending upon the environmental conditions and the species under consideration (Hutmacher and Krieg, 1983). It has been pointed out that photosynthesis is quite sensitive to drought stress. So the effects of drought stress on photosynthesis has received considerable attention.

The capacity of photosynthesis during and after drought stress is an important index of drought tolerance (Townley - Smith and Hurd (1979). It was observed that the ability of plants to continue relatively higher rate of photosynthesis activity under drought, contribute significantly to the yield (Thorne 1966).

Uprety and Sirohi (1985) studied the effect of water stress on photosynthesis and water relation of wheat varieties C-306 and Kalyansona. The results showed that stress affected both stomatal and non-stomatal components of photosynthesis. The comparatively higher photosynthesis in variety C-306 under water stress condition might probably be by the maintenance of higher turgor due to higher water potential of its leaves.

Dey and Rao (1989) observed that dehydration reduced the photosynthesis rate in two early rice varieties (Swarnaprabha and Ratna) to an extent of 70-86% at the leaf water potential of -9.0 to -11.0 bars. Sairam *et al.* (1990) observed the effect of moisture stress imposed at tillering and anthesis stages in four drought susceptible (HD-2329, HD-2001, WL-711, WH-149) and four drought tolerant (C-306, NI-5439, Pissi local and DL-153-2) genotypes of wheat and reported that photosynthesis decreased under moisture stress. Tolerant genotypes generally had higher photosynthesis than the susceptible genotype.

Scartazza *et al.* (1998) studied gas exchange characteristics in rice plant subjected to drought during different developmental stages. The results showed that drought significantly reduces the photosynthetic rate at all the developmental stages. Choi *et al.* (1999) determined the photosynthesis rate at different growth stage in rice subjected to soil moisture stress. The photosynthesis rate at all growth stages was rapidly decreased and reach nearly zero at initial wilting point. The degree of recovery of photosynthesis rate after watering ranged from 20 to 90 per cent. Hirasawaj *et al.* (1999) studied the photosynthesis in rice under depleting soil moisture conditions. The results showed that photosynthesis rate diminished because of senescence, closing of stomata due to the reduction in leaf water potential.

2.3 Effect of drought-stress on stomatal conductance:

Stomatal control is responsible for reduction in photosynthesis particularly under drought stress conditions. Hsiao (1973) attributed most of the decreases in photosynthesis due to stomatal closure. However it is not clear to what extent the stomatal control is responsible for reduction in photosynthesis under drought (Beadle *et al.* 1973) shown that under low water potential, mesophyll resistance increases rapidly, indicates that the effects of other factors also influence the rate of photosynthesis under drought.

Singh and Singh (1989) reported that stomatal conductance firstly increased upto 1100 hours then decreased till 1300 hours, increased there after till 1500 hours and started again decreasing from 1500 hours and attained a minimum at 1900 hours. Higher stomatal conductance was recorded in no stress treatment as compared to –1.5 Mpa stress.

Dingkuhn *et al.* (1999) studied the stomatal conductance of different varieties under irrigated and drought conditions. It was concluded that stomatal conductance was controlled by a soil moisture dependent root signal.

2. 4 Effect of drought-stress on transpiration:

The transpiration is an essential process because it causes ascent of sap, increased absorption of minerals and cools the leaves. On the other hand these process become evil as it often produces water deficits and injury by dehydration (Bois and Couchat 1983) noted that transpiration and photosynthesis are independent of the soil water potential after a thresh hold value

Pal and Varade (1980) reported that the transpiration rate remained nearly constant at high soil moisture contents and it decreases as the soil moisture content start decreasing. Sairam *et al.* (1990) observed the effect of imposed moisture stress at tillering and anthesis stages on four drought susceptible (HD-2329, HD-2001, WL-711, WH-147) and four drought tolerant (C-306, NI-5439, Pissi local and DL-153-2) genotypes of wheat and reported that transpiration rate decreased under moisture stress. Tolerant genotypes generally had lower rates of transpiration than the susceptible genotype.

Chauhan *et al.* (1999) in their experiment reported that when rice cv. Browngora and Vandana were subjected to water stress at booting or anthesis stage the stressed plant of both cultivars shows lower transpiration. Choi *et al.* (1999) determined the transpiration rate in different growth stage of rice, subjected to soil moisture stress in cultivars Japonica rice cv. Dingjinbyeo. The transpiration rate rapidly decreases during soil moisture stress and the transpiration rate at initial wilting point of the stressed plant was only 10-20 per cent of controls.

2.5 Effect of drought-stress on leaf water potential:

Tissue water potential has been used widely as a measure of water stress. The maintenance of high leaf water potential was related very well with drought resistance in several studies.

Pal and Varade (1980) reported that the leaf water potential of leaves declined exponentially with decreasing soil water potential. Patil *et al*. (1984) grown the plants in pots and irrigated regularly upto 30 days. After 30 days stress was induced and relative water content were estimated in root, leaf sheath and leaf blade. With the advance in stress, RWC decreased. Among the plant parts leaf sheath had higher RWC while lowest was recorded in root.

Singh and Singh (1989) studied the effect of various degrees of plant water stress on diurnal variation in leaf water potential and revealed that leaf water potential decreased during the day upto 1300 hours, remained static between 1300 and 1500 hours and increased there-after. Higher leaf water potential was recorded in no stress treatment as compared to –1.5 Mpa stress.

Sairam *et al.* (1990) observed the effect of moisture stress, imposed at tillering and anthesis stages on four drought susceptible (HD-2329, HD-2001, WL-711, WH-147) and four drought tolerant (C-306, NI-5439, Pissi local and DL-153-2) genotypes of wheat and reported that water potential decreased under moisture stress. Tolerant genotypes generally had higher leaf water potential under moisture stress. Singh *et al.* (1990) observed the significant genotypic differences in water potential, osmotic potential and pressure potential in wheat genotypes. Gradual water stress in soil culture reduced the water potential in all the genotypes.

Thangaraj and Sivasubramanian (1990) studied about 22 upland rice cultivars for their responses to fifteen day water stress at reproductive phase. The ability to withstand drought was found to be conditioned by the number of days taken to wilt, relative leaf water content, drought recovery ability and leaf rolling score. The results indicate that visual scoring of rice genotypes is effective in identifying the plant with high leaf water status at reproductive phase.

Krishnayya and Murty (1991) exposed five upland rice varieties to soil moisture stress of 25 per cent field capacity at seedling stage. With increase in soil moisture stress, there was decrease in relative water content and water potential of leaf. The cultivar which maintained high 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 (1994) 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, Riknto-Norin 12 (RN), and Todoroki-wase (TW) were known to have different responses to water deficit. Cultivar RN had poor water extraction and was most sensitive to water deficit. TW also had poor water extraction but plants were small and this cultivar escaped severe stress, particularly in the vegetative phase. CPIC 8 and Lemont extracted more soil water and were less sensitive to water deficit.

Tyagi *et al*. (1999) conducted an experiment with known tolerant and susceptible genotypes of rice. They recorded observations on membrane stability, osmotic potential and root biomass at anthesis stage. Drought tolerant genotypes CR 143-2.2, Salam pikit and JD 8 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 showed considerably lower root biomass under water stress but it also showed higher membrane stability and lower osmotic potential.

2.6 Effect of drought-stress on dry matter production:

Biomass production decreases due to water shortage in cereal crops (Turner *et al* 1986). Puckridge and O'Toole (1981) have shown that biomass production of rice is function of water use. The shortage of water in the soil suppress leaf expansion, tillering and photosynthetic rate along with leaf area due to senescence. All these factors are reasonable for reduction in dry matter accumulation.

Lilley and Fukai (1994) found that water deficit is known to retard phenological development. Four contrasting rice cultivars (CPIC 8, Lemont, Riknto-Norin 12 and todoroki wase) were subjected to water deficit during either vegetative or reproductive growth stages. Biomass production during water deficit was less than 56% 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.) was investigated at 100, 80, 60 and 40% of water holding capacity. Results revealed that improved cv. Vandana transpired less water and exhibited higher stomatal diffusive resistance than the traditional cv. Brown gora under stressed conditions. The effect of moisture stress became more apparent during later period of stress when water was applied at 60 and 40% of water holding capacity. The reduction was 67.3% and 40.3% in dry matter accumulation and 53.4 and 54.4% in leaf area at 40% water holding capacity as compared to 100% water holding capacity in Brown gora and Vandana, respectively at 35 days after stress imposition.

Lu. *et al.* (1998) worked on two varieties of rice Shanyon-63 (Indica hybrid) and ganging-2 (Japonica normal cultivar). Water deficit treatment were imposed in the whole growth period and it was found that increasing soil water deficit progressively decreases the dry matter production. The sensitivity of different plant organs to water stress in terms of dry matter accumulation was in the order of stem>sheath>leaf. Higher rate of dry matter translocation from stem and sheaths were found in Shanyon-63, where in Ganjing-2 such a translocation was observed only in the most severe water stress conditions.

Chauhan *et al.* (1999) reported that in a field trial, rice cv. Brongora and Vandana, when subjected to water stress at booting or anthesis stages. The results showed that total dry matter production was reduced significantly in both the cultivars. Banoc *et al.* (2000) examined dry matter production, root development and water use to changing soil moisture in diverse rice cultivars and found that progressive drought, right after planting greatly inhibit the shoot dry matter production, tiller development nodal root development and water uptake in all tested cultivars.

2.7 **Effect of drought stress on root growth:**

Rice frequency suffers from water stress because it lacks deep roots (Hsiao *et al.* 1980). Large variation exists for root depth in rice, but it typically has a large root density in the surface soil relative to other crops (Yoshida and Hasegawa 1982). In the absence of rainfall and irrigation, biomass production is a function of extractable soil water and this is related to the rooting pattern of the cultivar (Puckridge and O Toole 1981). Therefore severity of drought and its effect on crop growth and grain yield are determined by the water extraction capability of the cultivar.

Reddy and Kuladaivelu (1992) reported the influence of different soil moisture regime on root growth of rice. The proportion of roots in the total biomass of plant at tillering was 28 per cent and gradually decreased to 15 per cent at flowering. Root volume and root dry weight were higher under continuous submergence. Soil strength was 0.2 kg/cm^2 with submergence and 20.0 kg/cm^2 with moisture level ranging from field capacity to 50 per cent depletion of available soil moisture.

Lilley and Fukai (1994) reported the ability of a plant to extract soil water during water deficit. Rooting pattern and soil water extraction 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, CPIC 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. Total root length, root length density and water extraction were similarly ranked among cultivars (CPIC 8 > Lemont > RN > TW).

Banoc *et al.* (2000) examines the responses of two different types of lateral roots, the generally long, thick 'L' type, capable of branching 'S' type. When the plants were grown under drought conditions, then rewatered, the seminal root system development in terms of dry weight and total length was promoted as compared with plants grown under continuously well water conditions in IRAT 109 and Dular, drought tolerant cultivars. Promoted production of 'L' types lateral roots mainly contributed to the development of the longer seminal root system. However in KDML 105, a drought, tolerant cultivar, the production of especially 'L' type laterals was substantially promoted under drought and rewatered conditions and there was a great reduction in root length when soil moisture becomes limited.

Kamoshita *et al.* (2000) reported that soil water extraction in relation to root system development with eight rice genotypes. The time course of cumulative soil water extraction from layers between 5 and 45 cm estimated by time domain reflectometer (TDR). The level of the TDR estimated water extraction was 75 per cent of the cumulative transpiration, and their coefficient if determination between the two was 96 per cent. The extraction rate in the sub soil was positively correlated with the average root length density at the corresponding depth during the latter half of the drought period, explaining 66 per cent and 58 per cent of the variation around the 30 cm and 40 cm depth respectively. Mahsuri and IR 58821 had higher water extraction rate from the subsoil layers than IR 20 and IR 62266 during the later drought period.

2.8 Role of flag leaf in contribution to yield and its stability:

The flag leaf is considered different from other leaves because of its prominent role in starch formation and grain filling. Grain yield is positively correlated with flag leaf area (Padmaja Rao 1991). However, little efforts have been made to find out the time upto which flag leaf really contributes towards grain yield. The contribution to grain yield from flag leaves becomes more prominent under drought. The reduction in flag leaf area under drought can effect the grain yield.

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 gave the higher grain yield. There was a marked improvement in grain yield in all varieties as the flag leaf removal was delayed. In all varieties a marked increase in spikelet fertility was observed with delay in process of flag leaf removal. The spikelet sterility percentage was low in tall traditional varieties than in semi-dwarfs.

Sen *et al.* (2000) studied on 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. pushpanjali and indicated 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. Grain yield was minimum at 0 DAE of defoliation, which was significantly less than control. N, P and K contents in grain and straw were also highly affected due to defoliation during initial stages. It seemed the critical period of flag leaf duration was only upto the 4-6 days of panicle emergence.

2.9 Effect of water stress on leaf area:

The primary effect of drought is mostly on expansive growth which has been defined as irreversible cell enlargement. The expansive growth control leaf area development which provides the means for intercepting the light and carrying out photosynthesis and ultimately dry matter production.

Boyer (1968) observed that leaf enlargement can be reduced by only small degree of desication, generally long before stomatal closure and photosynthesis is affected. In determinate crops where leaf area is fixed at flowering, yield under drought conditions has been generally related to the rate of leaf senescence after flowering (Ludlow 1975). Most of the reduction in leaf area due to lower leaf water potential appears to be the consequence of slowed cell enlargement. Cell division and cell expansions are coordinated in the plant and prolonged suppression of expansion may restrict the potential size of a leaf (Hsiao *et al*, 1976).

2.9.1 Membrane stability under drought stress:

Membrane stability has been associated with water and high temperature stress tolerance in various crop plants (Sairam, 1999). Lower membrane stability or higher injury reflects the extent of lipid peroxidation (Dhindsa *et al.*, 1981) which in turn is a consequence of higher oxidative stress due to various environmental stress. Premchandra *et al.* (1990) reported that lower cell membrane stability can be the cause of higher yield reduction in susceptible genotypes of wheat (Sairam *et al.*, 1999).

2.9.2 Effect of drought-stress on grain yield:

There are numerous reports in the literature showing that water deficits limit yield (Turner, 1979). The degree of yield reduction by a water deficit will depend on the degree, duration and timing of the deficit and on the proportion of the total yield that comprises the economic yield of the crop (Fischer and Kohn, 1966). The components of yield that are influenced by water stress depend largely on the timing of stress in relation to development of the promotion of the plant utilize for the economic yield (Begg, Turner, 1976).

Nayak *et al.* (1974) reported that in three varieties of rice i.e. Padma, Jamuna and IR-8, drought during the flowering stage caused severe reduction in 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. Sahu and Rao (1974) found that all the three rice plant type, Tall-Indica, PTB-10, Dwarf-Indica, Jaya and Japonica-Indica ADT-27 are adversely affected by soil moisture stress. Stress during the grain filling and ripening phases resulted in death of ear-bearing tillers, reduction in the number of filled grains by 20 to 40 per cent in Tall-Indica and Japonica-Indica and 80 percent in Dwarf-Indica and in yield from 12 to 15.4 per cent depending upon the plant type.

Row and Venkateshwarle (1983) noticed a decrease in yield components of Rasi and IR-20 with moisture stress. The reproductive and ripening phases were vulnerable and crucial for moisture stress, which resulted in permanent damage to growth and yield factors. Ripening phases appeared to be crucial and irreversible. Rasi showed its superiority for moisture stress during ripening phase compared to IR-20.

Kumar *et al.* (1987) reported the pattern of pre anthesis and post anthesis contribution of assimilates to grain yield differed markedly between durun and aestivum wheats. The pre anthesis contribution to grain yield increased with moisture stress. The pre anthesis contribution to grain yield was markedly higher in cv. WH-147 under non-irrigated condition as compared to P-1200 and DWL-5023.

Bhardwaj *et al.* (1987) reported in wheat cv. Kalyan Sona and C-306, water stress treatments during grain elongation and maturation phases reduced the weight of grains present in the basal position within the spikelets of the middle region of the ear to a lesser extent than that of the distally located grains in basal and apical regions. These differences appear to be related with the vascular supply of assimilates reaching the grain.

Sharma (1989) reported that moisture stress significantly lowered the grain yield and its components in rice composed to well water controls. Sairam *et al.* (1990) observed the effect of moisture stress imposed at tillering and anthesis stages on four drought susceptible (HD-2329, HD-2001, WL-711 and WH-147) and four drought tolerant (C-306, NI-5439, Pissi local and DL-153-2) genotypes of wheat and reported that grain yield decreased under moisture stress. Tolerant genotypes generally had higher grain yield than the susceptible genotype.

Lilley and Fukai (1994) reported that water deficit retard phenological development and consequently grain yield. Four contrasting rice cultivars (CPIC 8, Lemont, Rikhto-Norin 12 and Todoroki-wase) were subjected to water deficit during either vegetative or reproductive growth stages and reduced grain yield to 20-27% compared to the irrigated control. A small growth rate during panicle development after water deficit reduced grain number and potential grain size, while cultivars which recovered quickly after water deficit had a relatively larger grain yield.

Ravichandran and Mungse (1997) studied the effect of moisture stress at critical growth stages on yield and yield components and observed that the moisture stress at any of the critical growth stages decreases the yield contributing character. The grain yield reduced by 17.73% at flowering stage drought as compared to control followed by grain filling (10.96%) and tillering (9.06%).

Lai *et al.* (1998) reported that grain yield decreased due to water deficit. Water deficits affected panicle numbers and grain number per panicle in lowland rice, while panicle number and percentage grain filling were reduced in upland rice. Costa and De-costa (1998) reported that under drought conditions the leaf area and carbon assimilation decrease and it results in reduction of yield. Xu *et al.* (1998) imposed the drought in rice at the heading and seed setting stage. They observed that filled grains per panicle, seed setting rate, test weight and grain yield decreases due to moisture stress.

Chauhan *et al.* (1999) in a field trial, rice cv. Brongora and Vandana were subjected to water stress at booting or anthesis stages. The grain yield was significantly reduced due to drought in both the varieties. The decrease in yield was related with reduction in single grain weight, total dry matter and harvest index.

Park *et al.* (1999) investigated the influence of soil moisture stress at different growth stages, on the yield and quality of rice in the cultivars Japonica and Dongjinbyes. The above varieties were subjected to soil moisture stress at five growth stages until the initial wilting point (about 10% soil moisture content) and was then reirrigated. At maturity the plant height, leaf area, tiller numbers, spikelet numbers per panicle and panicle number per hill was reduced significantly due to moisture stress. All these characters were found responsible for decrease in grain yield under drought.

Materials and Methods

CHAPTER III

MATERIALS AND METHODS

The studies entitled **"Effect of reproductive stage drought on rice physiology"** were carried out at the Agricultural Instructional Farm of Indira Gandhi Agricultural University, Raipur (C.G.) during the Kharif (wet) season of 2000. The materials used and methodology adopted in the investigation are described below:

3.1 Geographical location:

Raipur is situated in the central part of Chhattisgarh and lies at 21 16'N latitude and 81 36' E longitude and at an altitude of 293 m above the mean sea level.

3.2 Climate:

Raipur is located in the dry, subhumid agroclimatic region. The annual rainfall of this region ranges between 1200-1400 mm, of which about 85 per cent is received from third week of June to mid of September and very little during October and February. May is the hottest month and December the coolest at Raipur. The maximum temperature of this region may reach as high as 46 C during summer season. The atmospheric humidity is high from June to October. The highest day temperature during the crop season was recorded between 27.2 C to 34.8^{o}C. The experimental crop received the sunshine hours from 2.3 to 9.8 hours per day. The maximum and minimum humidity during the crop period was

92 and 17 per cent respectively. The highest rainfall was recorded during July (295.3 mm) and lowest in September (56.1 mm).

3.3 Site characterization:

For site characterization plow layer soil samples (0-10 cm) were taken with a soil auger before starting the experiment. The samples were air dried, grinded, sieved (2 mm sieve) and used for the following chemical analysis. The pH was determined by glass electrode pH meter in soil water suspension 1:2 (Piper, 1950). Electrical conductivity was determined by the supernatant liquid of soil water 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 samples from 0-10, 10-20 and 20-30 cm depths were collected by undisturbed core sampler. Bulk density was calculated by recording oven dry weight of soil and volume of core. Soil texture (Sand, silt and clay percent of soil) was determined by using International Pipette method (Piper, 1960).

Experimental soil characterization:

Characteristics	Value
Available N	243 kg/ha
Available P	13 kg/ha
Available K	318 kg/ha

pH (1.2 soil : water)	7.21
Electrical conductivity	185 μS/cm
Organic carbon	0.35%
Sand	31.4%
Silt	35.8%
Clay	32.8%
Soil texture class	Clay-loam
Soil order	Alfisol

3.4 Varieties tested:

Table 1 : Details of varieties included in the studies

Variety	Origin	Duration (days)	Yield potential (q/ha)	Remarks
Indira A-9	Raipur (C.G.), India	130	40	Improved, photo-insensitive
Kranti	Raipur (C.G.), India	128	55	Improved, photo-insensitive, semi tall, drought tolerance, low land cultivar
Mahamaya	Raipur (C.G.), India	128	60	Improved, photo-insensitive, semi tall, BLB and gallmidge resistance
R-405-A-4	Raipur (C.G.), India	130	45	Improved, long slender grain, photo insensitive
R-827-287	Raipur (C.G.), India	135	40	Improved, very fine grain, variety photo insensitive
Shyamla	Raipur (C.G.) India	130	35	Purple colour, used to eradicate wild rice

3.5 Cultural operations:

3.5.1 Raising the nursery:

Well pulverised raised nursery beds were prepared. The size of each nursery beds was 1 x 0.25 m, drainage channel of 30 cm width was provided between beds. The basal application of fertilizers was given at the time of nursery bed preparation at the rate of 80 kg N, 60 kg P_2O_5 and 40 kg K_2O per ha. The seeds were treated with organomercurial fungicide before sowing in nursery. The seeds were sown in the raised nursery bed by hand drilling method in rows. The seeds were thoroughly covered upto the top 2 to 3 cm. Light and frequent irrigation were given until the seedling were transplanted.

3.5.2 Field preparation for transplanting:

The experimental field was prepared by giving cross-ploughing by cultivator after impounding about 5 cm standing water in the field. Puddling was done by tractor puddler followed by datari for proper levelling. The experiment was laid out in the field, with the help of tape, rope and bamboo pegs. The field was divided into three replications. Each plots and replication were demarcated with the help of check bunds.

3.5.3 Fertilizer application:

The fertilizer was applied at the rate of 100 kg, 50 kg and 30 kg per hectare of N, P and K respectively. Whole amount of phosphorus and potassium was applied as basel dressing. The half nitrogen was applied as basel dose and rest half was applied in two split doses after 30 and 50 days of transplanting respectively.

3.5.4 Transplanting:

Twenty days old seedling were transplanted in the field. The transplanting was done by using 20 x 20 cm spacing.

3.5.5 Water management:

After transplanting the soil was kept saturated until planted seedlings get established. This was judged by the emergence of new leaves. After seedling establishment 5 ± 2 cm water level was maintained in the irrigated plot. In drought plots irrigation was stopped to impose drought after fifteen days of PI stage.

3.5.6. Weed management:

The crop was kept weed free throughout its growth period to avoid crop weed competition. The weeds were removed from the plots manually as and when required.

3.5.7 Plant protection:

Plant protection measures were adopted as and when needed during the crop period. Incidence of paddy case-worm, cutworm and stem sheath rot were observed during crop season. The necessary plant protection measures were adopted to control the insect pest and disease.

3.6 Experimental details:

The studies were conducted by using split plot design. The main plot treatment was water regime (irrigated and drought from fifteen days after panicle initiation) and sub plot treatment was varieties (six.). The experiment was conducted with three replicates. The size of main plot and sub plot was 70.4 m^2

and 9.6 m^2, respectively. The varieties were staggered in the nursery to match the phenological stages during the experiment. The staggering was done on the basis of last three years phenological data obtained from Breeding Department of IGAU, Raipur. A distance of 4 meters were kept between plots and replications to stop the water movement from one plot to another. Rain out shelters were installed to protect the drought plots from rains. Rain out shelters were made by using transparent polythene sheet. All the sides of these rain out shelters were kept open except during rains to provide free aeration and to stop temperature rise in plots. These rainout shelters was installed about from fifteen days after panicle initiation stage till maturity in drought plots. The observations were recorded at flowering, fifteen days after flowering and at maturity stages.

3.7 **Observations:**

The following observations were recorded at flowering, 15 days after flowering and at maturity from the irrigated and drought plots.

3.7.1 **Dry matter production and its partitioning into various plant parts:**

Above ground dry matter was estimated at above mentioned three stages. Six hills were destructively harvested for the estimation of dry matter production and its partitioning into various plant parts. The leaves (green and dry), stem and panicle were separated and was kept for dry matter estimation in hot air oven at 70°C. The dry matter was recorded when constant dry weight was observed. Care was taken that the area sampled is representative of the plot and the harvested area is at least three rows of plants away from the border and other previously harvested areas in the plot. The dry matter was expressed as g/m^2.

3.7.2 Phenology:

Panicle initiation : For estimation of panicle initiation stage, plants were uprooted and main culm was dissected form the base and was seen by magnifying lense. When a silky appearance was observed at the base, it was considered as panicle initiationstage.

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 50 per cent flowers were appeared.

3.7.3 Photosynthesis, stomatal conductance and transpiration:

Photosynthesis, stomatal conductance and transpiration were measured with the help of a portable photosynthesis system (Licor, U.S.A. LI-6400) between 0930 hours to 1030 hours on clear sky day. Photosynthesis and associated parameters were estimated in the three centre rows of the sub plot. These observations were recorded in the flag leaf of the mother shoot from irrigated and drought plots. Five observations were recorded from each subplot. The photosynthesis, stomatal conductance and transpiration was expressed as μ mol $m^{-2}s^{-1}$, mol $m^{-2}s^{-1}$ and m mol $m^{-2}s^{-1}$, respectively.

3.7.4 Plant height:

The maximum height of the plant was measured with the help of scale at maturity stage. It was expressed in cms.

3.7.5 **Flag leaf area:**

Upper most fully expanded leaf of the mother tiller was used for the estimation of flag leaf area at flowering stage. The length and maximum width of the flag leaves were recorded at flowering stage. The flag leaf area was expressed as cm^2.

3.7.6 Leaf area index:

Six hills were harvested for measurement of LAI. From these hills, six 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 present 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. The green leaves of mother tiller were dried separately. A factor of 0.75 (at flowering and 15 days after flowering) and 0.67 (at maturity) was used to calculate the leaf area.

The leaf area was calculated as follows:

$$\text{Leaf area} =- \quad \begin{matrix} & W \\ w & \end{matrix}$$

where, A = Length x width x factor

W= Dry weight green leaves from all tillers including mother tiller.

w= Dry weight of six mother tillers green leaves

Leaf area index was calculated as follows:

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

3.7.7 **Root dry weight measurement:**

Root dry weight of the plants were determined by taking the duplicate root samples from 0-10, 10-20 and 20-30 cms soil depths by using a undisturbed core sampler. The shoot portion of the plants was cut off at the ground level. Then the undisturbed root core samples 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 and then dry weight were recorded on an electronic balance. Root dry weight was expressed as grams/ hill.

3.7.8 Measurement of leaf water potential:

Leaf water potential was measured with the help of a portable pressure chamber (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 the mother tiller. Three observation were taken from each treatment.

After taking the observation like photosynthesis, stomatal conductance and transpiration, the leaves were removed from the plant and was used for measuring water potential. Leaves were kept in butter paper bags and then in polythene envelope, kept in ice box. This was done to check further reduction in leaf water potential. The leaf was then 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 the pressure was stopped and the water potential was recorded directly from the gauge. The pressure was then released and the leaf was taken out of the chamber. The water potential was expressed as bars.

3.7.9 Membrane stability:

Leaf membrane stability index (MSI) was determined according to the method of Premachandra *et al.* (1990) as modified by Sairam (1994). Leaf disc (0.1g) were thoroughly washed in running tap water and double distilled water. After washing leaves were placed in double distilled water at 40°C for 30 minutes. After that the electric conductivity (C_1) of the sample was recorded by conductivity bridge (Elico India, Model CM-180). Subsequently the samples were placed in boiling water bath (100°C) for 10 minutes and electrical conductivity was recorded as above (C_2). The membrane stability index (MSI) was calculated as: $MSI = [1 - (C_1/C_2)]\ 100$

3.7.10 Measurement of yield and its attributes:

A total of 9.6 m^2 area was harvested for yield measurement. The yield attributes were estimated from the six hills. All the panicles from six hills were threshed. The filled and unfilled grains were separated and counted. The weight of the filled and unfilled grains were recorded separately.

t The yield attributes were calculated by using the following formulas

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

$$\text{ii. Test weight} = \frac{\text{Filled grains weight per six hills}}{\text{Filled grains number per six hills}} \times 1000$$

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

3.7.11 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/ meter square.

3.7.12 Apparent translocation rate:

Apparent translocation rate from stem was estimated as follows:

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

3.7.13 Soil moisture:

Soil moisture contents were measured during stress period by taking duplicate soil samples at depths of 0-10, 10-20, and 20-30 cm. The fresh weight of the soil was noted. After that the soil were dried in an oven at 100°C upto the constant weight. The gravimetric soil moisture was determined as follows

$$\text{Soil moisture } (\%) = \frac{\text{Fresh weight - Dry weight}}{\text{Dry weight}} \times 100$$

The volumetric soil moisture content was calculated by multiplying the bulk density with the gravimetric soil moisture.

Harvesting:

The experimental plots were harvested by manual labour. The harvested crop was allowed to dry in the field for three days. Paddle thresher was used to thresh the crop of individual plot manually. The grain yield of each plot was recorded separately. The yield was corrected at 14 per cent moisture.

Results

CHAPTER-IV

RESULTS

4.1 Dry matter production and its partitioning into various plant parts at flowering stage:

The data pertaining to dry matter production and its partitioning into various plant parts at flowering have been presented in Table 2. The result showed that total dry matter production between irrigated and drought plots were statistically at par however, varietal differences were recorded significant. The green leaf dry matter was recorded significantly lower in drought conditions as compared to irrigated conditions while, the dry leaf dry matter, stem dry matter and panicle dry matter was statistically at par between two water regimes.

Under irrigated conditions total dry matter was recorded highest (840.53 g/ m^2) in R-405-A-4 which was statistically at par with Indira A-9 and R-827-287. The dry matter production under irrigated conditions was recorded lowest in Shyamla (488.92 g/ m^2) which was statistically at par with Kranti.

The green leaf dry matter under irrigated conditions was produced highest by R-405-A-4 (172.28 g/ m^2) which was statistically at par with Indira A-9. The green leaf dry matter under irrigated conditions was recorded lowest in Kranti (118.36 g/ m^2) which was statistically at par with Mahamaya and R-827-287. Drought significantly decreases the green leaf dry matter and such a decrease was lowest in Mahamaya as compared to other varieties. The reduction in green leaf dry matter due to drought was observed highest (26%) in Indira A-9 compared to other varieties.

Table 2 : Dry matter production and its partitioning into various plant parts under irrigated and drought conditions at flowering stage

Water Regime	Variety	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	Indira A-9	166.53	102.08	374.44	113.50	756.56
	Kranti	118.36	53.83	308.92	105.44	586.56
	Mahamaya	118.95	73.62	368.64	144.71	705.50
	R-405-A-4	172.28	85.11	429.64	153.50	840.53
	R-827-287	120.78	97.59	312.80	176.59	709.37
	Shyamla	139.72	48.58	167.56	133.06	488.92
W-mean		139.44	76.80	326.93	137.81	681.23
Drought	Indira A-9	123.14	114.89	302.22	70.06	610.31
	Kranti	111.92	56.30	327.94	86.17	582.33
	Mahamaya	115.41	73.03	351.67	101.67	641.78
	R-405-A-4	166.43	91.14	379.56	104.81	741.93
	R-827-287	112.60	128.25	272.99	166.31	680.17
	Shyamla	135.47	63.33	159.44	120.80	479.05
W-mean		127.50	87.82	298.97	108.30	622.60
CD (5%)	W	7.14	NS	NS	NS	NS
	V	30.12	24.88	72.07	NS	133.31
	(W x V)	NS	NS	NS	44.01	NS
	(V x W)	NS	NS	NS	NS	NS

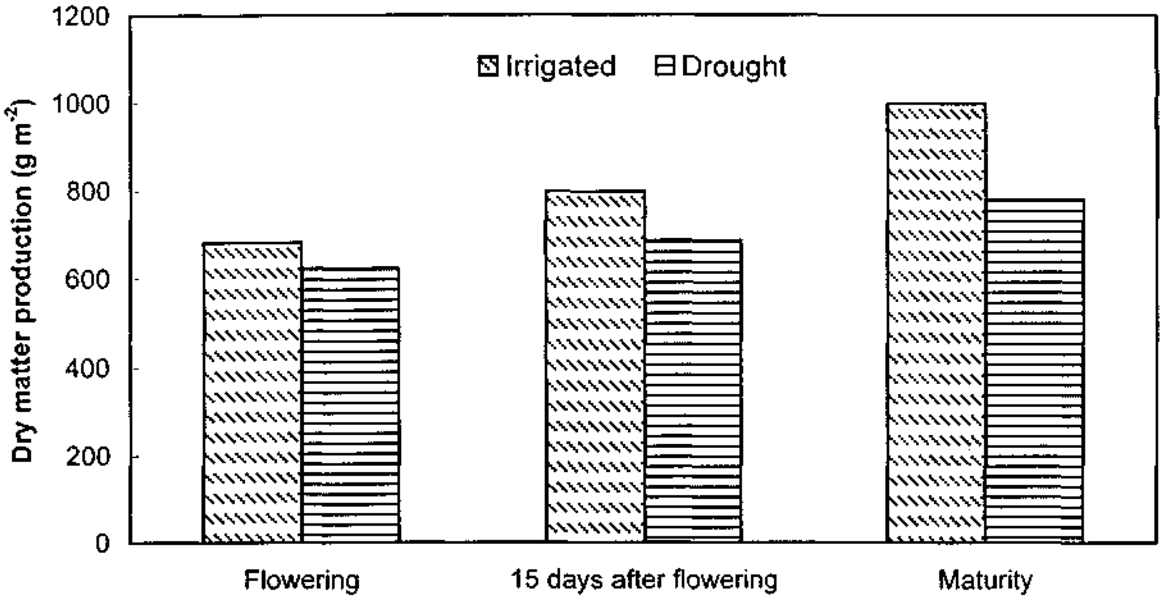

Fig. 1 (a) : Total average dry matter production under irrigated and drought conditions

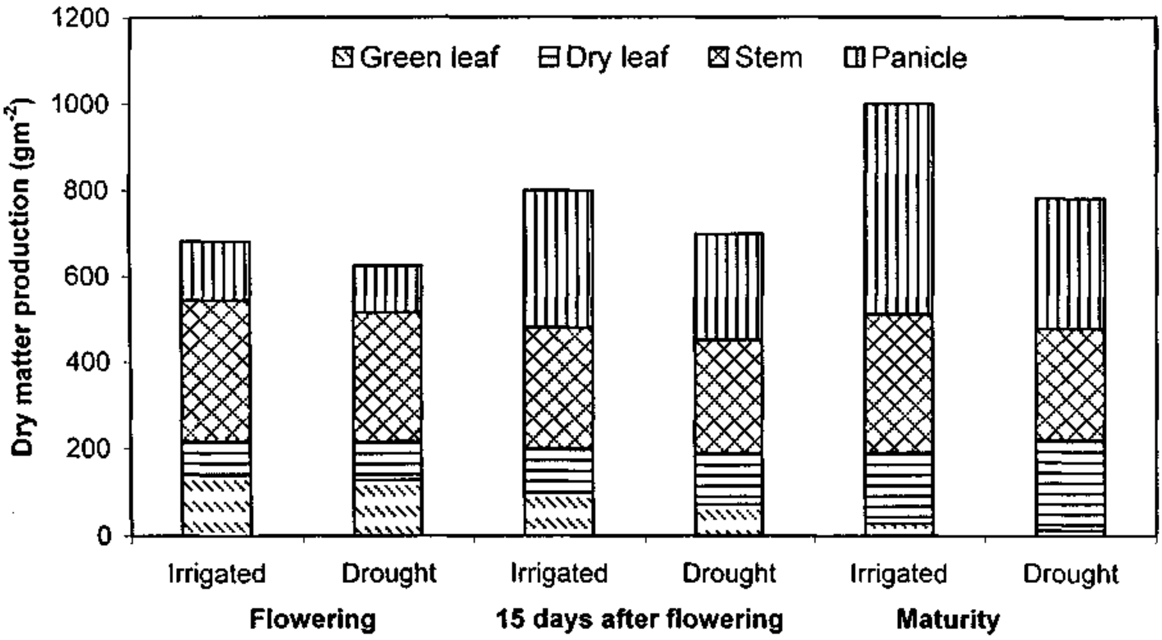

***Fig.1(b)* : Average dry matter partitioning into various plant parts under irrigated and drought conditions**

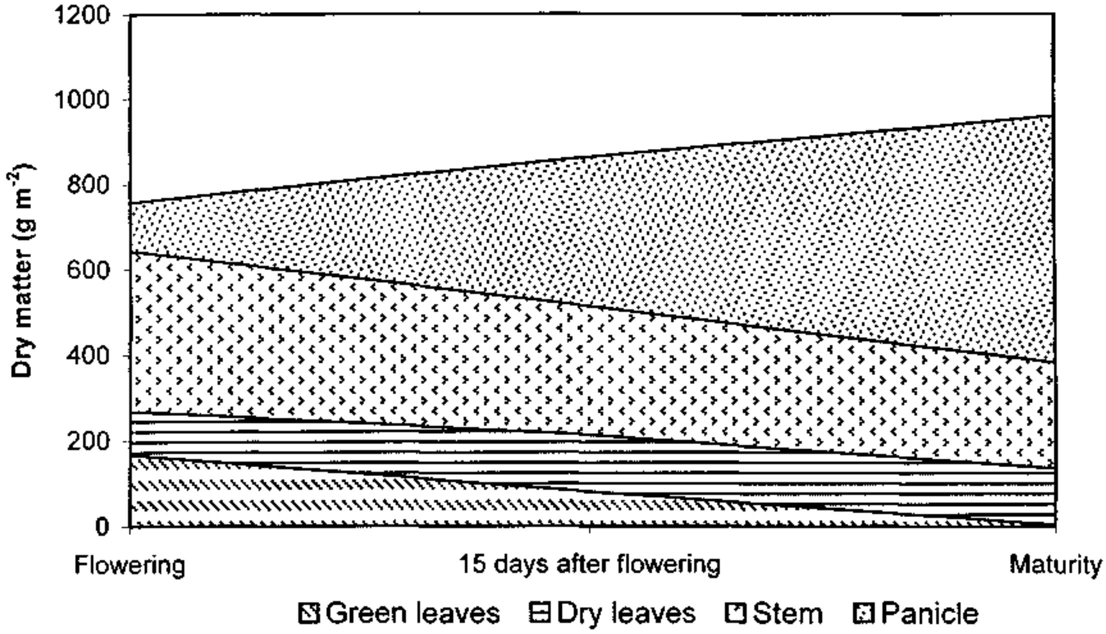

Fig. 2(*a*): Dry matter partitioning in Indira A-9 under irrigated conditions at various stages

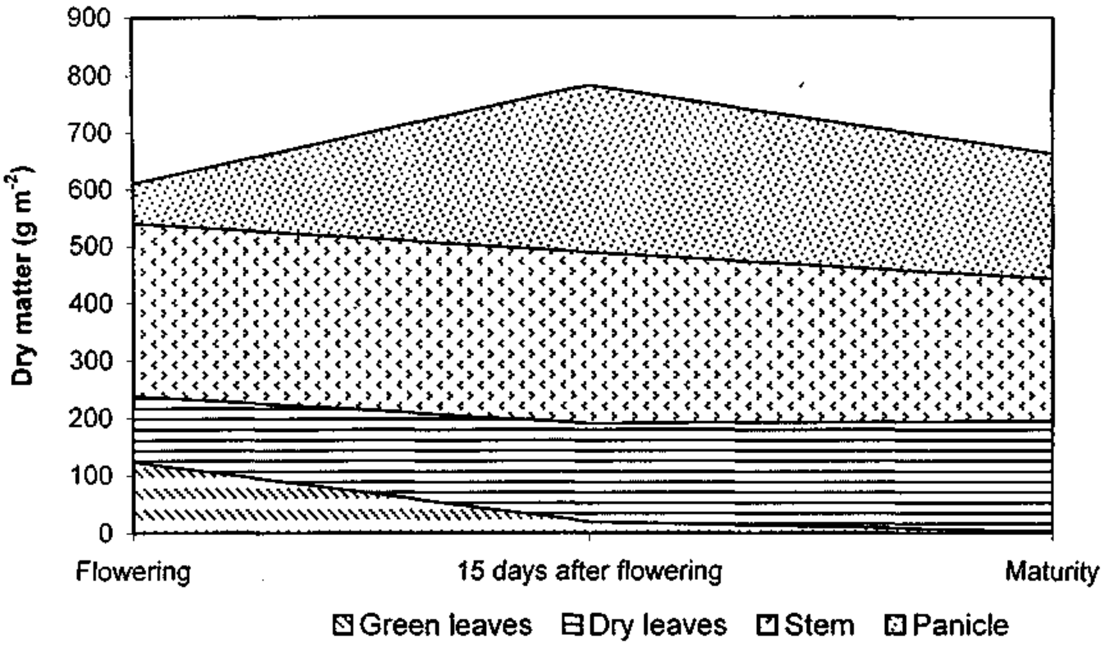

Fig.2(b): Dry matter partitioning in Indira A-9 under drought conditions at various stages

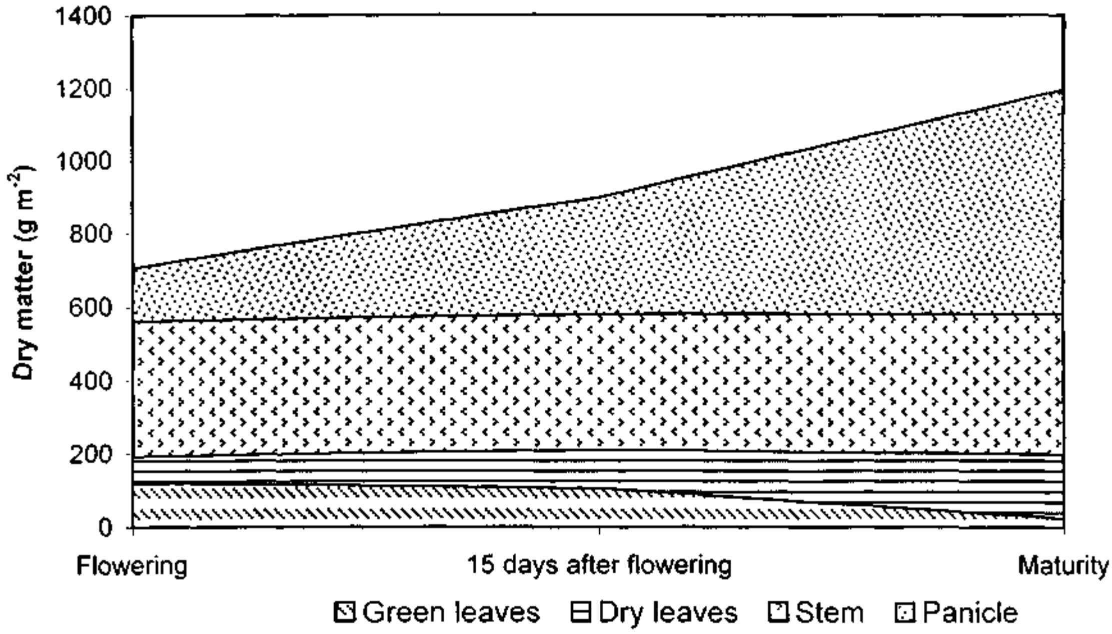

Fig.3(a): Dry matter partitioning in Kranti under irrigated conditions at various stages

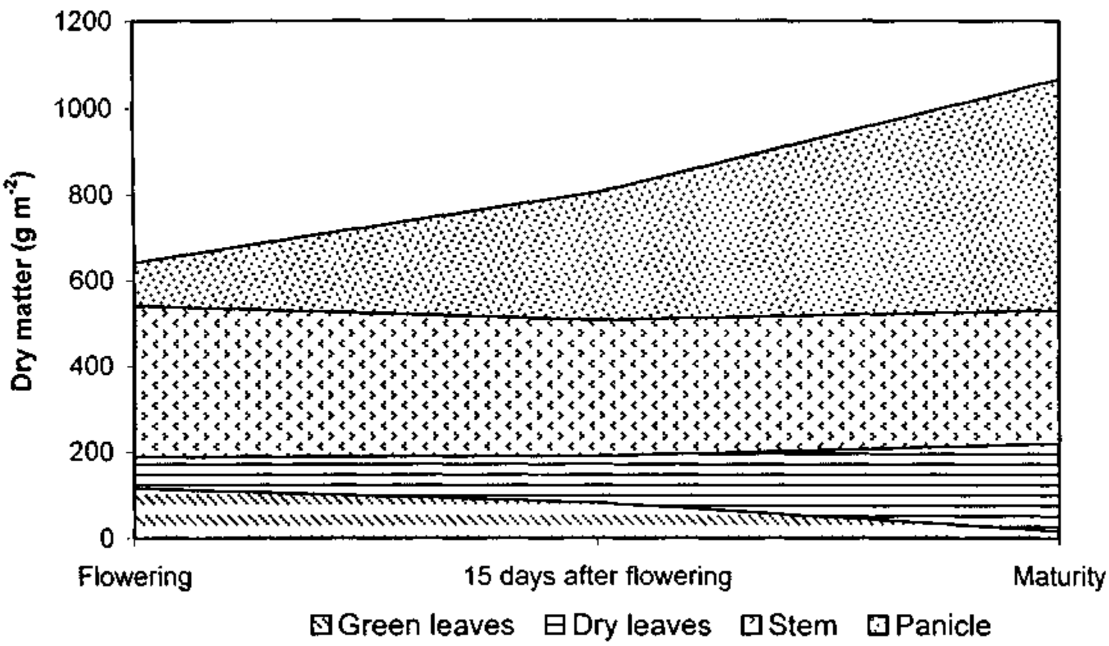

Fig.3(b): Dry matter partitioning in Kranti under drought conditions at various stages

The dry leaf dry matter between water regimes was not significant while the varietal differences were significant. Under irrigated conditions Indira A-9 produced highest dry leaves compared to other varieties. The increase in dry leaves due to drought was observed higher in R-827-287, Indira A-9 and Shyamla compare to other varieties.

The stem dry matter accumulation under irrigated condition was observed maximum in R-405-A-4 (429.64 g/ m^2) and it was at par with Indira A-9 and Mahamaya. Shyamla accumulates lower dry matter in stem compare to other varieties under irrigated conditions. Drought decreases the stem dry matter production however the decrease was not statistically significant. Kranti accumulates higher dry matter under drought in stem compare to irrigated conditions. Such an increase in stem dry matter under drought was not observed in other varieties.

Panicle dry matter was recorded highest and lowest in R-827-287 and Kranti respectively under irrigated conditions. Drought decreases the panicle dry matter in all the varieties however the decrease was not statistically significant. The reduction in panicle dry matter due drought was recorded highest (38%) in Indira A-9 compared to other varieties.

4.2 Dry matter production and its partitioning into various plant parts after fifteen days of flowering:

The results on dry matter production and its partitioning into various plant parts have been presented in Table 3. Under irrigated conditions total dry matter production was recorded highest in R-405-A-4 (938.49 g/ m^2) and lowest in Shyamla (690.28 g/ m^2). Drought significantly decreases the total dry matter

Table 3 : Dry matter production and its partitioning into various plant parts under irrigated and drought conditions after 15 days of flowering

Water Regime	Variety	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	Indira A-9	80.26	132.47	300.44	349.75	862.93
	Kranti	78.75	76.62	243.95	294.87	694.20
	Mahamaya	105.03	105.28	369.53	318.64	898.47
	R-405-A-4	143.24	105.65	354.34	335.16	938.39
	R-827-287	66.37	109.70	226.24	296.78	698.43
	Shyamla	121.19	71.06	182.39	315.64	690.28
W-mean		99.14	100.13	279.48	318.47	797.12
Drought	Indira A-9	19.49	171.21	298.19	293.98	716.21
	Kranti	76.16	78.01	220.97	238.46	613.61
	Mahamaya	82.22	107.92	316.58	298.16	804.86
	R-405-A-4	113.78	135.44	357.92	173.39	780.53
	R-827-287	53.94	112.14	213.87	246.53	626.19
	Shyamla	88.56	94.35	165.87	226.67	575.54
W-mean		72.36	116.51	262.19	246.21	686.16
CD (5%)	W	NS	6.17	NS	NS	55.30
	V	38.96	23.72	87.13	NS	155.24
	(W x V)	NS	NS	NS	NS	NS
	(V x W)	NS	NS	NS	NS	NS

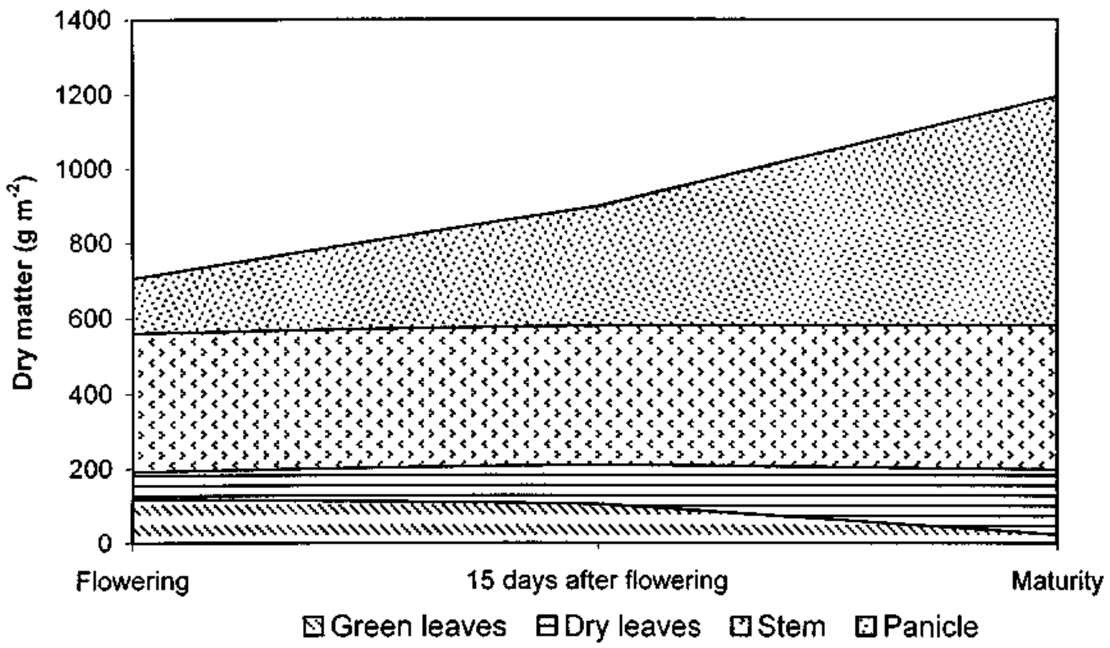

Fig. 4(a): Dry matter partitioning in Mahamaya under irrigated conditions at various stages

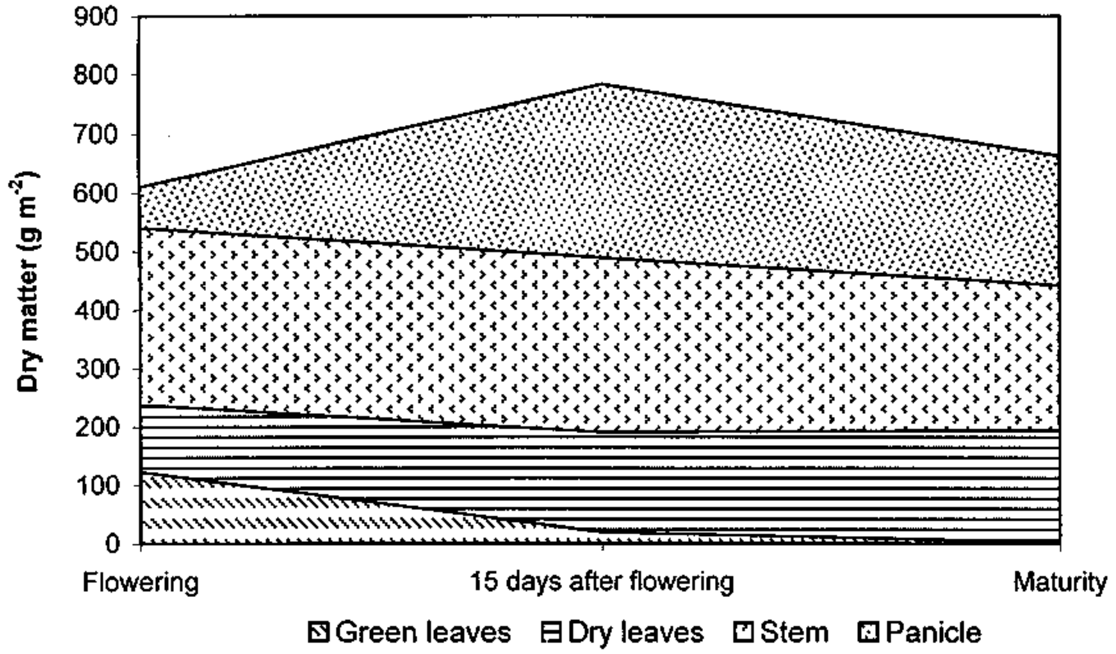

Fig.4(b): Dry matter partitioning in Mahamaya under drought conditions at various stages

Fig.5(a): Dry matter partitioning in R-405-A-4 under irrigated conditions at various stages

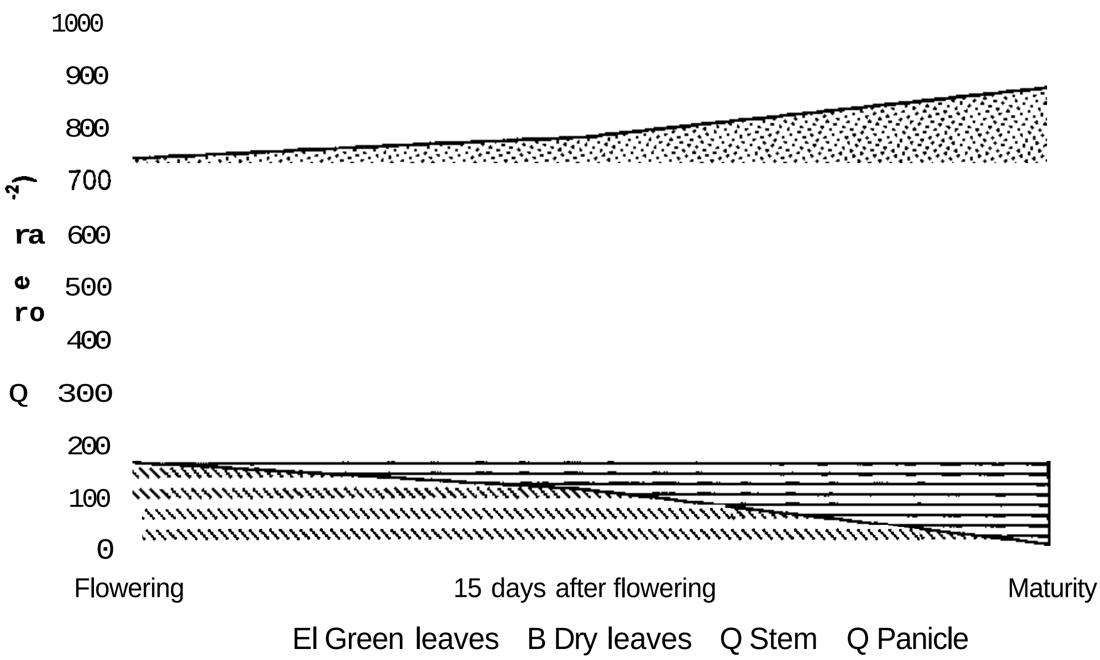

Fig.5(b): Dry matter partitioning in R-405-A-4 under drought conditions at various stages

production. The reduction in total dry matter due to drought was recorded significantly higher (17%) in Indira A-9 compared to other varieties.

The green leaf dry matter was observed highest in R-405-A-4 (143.24 g/ m^2). Drought reduces the green leaf dry matter. The highest reduction (75%) in green leaf dry matter was recorded in Indira A-9 while, the reduction was only three per cent in Kranti. Dry leaf dry matter was observed significantly higher in Indira-A-9 as compared to other varieties under irrigated conditions. Drought stress significantly increases the dry leaf dry matter production. Such increase in dry leaf was highest (32.78%) in Shyamla and lowest (1.81%) in Kranti.

Stem dry matter in irrigated plots was recorded highest in Mahamaya (369.53 g/ m^2) and lowest in Shyamla (182.39 g/ m^2). The stem dry matter between irrigated and drought plots were not observed significantly different however, the varietal difference was significant. The panicle dry matter was maximum in Indira-A-9 and minimum in Kranti, respectively under irrigated conditions. Drought reduces the panicle dry matter, however the reduction was not significantly different. The reduction in panicle dry matter was highest (48.26%) in R-405-A-4 compare to other varieties.

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

Data presented in Table 4 indicates that green leaf dry matter was 4.63 g/ m^2 in Indira A-9 while, it was 62.06 g/ m^2 in R-405-A-4. Drought stress significantly reduces the green leaf dry matter. Such a reduction was recorded highest (81.49 g/ m^2) in R-405-A-4 while, the reduction was only 20.87 per cent in Shyamla. The dry leaves under irrigated conditions was observed highest in R-

Table 4 : Dry matter production and its partitioning into various plant parts under irrigated and drought conditions at maturity stage

Water Regime	Variety	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	Indira A-9	4.63	131.17	247.09	578.04	960.92
	Kranti	28.88	128.53	310.71	418.56	877.67
	Mahamaya	23.46	173.94	384.24	613.75	1192.06
	R-405-A-4	62.06	237.67	471.94	522.23	1293.87
	R-827-287	14.21	175.88	264.29	463.24	917.61
	Shyamla	38.18	120.61	249.42	340.29	748.51
W-mean		28.57	161.30	319.78	489.35	998.44
Drought	Indira A-9	2.54	192.39	247.81	220.26	663.00
	Kranti	8.83	202.29	211.55	367.00	789.67
	Mahamaya	16.43	202.69	310.70	536.08	1065.91
	R-405-A-4	11.49	252.35	347.00	264.14	874.97
	R-827-287	6.27	210.17	237.61	236.25	690.29
	Shyamla	30.21	182.57	189.65	192.53	594.96
W-mean		12.63	207.08	257.39	302.71	779.80
CD (5%)	W	8.95	NS	51.09	142.36	135.33
	V	6.10	40.53	69.24	89.31	134.96
	(W x V)	8.63	NS	NS	126.31	NS
	(V x W)	18.55	NS	NS	277.20	NS

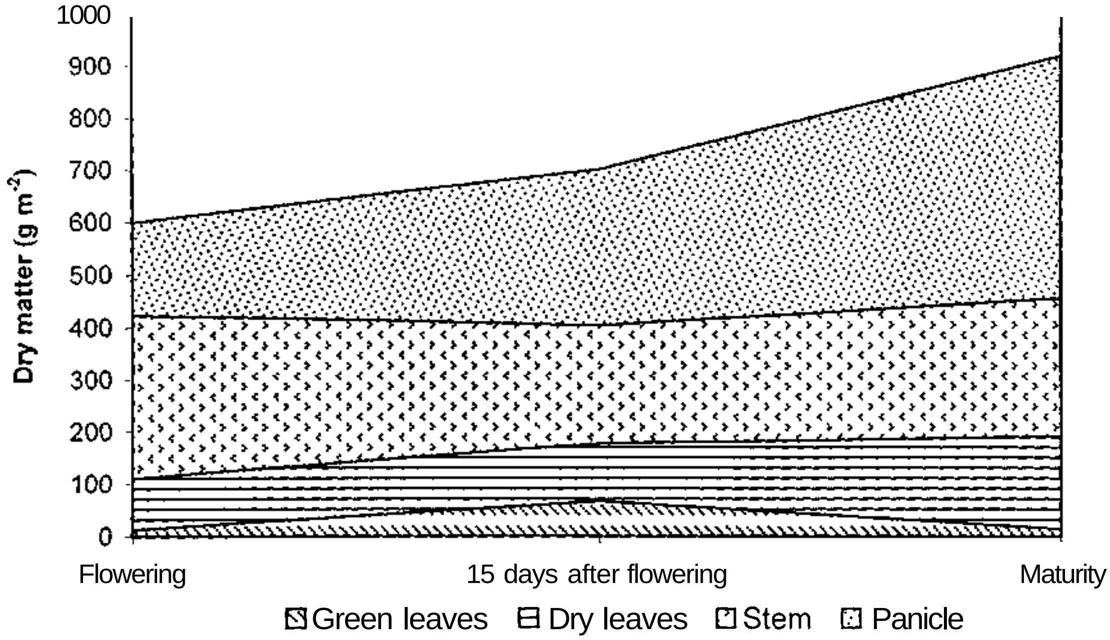

Fig.6(a): Dry matter partitioning in R-827-287under irrigated conditions at various stages

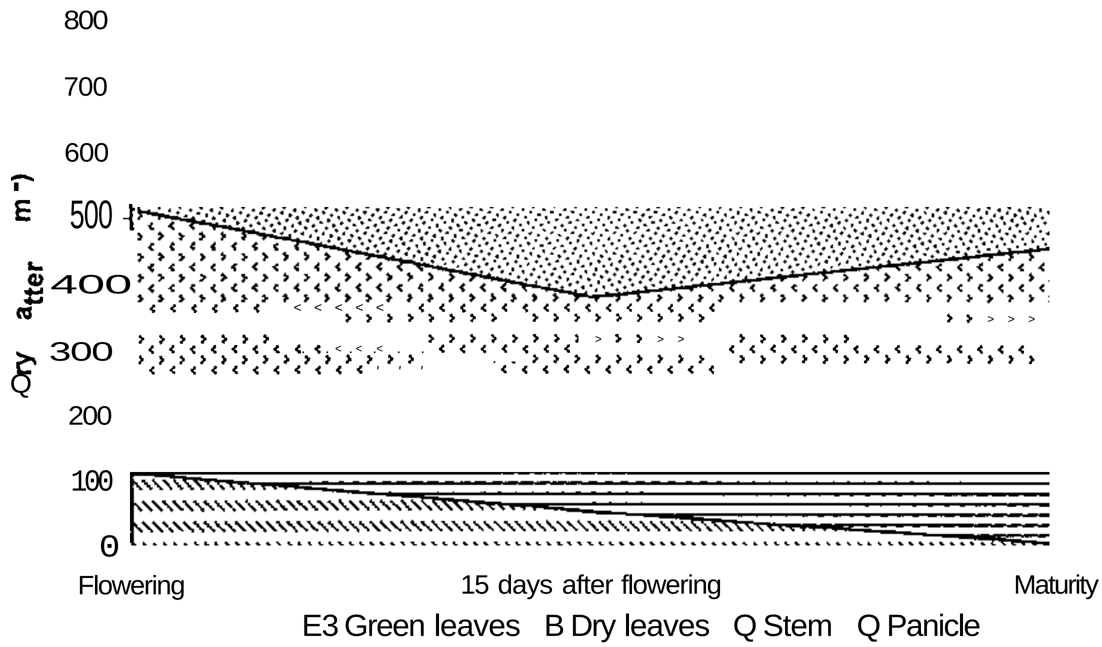

Fig.6(b): Dry matter partitioning in R-827-287under drought conditions at various stages

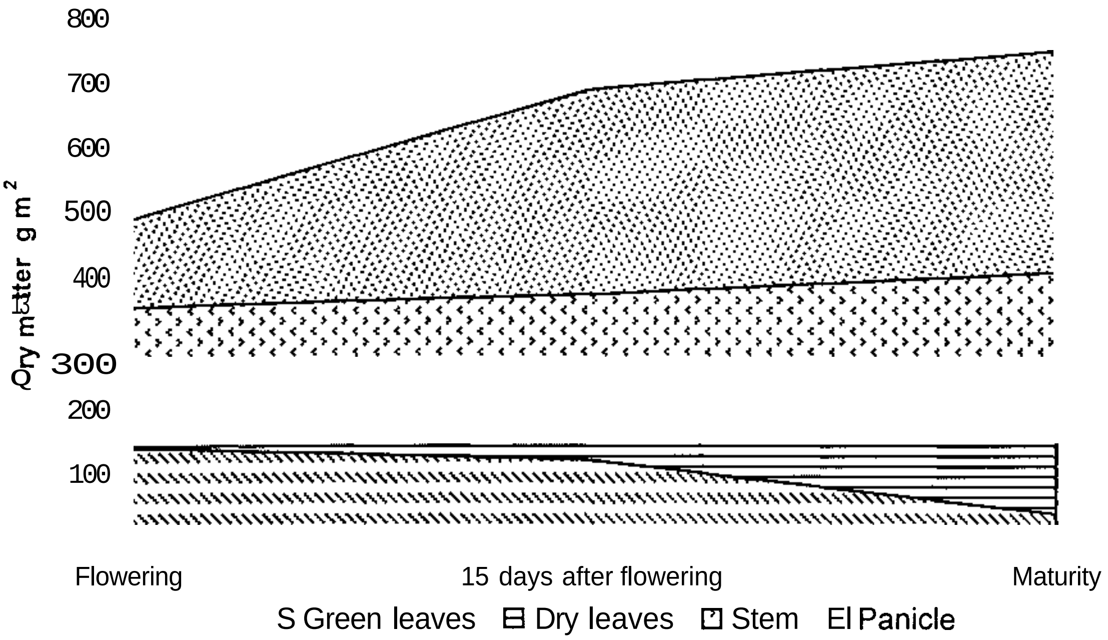

Fig. 7(a): Dry matter partitioning in Shyamla under irrigated conditions at various stages

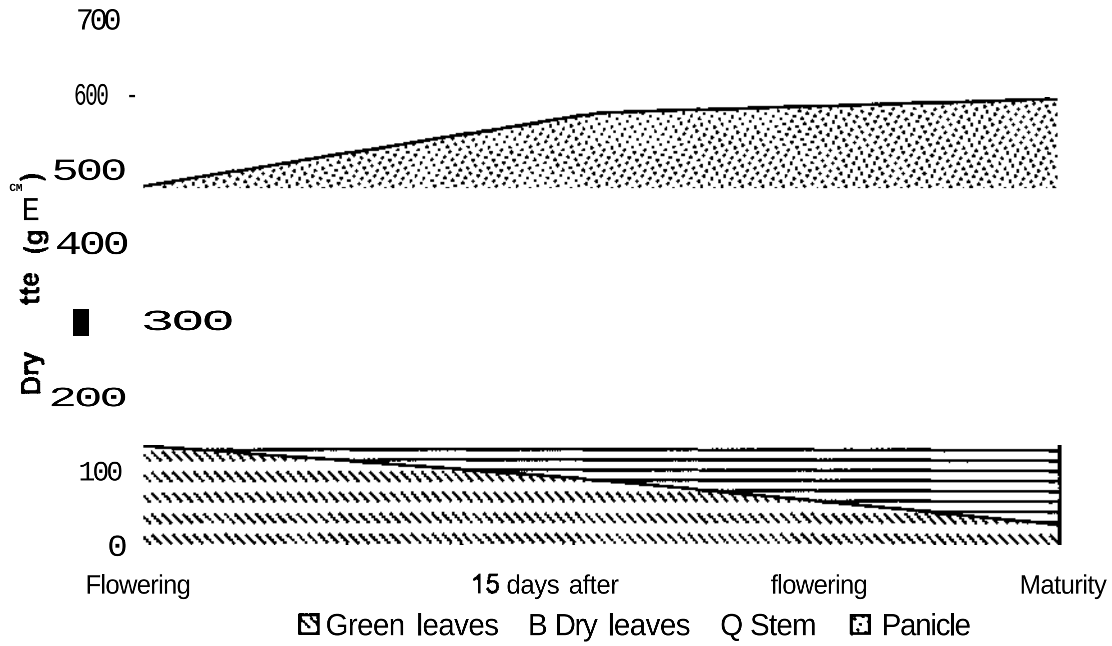

Fig.7(b): Dry matter partitioning in Shyamla under drought conditions at various stages

405-A-4 (237.67 g/ m^2). Drought significantly increases the dry leaf as compared to irrigated conditions. The increase in dry leaves due to drought was highest and lowest in Kranti and R-405-A-4 respectively.

Stem dry matter under irrigated conditions was recorded significantly higher in R-405-A-4 (471.94 g/ m^2) while it was lowest (247.09 g/ m^2) in Indira-A-9. Drought significantly reduces the stem dry matter as compared to irrigated conditions. The reduction in stem dry matter under drought was observed highest (31.91%) in Kranti and lowest in Indira-A-9 (0.29%). The panicle dry matter under irrigated conditions was recorded significantly higher in Mahamaya (613.75 g/ m^2), while lowest (340.29 g/ m^2) in Shymala. Drought significantly reduces the panicle dry matter. The reduction in panicle dry matter due to drought was significantly higher in Indira A-9 (61.9%). The lowest reduction (12.32%) in panicle dry matter was observed Kranti and the reduction was at par with Mahamaya.

Under irrigated conditions R-405-A-4 produces significantly higher amount of total dry matter compared to other varieties. Drought significantly decreases the total dry matter production at maturity. The reduction in total dry matter ranges from 10.58 per cent to 32.38 per cent in different varieties. The dry matter stability under drought was observed higher in Kranti and Mahamaya as compared to other varieties.

4.4 Photosynthesis under irrigated and drought conditions at flowering and fifteen days after flowering:

The results related to photosynthesis measurements at two stages have been presented in Table 5. The results showed that under irrigated conditions photosynthetic rate was recorded significantly higher in R-405-A-4 at both the stages of measurement as compared to other varieties. The rate of photosynthesis was recorded significantly lower in Shyamla at flowering stage under irrigated conditions.

Table 5 : Effect of drought on photosynthetic rate under irrigated and drought conditions in different varieties

Water Regime	Variety	Photosynthesis (μ mol m^{-2} s^{-1})	
		Flowering	15 days after flowering
Irrigated	Indira A-9	20.97	16.66
	Kranti	15.15	16.11
	Mahamaya	20.63	23.43
	R-405-A-4	22.07	24.76
	R-827-287	18.15	13.78
	Shyamla	12.64	13.79
W-mean		18.27	18.09
Drought	Indira A-9	12.55	4.63
	Kranti	12.86	8.72
	Mahamaya	16.61	12.85
	R-405-A-4	11.62	6.28
	R-827-287	12.70	3.76
	Shyamla	11.05	5.90
W-mean		12.90	7.02
CD (5%)	W	1.74	0.78
	V	1.05	0.98
	(W x V)	1.49	1.38
	(V x W)	3.30	2.72

The results showed that rate of photosynthesis decreased due to drought at both the stages. The reduction in photosynthetic rate was higher at fifteen days after flowering (61.19%) as compared to flowering stage (29.39%) due to the progress in drought severity. The results showed that reduction in photosynthetic rate due to drought was significantly higher in R-405-A-4 at flowering (47.35%)

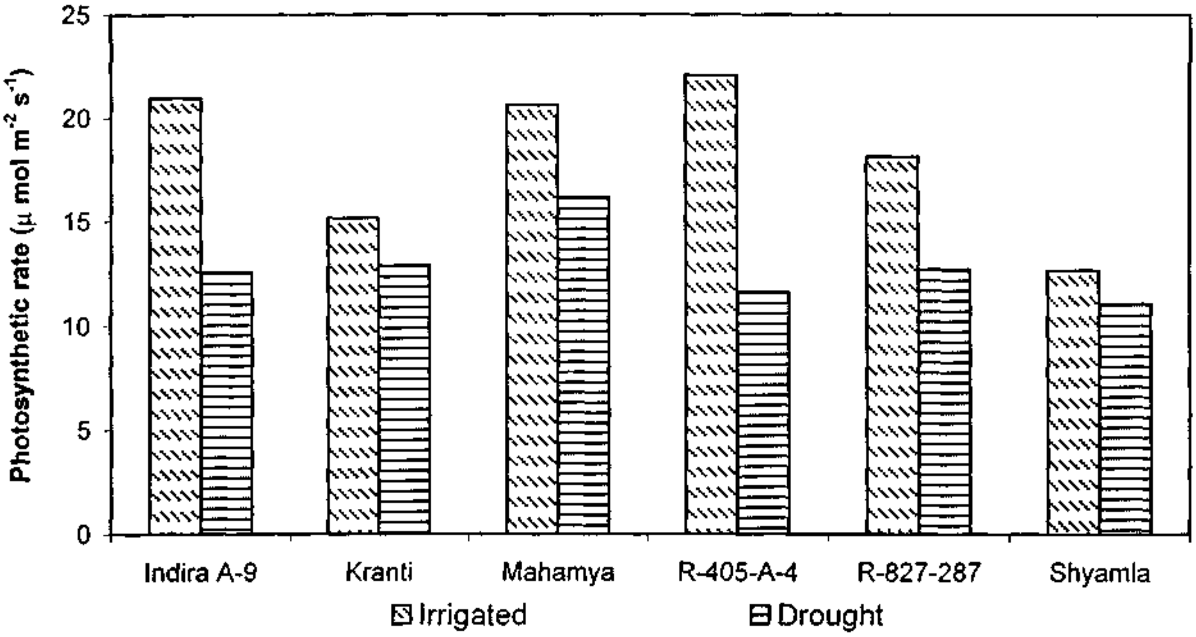

Fig. 8(a): Photosynthetic rate under irrigated and drought conditions at flowering stage of different varieties

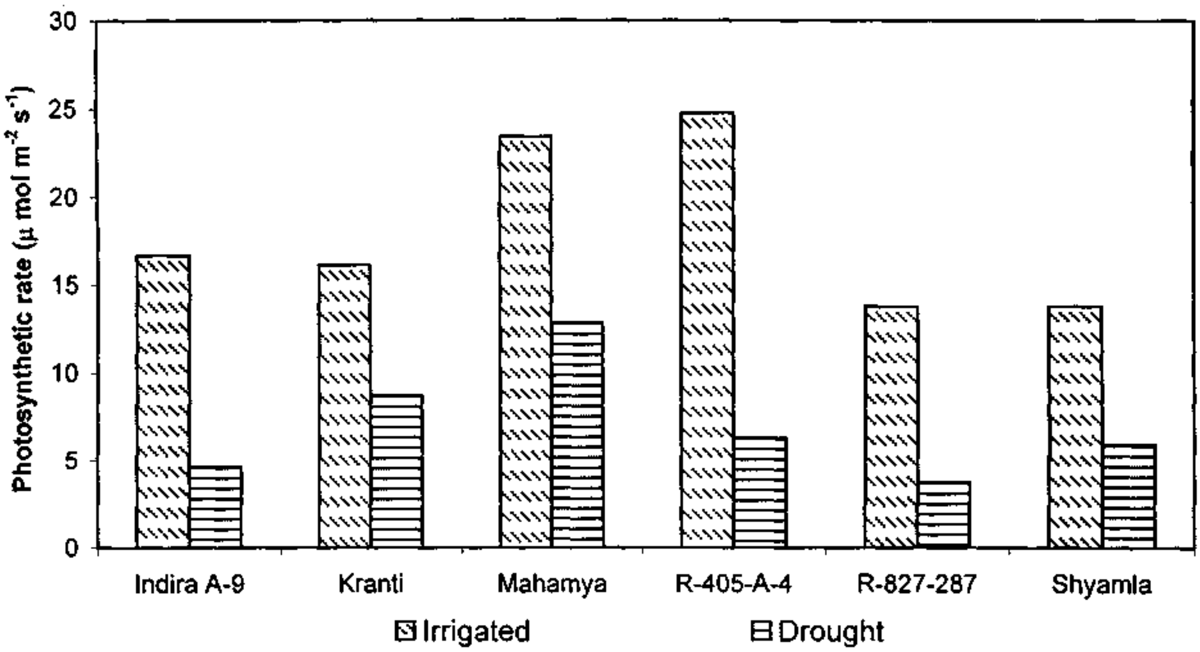

Fig.8(b): Photosynthetic rate under irrigated and drought conditions at fifteen days after flowering of different varieties

and fifteen days after flowering (74.64%) as compared to other varieties. Under drought the lowest reduction in photosynthetic rate was observed in Shyamla (12.58%) at flowering stage while the reduction was lowest in Mahamaya and Kranti (45.16%) after fifteen days of flowering.

4.5 Stomatal conductance under irrigated and drought conditions at flowering and fifteen days after flowering:

The results related to stomatal conductance have been presented in Table 6. The results showed that under irrigated conditions stomatal conductance was significantly higher in R-405-A-4 at both the stages of measurement as compared to other varieties. Stomatal conductance was observed significantly lower in Shyamla at flowering (0.44 mol m^{-} s^{-1}) and fifteen days after flowering (0.51 mol m^{-2} s^{-1}) under irrigated conditions.

Table 6 : Effect of drought on stomatal conductance under irrigated and drought conditions in different varieties

Water Regime	Variety	Stomatal conductance (mol m^{-2} s^{-1})	
		Flowering	15 days after flowering
Irrigated	Indira A-9	0.83	0.65
	Kranti	0.60	0.61
	Mahamaya	0.79	0.97
	R-405-A-4	0.88	1.01
	R-827-287	0.64	0.59
	Shyamla	0.44	0.51
W-mean		0.70	0.73
Drought	Indira A-9	0.35	0.13
	Kranti	0.54	0.31
	Mahamaya	0.67	0.30
	R-405-A-4	0.33	0.10
	R-827-287	0.38	0.10
	Shyamla	0.39	0.13
W-mean		0.44	0.18
CD (5%)	W	0.04	0.05
	V	0.04	0.05
	(W x V)	0.06	0.07
	(V x W)	0.12	0.15

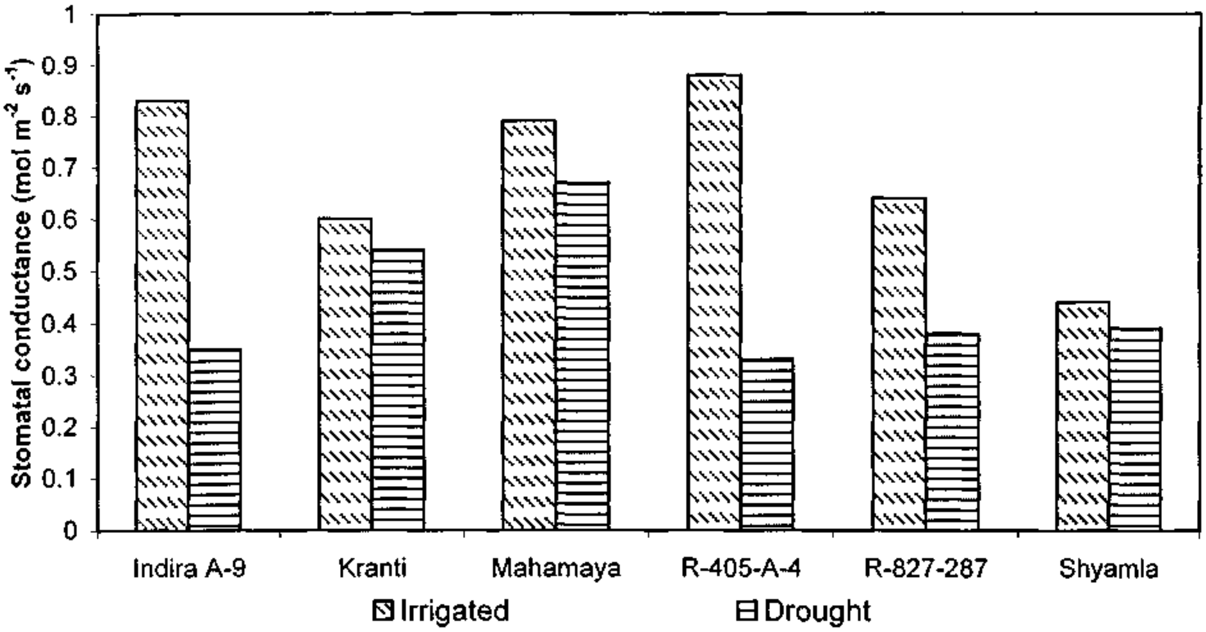

Fig.9(a) : Stomatal conductance under irrigated and drought condition at flowering stage of different varieties

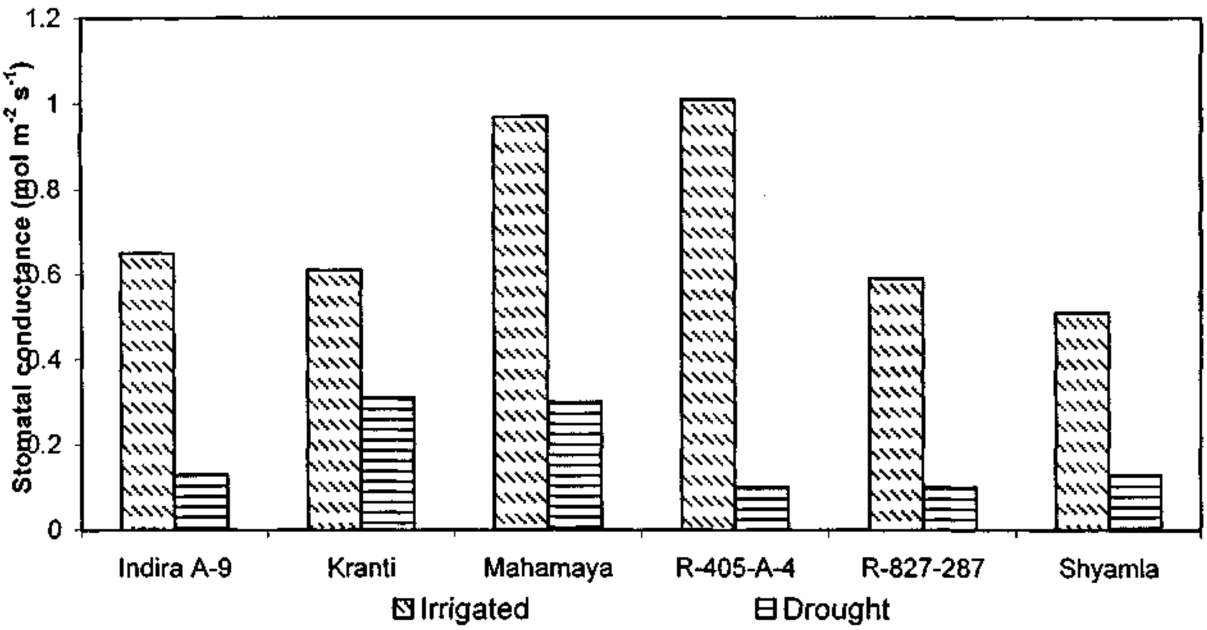

Fig.9(b) : Stomatal conductance under irrigated and drought condition at fifteen days after flowering of different varieties

Drought significantly decreases the stomatal conductance. The reduction in stomatal conductance was observed higher (75.34%) at fifteen days after flowering as compared to flowering stage (37.4%). The reduction in stomatal conduction due to drought was recorded significantly higher in R-405-A-4 at both the stages. The lowest reduction in stomatal conduction due to drought was observed in Kranti at both the stages of measurements as compared to other varieties.

4.6 Transpiration rate under irrigated and drought conditions at flowering and fifteen days after flowering:

The results related to transpiration have been presented in Table 7. The results showed that transpiration rate under irrigated conditions was highest in R-405-A-4 (8.96 m mol m^{-2} s^{-1}) which was at par with Mahamaya at flowering stages. After fifteen days of flowering transpiration rate was recorded significantly higher in R-405-A-4 (10.47 m mol m^{-2} s^{-1}) under irrigated condition. Drought significantly decreases the transpiration rate at both the stages of measurements. The reduction due to drought in transpiration rate was higher (72.01%) after fifteen days of flowering as compared to flowering stage (40.77%). The reduction in transpiration due to drought was observed significantly higher in R-405-A-4 at both the stages as compared to other varieties. The lowest reduction in transpiration due to drought was observed in Shyamla and Kranti at flowering and fifteen days after flowering respectively compare to other varieties.

Table 7 : Effect of drought on transpiration rate under irrigated and drought conditions in different varieties

Water Regime	Variety	Transpiration (m **mol** m" **s**)	
		Flowering	15 days after flowering
Irrigated	Indira A-9	7.11	5.81
	Kranti	5.55	6.04
	Mahamaya	8.64	9.49
	R-405-A-4	8.96	10.47
	R-827-287	5.44	5.00
	Shyamla	4.59	4.36
W-mean		6.72	6.86
Drought	Indira A-9	3.84	1.11
	Kranti	4.25	3.07
	Mahamaya	6.55	3.85
	R-405-A-4	2.67	1.15
	R-827-287	2.62	1.16
	Shyamla	3.92	1.19
W-mean		3.98	1.92
CD (5%)	W	0.16	0.68
	V	0.71	0.55
	(W x V)	1.01	0.29
	(V x W)	1.91	1.62

4.7 **Phenology under irrigated and drought conditions:**

The data on phenology have been presented on Table 8. The results showed that Indira A-9 and R-405-A-4 took sixty seven days for panicle initiation under irrigated conditions while, Kranti took only fifty seven days. No significant difference between irrigated and drought plots were observed, for days to panicle initiation since drought was imposed after PI stage. Indira A-9 and R-405-A-4 took significantly higher time (102 days) for 50 per cent flowering as compared to other varieties. Drought significantly increases the time for 50 per cent flowering

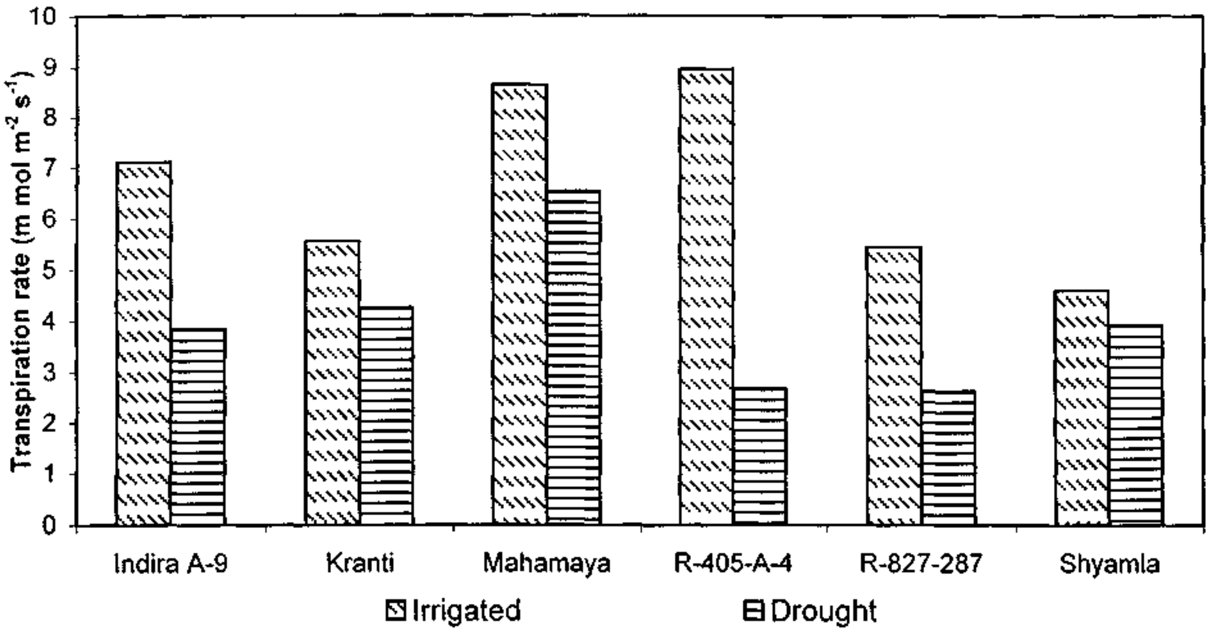

Fig.10(a) : Transpiration rate under irrigated and drought condition at flowering stage of different varieties

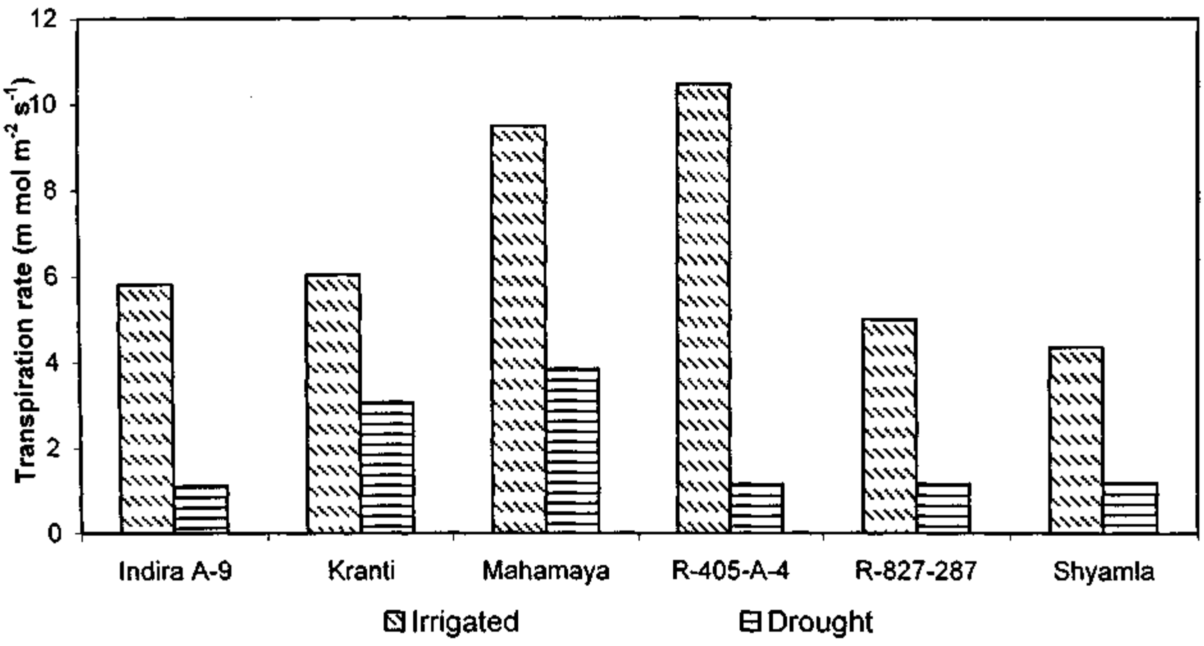

Fig.10(b) : Transpiration rate under irrigated and drought condition at fifteen days after flowering of different varieties

as compared to irrigated conditions. Flowering was delayed by 11 days in Indira A-9 while, such a delay was only one day in Kranti.

Table 8 : Phenology under irrigated and drought condition of different varieties

Water Regime	Variety	Stages	
		Panicle initiation (Days)	50% flowering (Days)
Irrigated	Indira A-9	67.00	102.33
	Kranti	57.67	84.00
	Mahamaya	58.33	96.00
	R-405-A-4	67.00	102.33
	R-827-287	66.67	99.00
	Shyamla	61.00	96.00
W-mean		62.94	96.61
Drought	Indira A-9	67.33	113.00
	Kranti	57.67	85.00
	Mahamaya	59.00	98.00
	R-405-A-4	67.00	107.00
	R-827-287	66.67	103.00
	Shyamla	60.33	101.00
W-mean		63.00	101.17
CD (5%)	W	NS	4.15
	V	0.74	2.52
	(W x V)	NS	3.56
	(V x W)	NS	4.94

4.8 Plant height at physiological maturity under irrigated and drought conditions:

The results related to plant height at physiological maturity have been presented in Table 9. Under irrigated conditions, the plant height was recorded highest and lowest in R-405-A-4 and Shyamla respectively. Drought significantly decreases the plant height at physiological maturity. The highest reduction in plant height was recorded in R-405-A-4 (11.42%). The reduction in plant height due to drought was observed lowest in Kranti (1.63%).

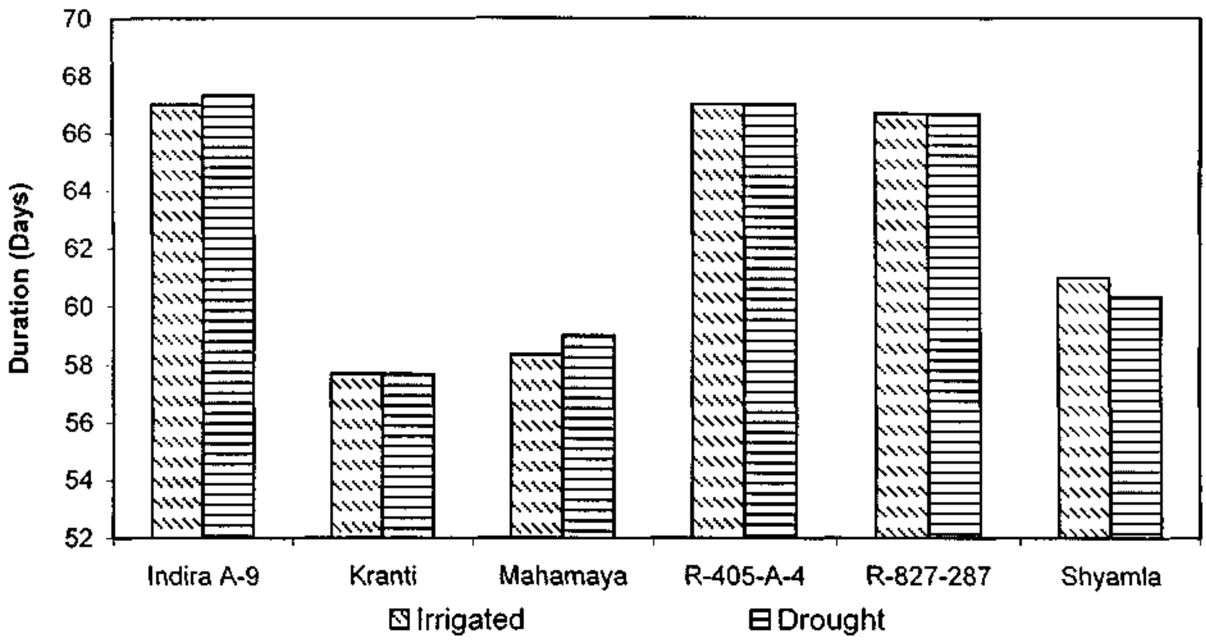

Fig. 11(a): Duration for panicle initiation under irrigated and drought conditions of different varieties

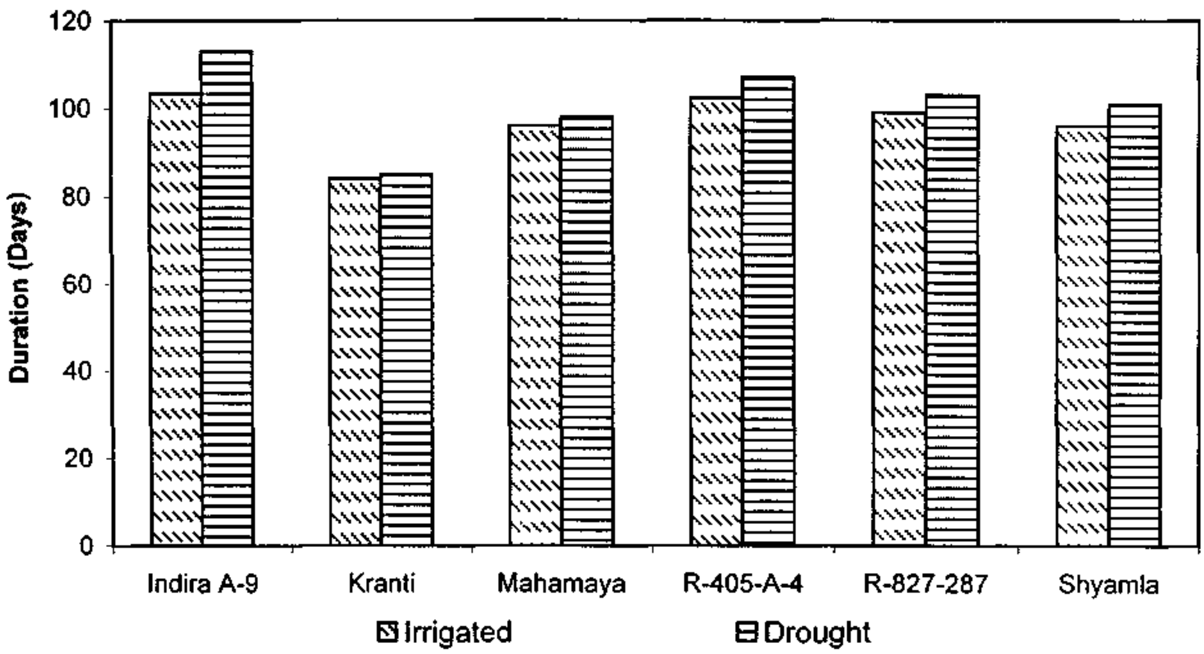

Fig. 11(b): Duration for flowering (50%) under irrigated and drought conditions of different varieties

Table 9 : Plant height at physiological maturity under irrigated and drought conditions in different varieties

Water Regime	Variety	Plant height (cm)
Irrigated	Indira A-9	84.15
	Kranti	82.33
	Mahamaya	82.84
	R-405-A-4	87.48
	R-827-287	80.37
	Shyamla	77.35
W-mean		82.42
Drought	Indira A-9	77.19
	Kranti	80.99
	Mahamaya	80.54
	R.405-A-4	83.13
	R-827-287	71.19
	Shyamla	75.09
W-mean		78.02
CD (5%)	W	3.39
	V	3.67
	(W x V)	NS
	(V x W)	NS

4.9 Leaf area index at various stages under irrigated and drought condition:

The result related to leaf area index have been presented in Table 10. The results showed that under irrigated and drought conditions, the leaf area index was highest at flowering and decreases thereafter as the plant grew older. Under irrigated conditions the leaf area index was observed highest in R-405-A-4 at all three stages. Drought significantly decreases the leaf area index at flowering and fifteen days after flowering. The reduction in leaf area index due to drought was (27.35%), (43.25%) and (54.46%) at flowering, fifteen days after flowering and at maturity respectively. A reduction of 70.09 per cent in LAI due to drought was

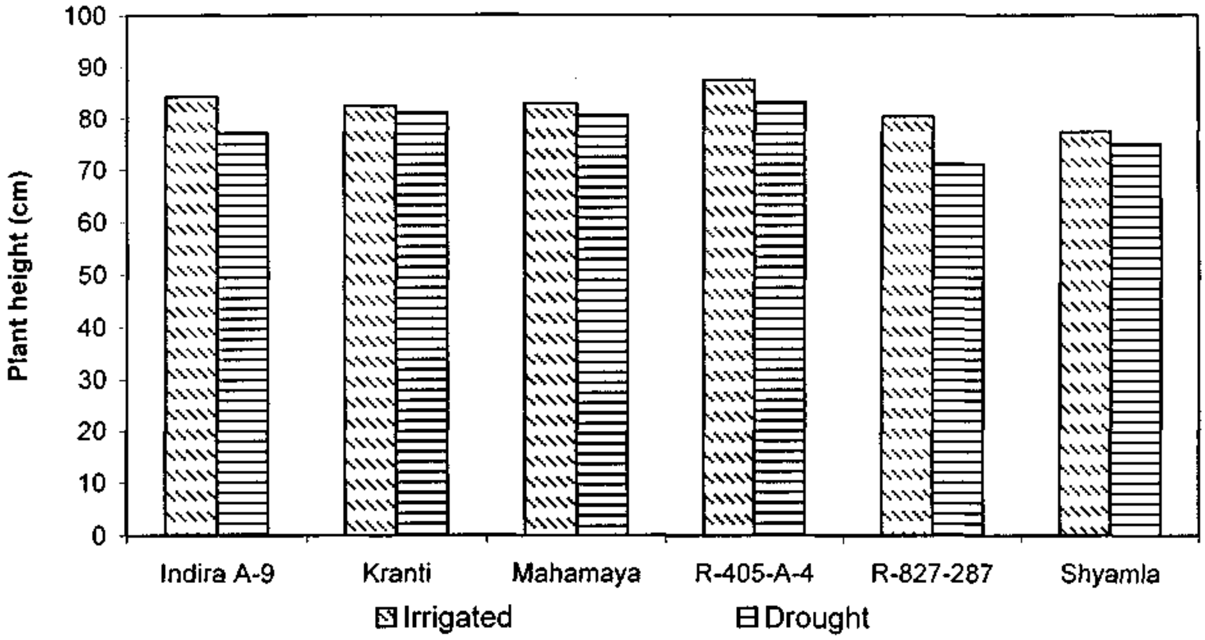

Fig. 13(a): Plant height under irrigated and drought conditions at physiological maturity of different varieties.

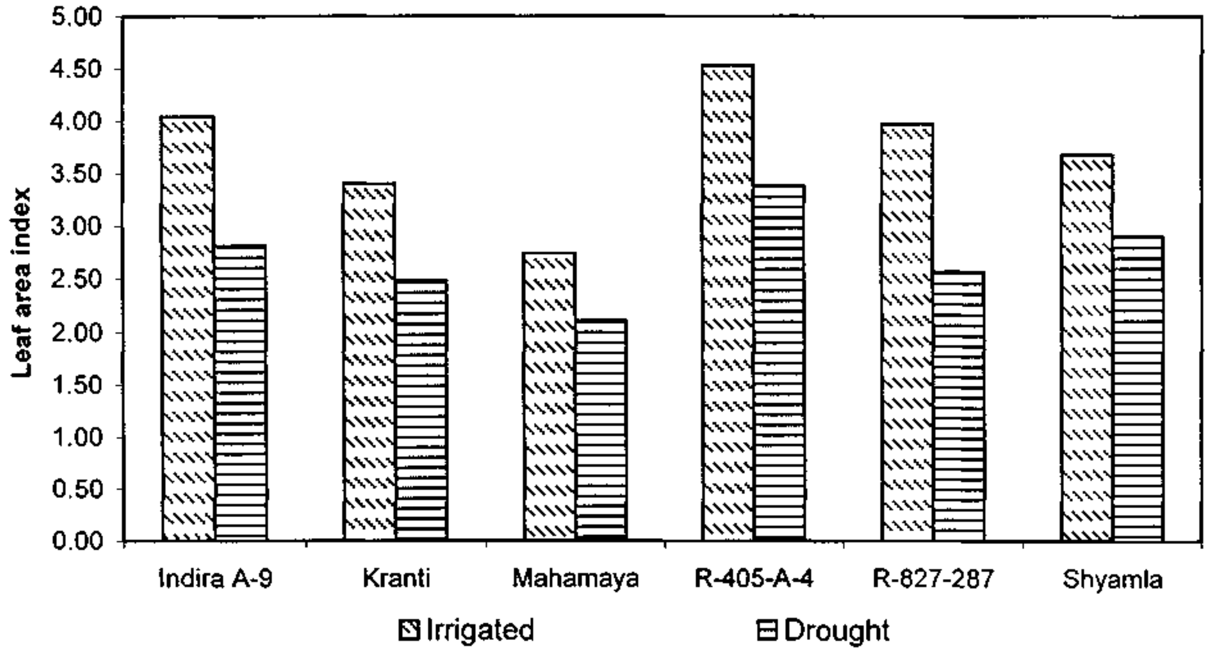

Fig.13(b): Leaf area index under irrigated and drought conditions at flowering stage of different varieties

observed in Indira-A-9 after fifteen days of flowering while, the reduction was only 30.25 per cent in R-827-287.

Table 10: Leaf area index at flowering, fifteen days after flowering and maturity under irrigated and drought conditions in different varieties

Water Regime	Variety	Flowering	15 days after flowering	Maturity
Irrigated	Indira A-9	4.04	2.24	0.58
	Kranti	3.40	2.24	1.14
	Mahamaya	2.74	2.68	1.03
	R-405-A-4	4.53	2.91	1.75
	R-827-287	3.97	2.52	0.66
	Shyamla	3.68	2.53	1.57
W-mean		3.73	2.52	1.12
Drought	Indira A-9	2.81	0.67	0.16
	Kranti	2.48	1.40	0.56
	Mahamaya	2.11	1.16	0.63
	R-405-A-4	3.38	2.00	0.43
	R-827-287	2.57	1.74	0.36
	Shyamla	2.91	1.61	0.92
W-mean		2.71	1.43	0.51
CD (5%)	W	0.11	1.05	NS
	V	0.90	NS	0.48
	(W x V)	NS	NS	NS
	(V x W)	NS	NS	NS

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4.10 Leaf water potential at flowering and fifteen days after flowering at drought conditions:

The results related to leaf water potential have been presented in Table 12. The results showed that water potential decreases as the drought progresses from flowering to fifteen days after flowering. At flowering stage the water potential was recorded highest in Mahamaya. The lowest (13.54 bar) water potential at flowering stages was recorded in Indira A-9. After 15 days of flowering the water

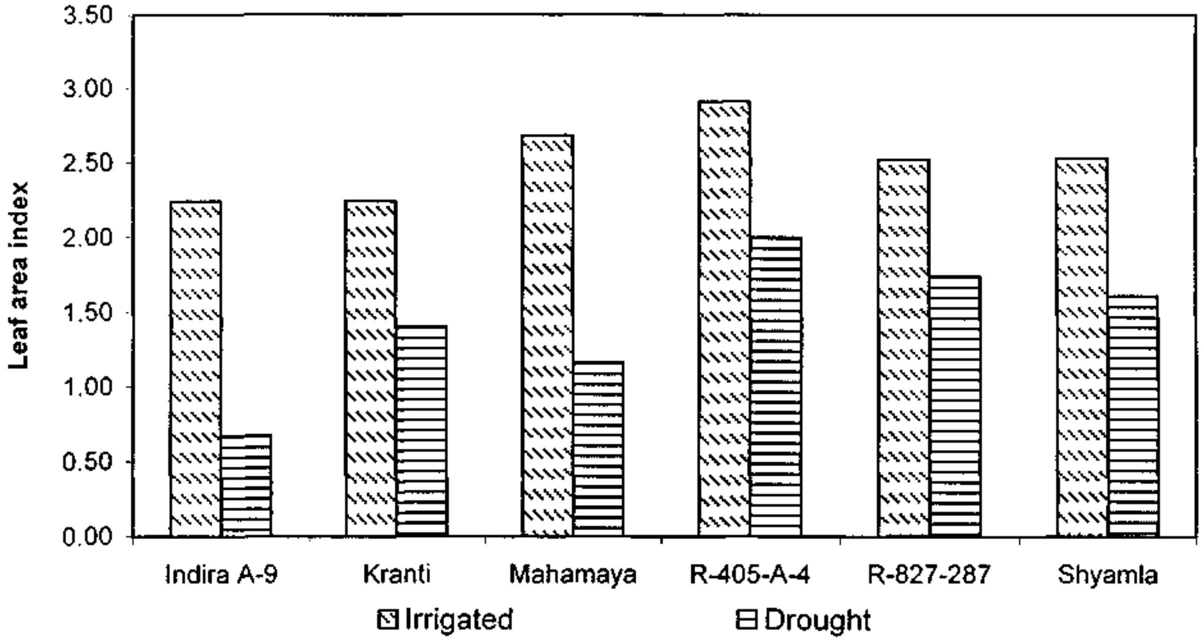

Fig.13(c): Leaf area index under irrigated and drought conditions at fifteen days after flowering of different varieties

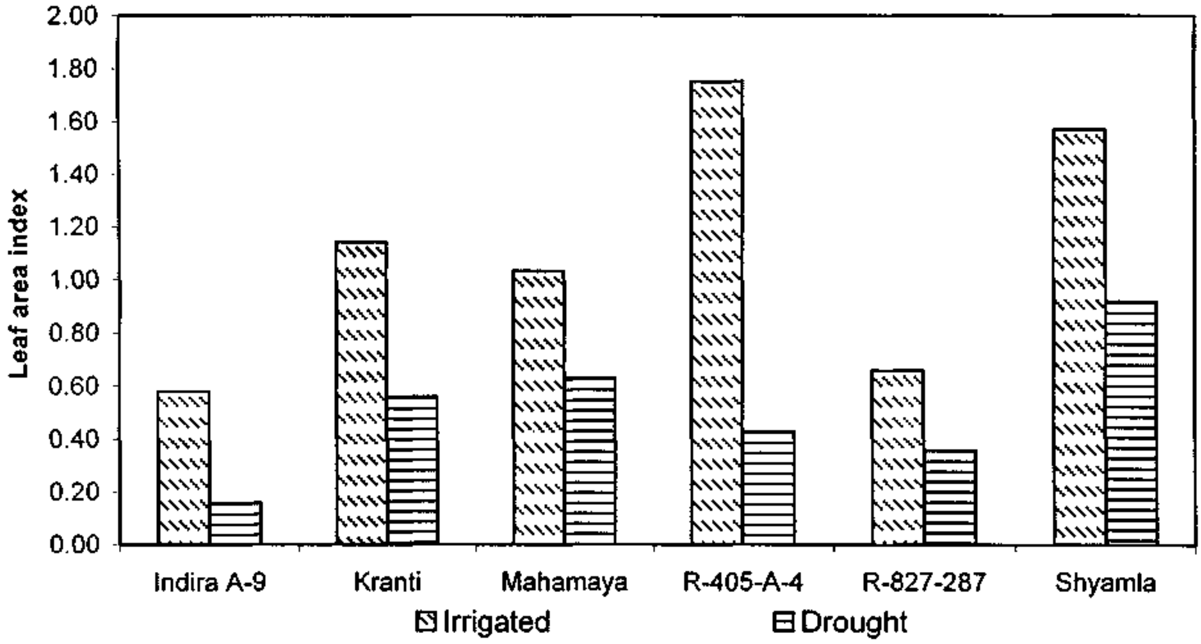

Fig.13(d): Leaf area index under irrigated and drought conditions at maturity of different varieties

Table 11 : Flag leaf area at flowering stage under irrigated and drought condition of different varieties

Water Regime	Variety	Flag leaf area (cm^2)
Irrigated	Indira A-9	66.57
	Kranti	59.26
	Mahamaya	69.08
	R-405-A-4	57.78
	R-827-287	53.59
	Shyamla	64.56
W-mean		61.81
Drought	Indira A-9	44.52
	Kranti	51.98
	Mahamaya	61.80
	R-405-A-4	46.72
	R-827-287	45.37
	Shyamla	50.14
W-mean		50.09
CD (5%)	W	4.63
	V	NS
	(W x V)	NS
	(V x W)	NS

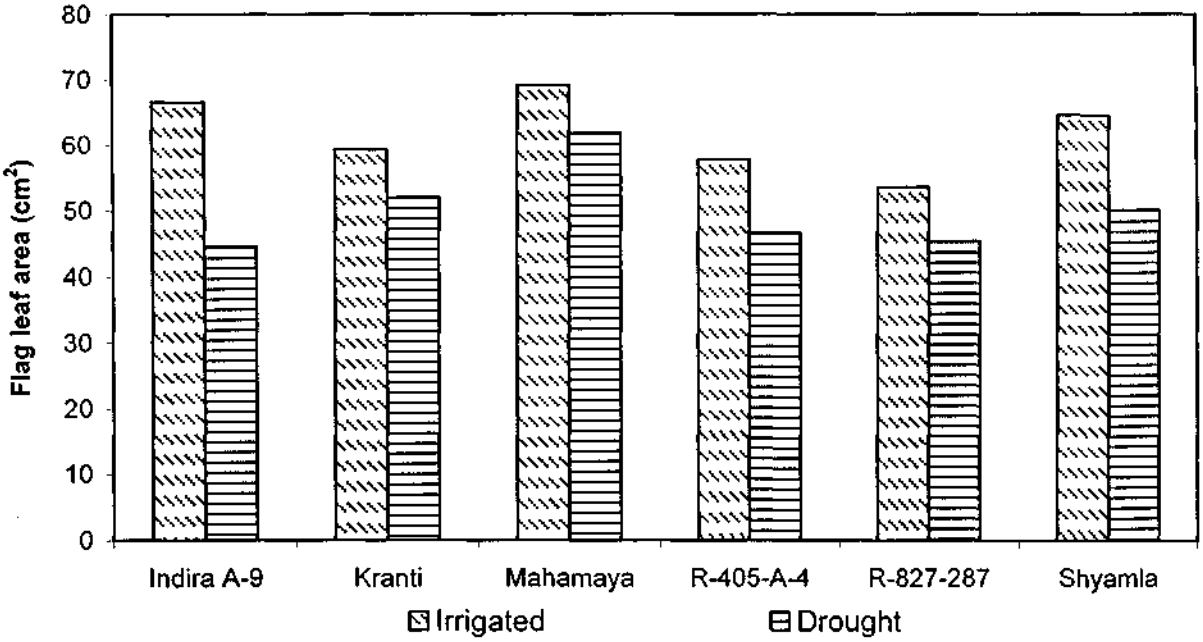

Fig.15: Flag leaf area under irrigated and drought condition at flowering stage of different varieties

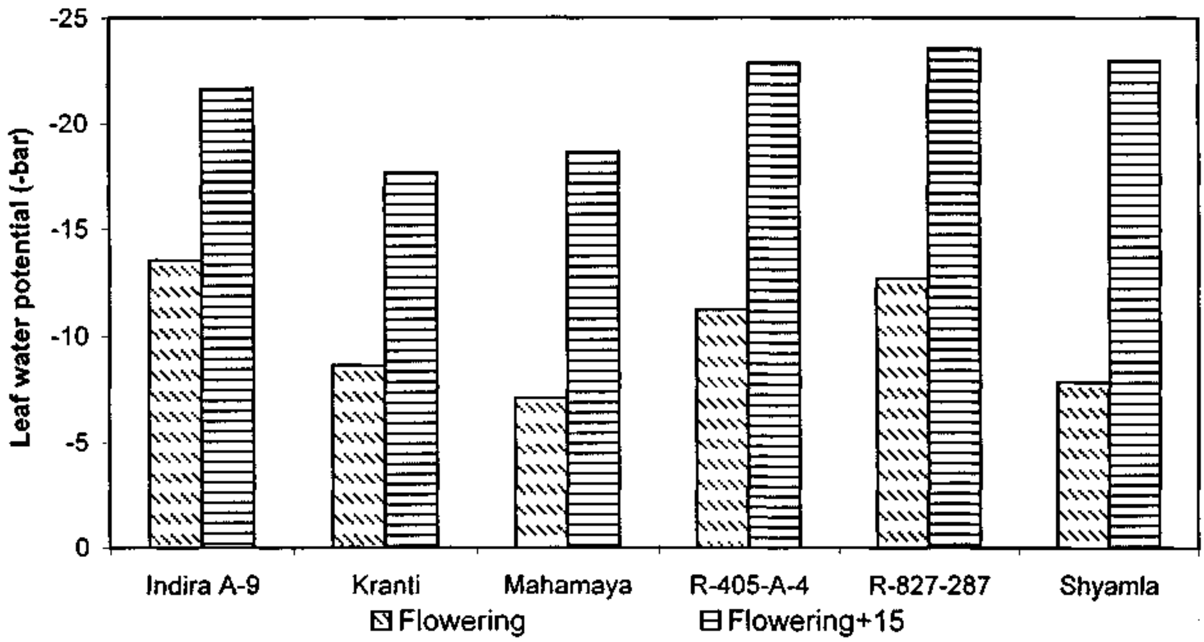

Fig.16 : Leaf water potential under drought condition at flowering annd fifteen days after flowering of different varieties

potential was observed highest (17.66 bar) in Kranti as compared to other varieties.

Table 12 : Leaf water potential at flowering and 15 days after flowering in different varieties under drought conditions

Stage	Variety	Water potential **(-Bar)**
Flowering	Indira A-9	13.54
	Kranti	8.63
	Mahamaya	7.13
	R-405-A-4	11.24
	R-827-287	12.71
	Shyamla	7.88
S-mean		10.19
15 days after flowering	Indira A-9	21.66
	Kranti	17.66
	Mahamaya	18.66
	R-405-A-4	22.88
	R-827-287	23.55
	Shyamla	22.99
S-mean		21.23
CD (5%)		0.68

4.11 Effect of drought on membrane stability at flowering and fifteen days after flowering:

The results related to membrane stability have been presented in Table 13. The results indicates that under irrigated conditions the difference between varieties in terms of membrane stability was not higher at both the stages. Drought significantly decreases the membrane stability at both the stages. The reduction in membrane stability was higher (25.86%) after fifteen days of flowering as compare to flowering (13.94%). The highest reduction in membrane stability due to drought was observed in R-827-287at both the stages. Mahamaya showed lowest reduction in membrane stability due to drought at both the stages.

Table 13 : Effect of drought on membrane stability (%) of different varieties

Water Regime	Variety	Stages	
		Flowering	15 days after flowering
Irrigated	Indira A-9	88.00	91.00
	Kranti	86.00	91.00
	Mahamaya	89.00	83.00
	R-405-A-4	91.00	86.00
	R-827-287	91.00	87.00
	Shyamla	93.00	88.00
W-mean		89.67	87.67
Drought	Indira A-9	71.00	63.00
	Kranti	79.00	71.00
	Mahamaya	84.00	74.00
	R-405-A-4	76.00	61.00
	R-827-287	72.00	54.00
	Shyamla	81.00	67.00
W-mean		77.17	65.00
CD (5%)	W	1.24	0.41
	V	2.84	2.82
	(W x V)	4.01	3.98
	(V x W)	3.82	3.64

4.12 Soil moisture content at varying stages under drought:

The soil moisture content under drought have been presented in Table 14. The results showed that volumetric soil moisture content decreases significantly as the drought progresses from flowering to maturity. The volumetric soil moisture was observed higher in deeper soil layers as compared to surface layer at all the stages.

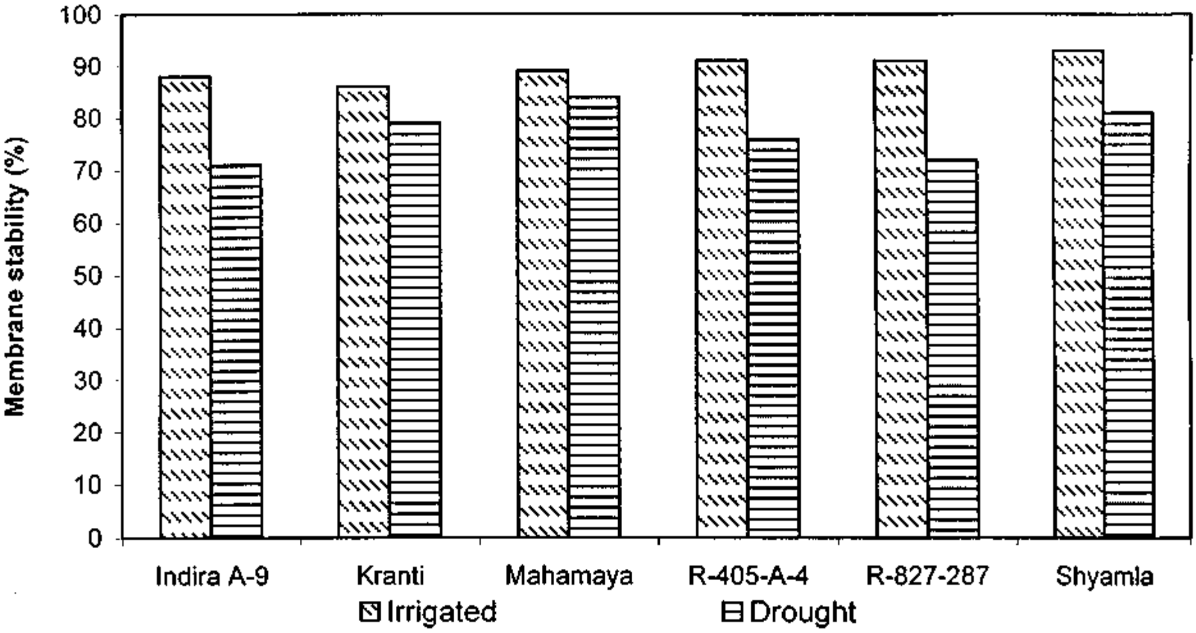

Fig.12(a) : Membrane stability under irrigated and drought conditions at flowering stage in different varieties

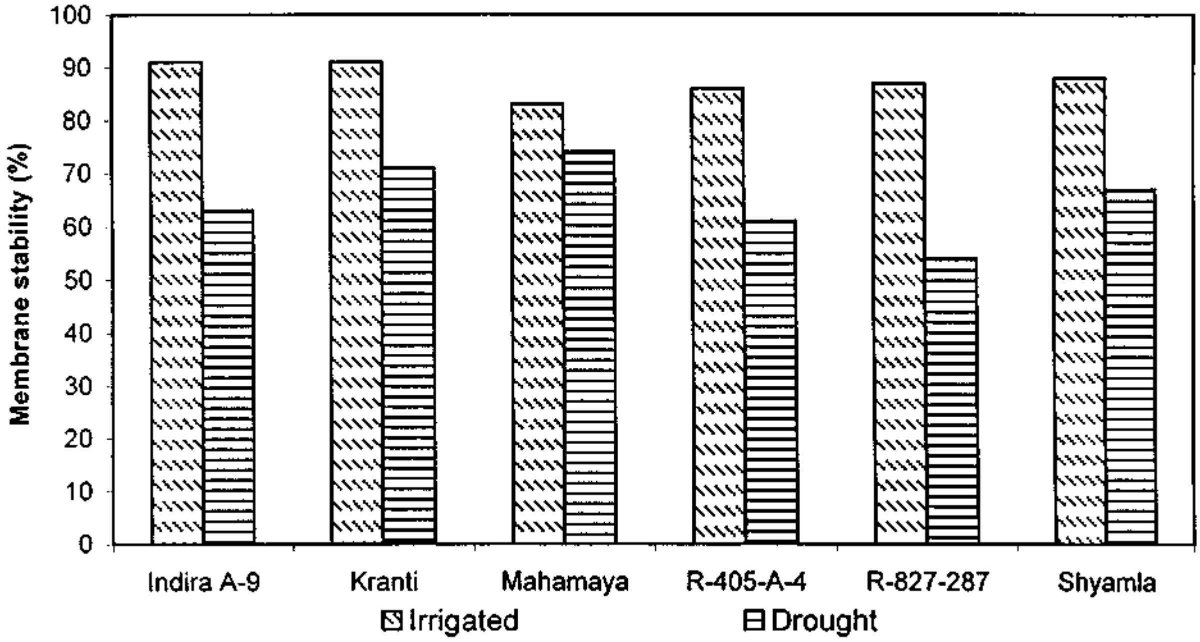

Fig.12(b) : Membrane stability under irrigated and drought conditions at fifteen days after flowering in different varieties

Table 14 : Effect of drought on volumetric soil moisture at flowering, fifteen days after flowering and maturity at different depth

Stage	Depth (cm)	Soil moisture (%) (θv)
Flowering	0-10	29.95
	10-20	31.71
	20-30	33.53
S-mean		31.73
15 days after flowering	0-10	20.78
	10-20	21.99
	20-30	23.66
S-mean		22.14
Maturity	0-10	14.65
	10-20	15.11
	20-30	16.78
S-mean		15.51
CD (5%)		0.60

Table 15 : Root dry weight (g) under irrigated and drought conditions of different varieties at flowering stage

Water Regime	Variety	Root dry weight (g hill^{-1})
Irrigated	Indira A-9	2.35
	Kranti	1.96
	Mahamaya	2.57
	R.405-A-4	2.89
	R-827-287	2.36
	Shyamla	1.30
W-mean		2.24
Drought	Indira A-9	2.19
	Kranti	2.80
	Mahamaya	3.10
	R-405-A-4	2.44
	R-827-287	2.58
	Shyamla	1.34
W-mean		2.41
CD (5%)	W	NS
	V	0.38
	(W x V)	NS
	(V x W)	NS

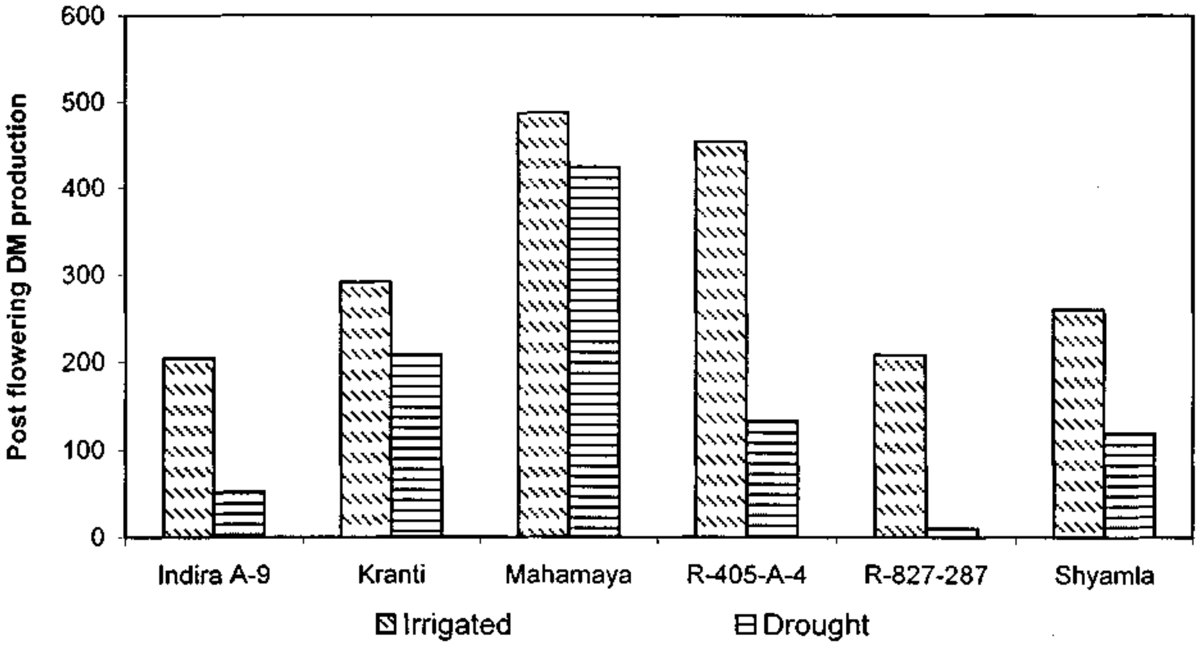

Fig. 17: Post flowering dry matter production under irrigated and drought condition of different varieties

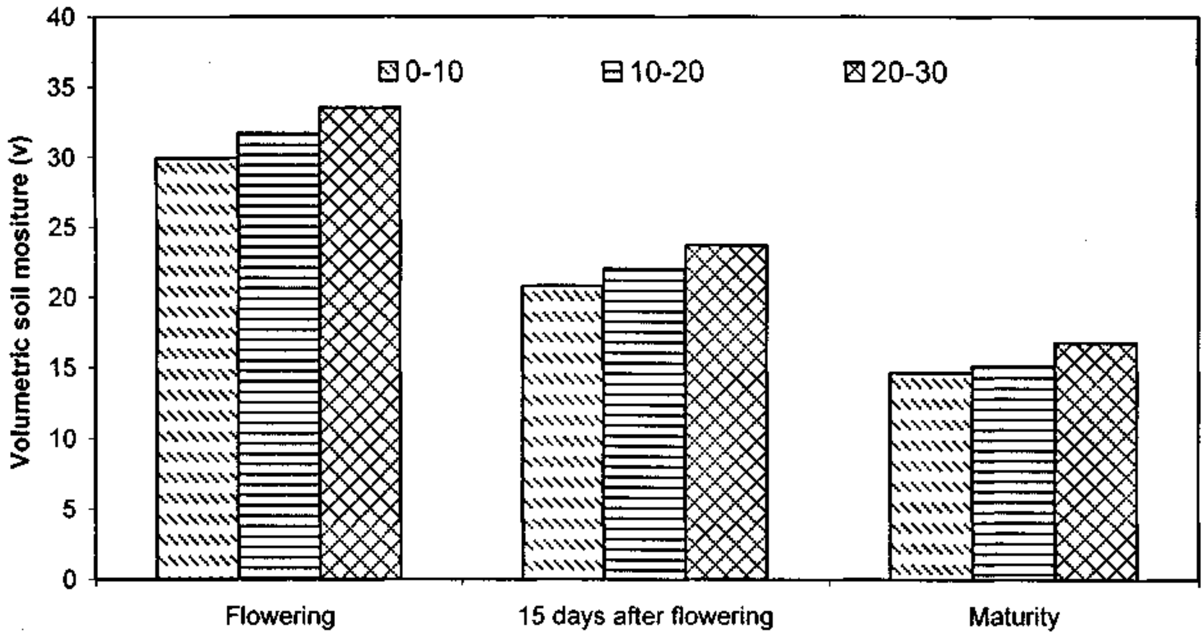

Fig. 18 : Volumetric soil moisture content at three stages under drought condition

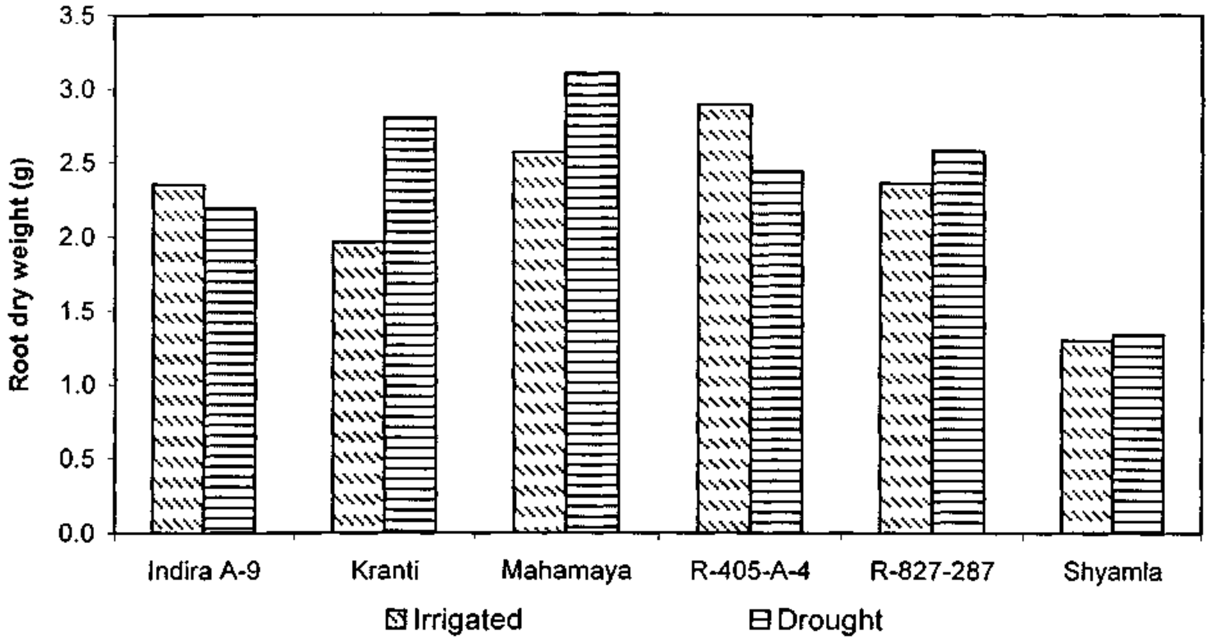

Fig.14 : Root dry weight under irrigated and drought condition at flowering stage of different varieties

4.13 Root dry weight under irrigated and drought condition at flowering stages:

The results on root dry weight have been presented in Table 15. The results showed that root dry weight was not significant among irrigated and drought plots. Under irrigated conditions the maximum root dry weight was observed in R-405-A-4 (2.89 g/hill) while it was lowest in Shyamla (1.30 g/hill). The results indicates that root dry weight decreases under drought in Indira A-9 and R-405-A-4 while, an increase in root dry weight under drought was observed in other varieties. The increase in root dry weight under drought was recorded higher in Kranti and Mahamaya compare to other varieties.

4.14 Post flowering dry matter production under irrigated and drought conditions:

The results on post flowering dry matter production have been presented in Table 16. Under irrigated conditions post flowering dry matter was observed highest (453.34 g) in R-405-A-4 and lowest (204.35 g) in Indira A-9. The reduction in post flowering dry matter production due to drought was highest (95.14%) in R-827-287 and lowest in Mahamaya (12.83%).

4.15 Apparent translocation rate from green leaf and stem under irrigated and drought conditions:

The results on apparent translocation rate have been presented in Table 16. The results showed that apparent translocation rate from stem increases under drought conditions as compared to irrigated conditions. However, the increase in stem apparent translocation rate under drought was non-significant. Under drought conditions the highest increase in stem apparent translocation rate was observed in Kranti compared to other varieties.

Table 16 : Apparent translocation rate (ATR) from stem and post flowering dry matter production under irrigated and drought conditions of different varieties

Water Regime	Variety	Stem (ATR)	Post flowering dry matter production (g)
Irrigated	Indira A-9	0.27	204.35
	Kranti	-0.01	291.11
	Mahamaya	-0.03	486.56
	R-405-A-4	-0.11	453.34
	R-827-287	0.17	208.24
	Shyamla	-0.39	259.58
W-mean		-0.02	317.20
Drought	Indira A-9	0.36	52.69
	Kranti	0.40	207.34
	Mahamaya	0.09	424.12
	R-405-A-4	0.18	133.04
	R-827-287	0.51	10.12
	Shyamla	-0.42	115.91
W-mean		0.18	157.20
CD (5%)	W	NS	NS
	V	0.06	230.12
	(W x V)	NS	NS
	(V x W)	NS	NS

4.16 Grain yield and its components under irrigated and drought conditions:

The results related to grain yield and its components have been presented in Table 17. The results showed that grain yield was significantly higher in R-405-A-4 which was at par with Mahamaya under irrigated conditions. The lowest grain yield under irrigated conditions was produced by Shyamla (2.5 t/ha) which was at par with R-827-287. Drought significantly decreases the grain yield. The highest (72%) reduction in grain yield due to drought was observed in Indira A-9. The lowest (21%) reduction in grain yield due to drought was observed in Kranti.

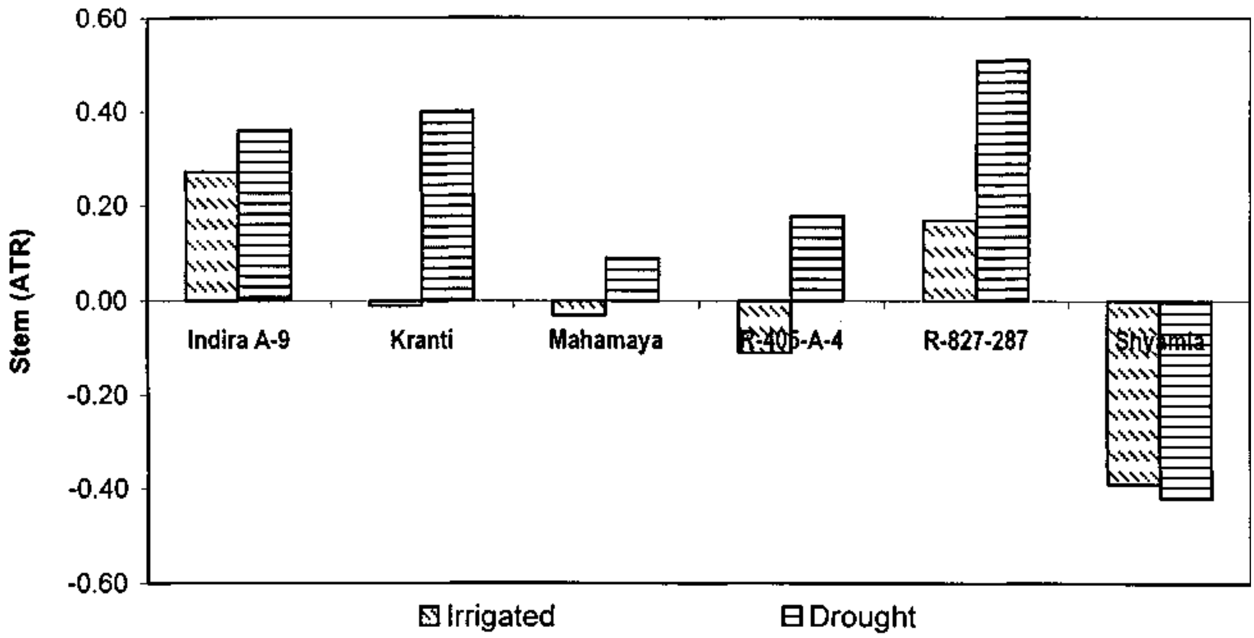

Fig. 19 : Apparent translocation rate from stem under irrigated and drought conditions of different varieties

Table 17 : Grain yield and its attributes under irrigated and drought conditions in different varieties

Variety		Grain yield (t ha^{-1})	Filled grain/ panicle (no)	Unfilled grain (%)	Test weight (g)
Irrigated					
Indira A-9		3.39	77.17	31.77	16.84
Kranti		3.29	76.62	25.00	22.96
Mahamaya		4.33	71.81	26.62	25.09
R-405-A-4		4.40	84.29	36.87	19.20
R-827-287		2.79	83.44	25.95	11.71
Shyamla		2.58	65.44	26.52	20.42
	Average	3.46	76.46	28.79	19.37
Drought					
Indira A-9		0.95	45.68	62.44	14.31
Kranti		2.45	66.91	36.60	22.31
Mahamaya		2.31	64.82	45.92	22.50
R-405-A-4		1.86	53.54	56.88	16.84
R-827-287		1.22	62.45	49.23	10.12
Shyamla		1.04	54.97	49.80	18.06
	Average	1.64	58.06	50.14	17.35
CD (5%)	W	1.04	NS	5.20	NS
	V	0.52	NS	6.37	0.99
	(W x V)	0.73	NS	NS	NS
	(V x W)	1.83	NS	NS	NS

The effect of water regime on filled grain number per panicle was not significant. The varietal differences and interaction was also not recorded significantly different. The decrease in filled grain number per panicle was observed highest and lowest in Indira A-9 and Mahamaya respectively. Drought significantly increases unfilled grains and such an increase was observed highest (97%) in Indira A-9 and lowest (46%) in Kranti. Under irrigated conditions the test weight was recorded highest in Mahamaya (25.07 g) and lowest in R-827-287(11.71 g). The reduction in test weight due to drought was highest in Indira A-9 (15.02%) and lowest in Kranti (2.83%).

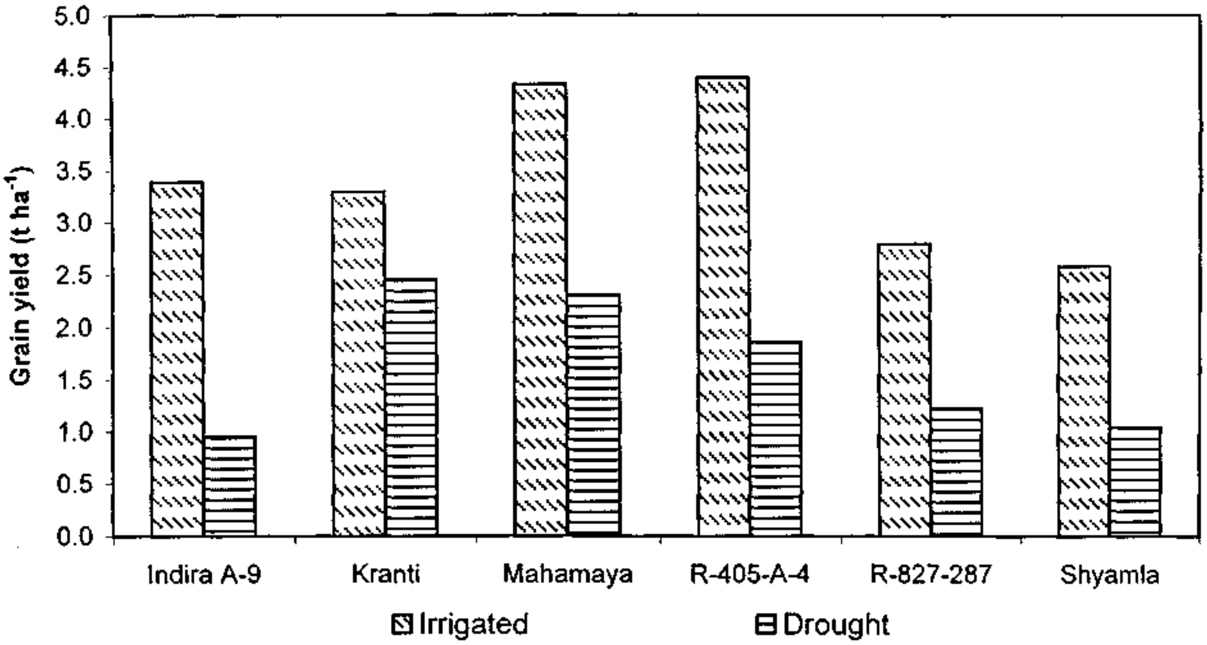

Fig. 20: Grain yield under irrigated and drought conditions of different varieties

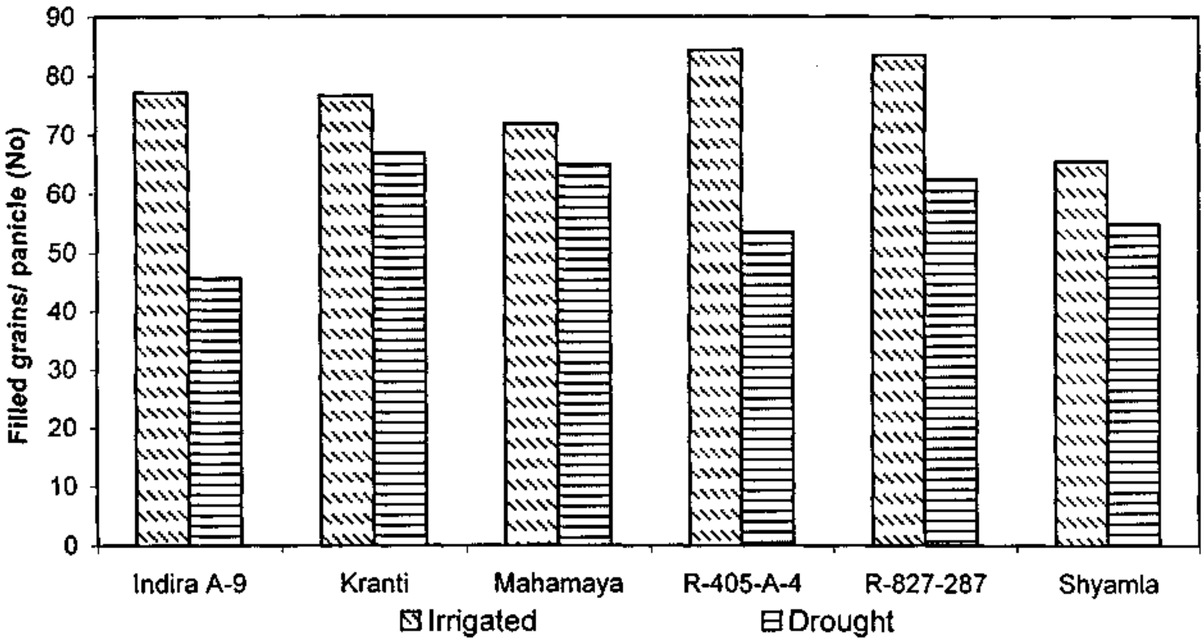

Fig. 21: Filled grain per panicle under irrigated and drought conditions of different varieties

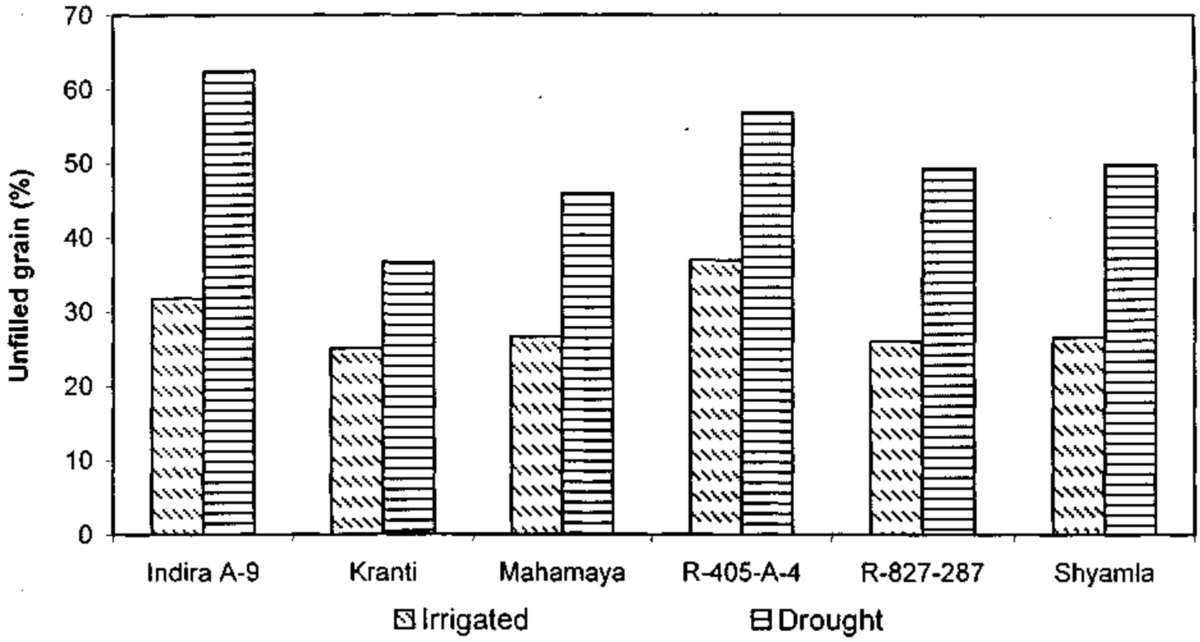

Fig. 22 : Per cent unfilled grain under irrigated and drought conditions of different varieties

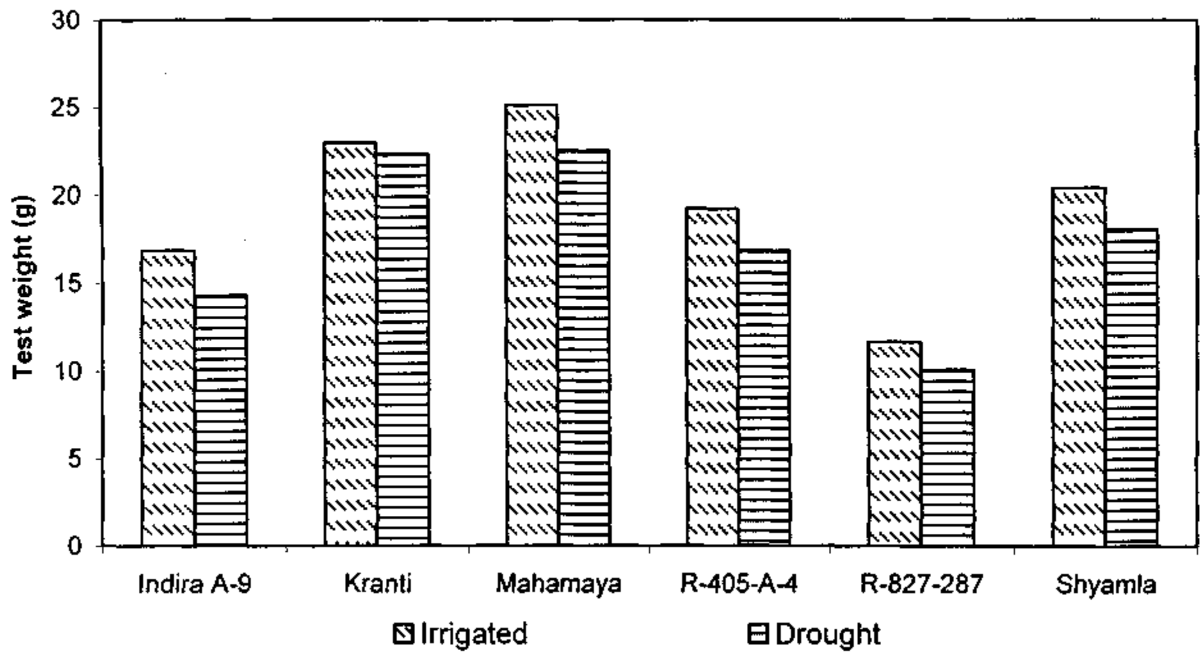

Fig. 23: Test weight under irrigated and drought conditions of different varieties

Discussion

CHAPTER-V

DISCUSSION

The objective of the present investigation was to understand the influence of drought stress on dry matter production ability and its partitioning into various plant parts, photosynthetic stability, membrane stability, contribution of flag leaf, and stem in yield building capacity, root characteristics, growth and water relation characteristics at different stages of growth and development in various rice varieties. The another objective of the current studies was to evaluate the contribution of various traits in improving the reproductive stage drought resistant in rice. Varieties were staggered in nursery to match the phenological stages during the experiment. Studied were conducted under field conditions and drought stress were imposed by withholding water supply after fifteen days of panicle initiation till maturity.Rainout shelters were installed to protect the drought plots from rains. Observation were recorded under irrigated and drought conditions at flowering stage, fifteen days after flowering and maturity.

From the results it was noticed that dry matter production capacity under drought reduced as the drought progresses from flowering to maturity (Fig.1a). Significant varietal variation were observed among varieties in terms of dry matter production capacity under drought. The dry matter production stability was observed highest in Kranti. Such a stability, in dry matter production was related with photosynthetic stability under drought. Indira A-9 and R-405-A-4 reduces the maximum dry matter and photosynthesis under drought. The results clearly indicates that the ability of varieties to continue relatively higher rate of photosynthetic activity under drought contributes significantly to the dry matter stability and drought resistance Thorne (1966) also reported that ability of plants to continue relatively higher rate of photosynthetic activity under drought, contributes significantly to the dry matter and yield. The stability in dry matter production under drought can also be related with root characteristics, which influence the water extraction capability of the cultivars. The higher root growth of Kranti and Mahamaya under drought as measured in terms of dry weight might have helped these varieties to extract more water from the soil as compared to other varieties. In water deficit situation, biomass production is a function of extractable soil water and this is related to the rooting pattern of the varieties (Puckridge and O'Toole, 1981).

The productivity of rice not only depends on the accumulation of total amount of dry matter, but its effective partitioning to economic part is a key to stabilize the yield particularly under reproductive stage drought stress conditions (Kumar *et al.* 2000). Under such conditions partitioning to economic part from stem play a important role in yield stability. The results showed that Kranti accumulates higher amount of dry matter in stem at flowering under drought compare to irrigated conditions. The reduction in stem dry matter under drought at maturity was also observed highest (39.19%) in Kranti compare to other varieties indicates higher amount of dry matter translocation from stem to economic part. The stem dry matter at maturity in Indira A-9 was equal in irrigated and drought conditions, indicates that dry matter was not diverted from stem. Such a low dry matter partitioning from stem in Indira-A-9 was associated with highest (61.90%) reduction in panicle dry matter at maturity under drought. Reyniers *et al.* (1982)

also reported that translocation of assimilates increases under stress in rice. Pre anthesis assimilates in wheat are also known to contribute to grain filling when drought occurs in the later stages of growth (Gallangher *et al.*, 1976)

Production of higher biomass is often fundamental to higher yield, so the photosynthetic activity of cells, leaves and plant have received much attention. In current studies R-405-A-4 photosynthesize at a higher rate under irrigated conditions at both the stages of measurements. Such a higher rate of photosynthesis in R-405-A-4 was related with highest dry matter production at all the stages and highest yield under irrigated conditions. Drought significantly reduces the photosynthesis rate at both the stages. Significant varietal differences were observed in terms of photosynthetic stability under drought. Kranti and Mahamaya showed the higher photosynthetic stability under drought upto fifteen days after flowering and was related with yield stability. The stability of photosynthesis in Kranti and Mahamaya under drought can be associated with maintenance of higher turgor due to the higher water potential of it 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 observed that tolerant genotype generally had higher photosynthesis than the susceptible genotypes. The photosynthetic stability under drought can be partly explained by low drought stress effect on stomatal conductance. The decrease in stomatal conductance under drought was observed lowest in Kranti compare to other varieties. Such a low reduction in stomatal conductance can be related with higher photosynthetic stability of Kranti. Hsiao (1973) attributed most of the decrease in photosynthesis under stress to stomatal closure. Barrs (1968) also concluded that stomatal control accounted for decrease in photosynthesis with increase in water deficit. However it was not clear from the current studies that to what extent the stomatal and non stomatal controls are responsible for reduction in photosynthesis under drought.

Transpiration rate under irrigated conditions was highest in R-405-A-4 and was related with higher stomatal conductance. The transpiration rate under drought decreases as the drought progress from flowering to fifteen days after flowering. Such a reduction in transpiration was associated with decreasing soil moisture as the drought progress (Choi *et al.*, 1999). The reduction in transpiration rate and stomatal conductance was recorded lowest in Kranti after fifteen days of flowering. Cabusley (1999) also reported that higher stomatal conductance under water deficit is responsible for higher transpiration rates in rice. The higher reduction in transpiration rate of other varieties can be related to the closing of stomata due to low leaf water potential (Hirasawaj *et al.*, 1999). The maintenance of higher transpiration rate by maintaining the higher stomatal conductance during drought in Kranti indicates that an efficient root and conductive system is keeping the aerial parts well supplied with water. The regular flow of water appeared to be supported by higher rate of transpiration. This type of regularization of water flow for maintenance of higher water potential has been reported by Uprety and Sirohi (1987).

The results related to phenology clearly showed that flowering is delayed under drought condition as compared to irrigated conditions. The flowering is delayed by eleven days in Indira A-9 under drought conditions. while, such a delay was not observed in Kranti. The delay in flowering under drought was related with drought susceptibility and vice versa. The varieties which delays their flowering experiences drought for a longer duration compare to those which do not delay flowering. Pantuwan *et al.* (2001) also reported that drought tended to delay flowering and larger delay in flowering was associated with higher reduction in grain yield, harvest index and percentage of fertile panicles and filled grains.

The reduction in plant height at maturity due to drought was observed lowest in Kranti. Such a low reduction in height was related with maintenance of higher leaf water status, which favours the shoot growth through cell enlargement and cell division (Boyer, 1968). Flag leaf contributes significantly to grain yield in rice (Padmaja Rao 1991). Drought significantly decreases the flag leaf area in current studies. The reduction in flag leaf area was observed highest (33.12%) in Indira A-9. The yield reduction was also highest in Indira A-9, indicates that stability in flag leaf area under drought contributes to yield stability. Hsiao *et al.* (1976) also reported that reduction in leaf area due to lower water potential appears to be the consequence of slowed cell enlargement.

Water potential decreases as the drought progress from flowering to fifteen days after flowering. Significant varietal variation were observed in maintaining water potential at flowering and fifteen days after flowering. Kranti and Mahamaya maintained relatively higher water potential at both the stages of measurements as compared to other varieties. Such a maintenance of higher water potential under drought helps in maintaining the membrane integrity and photosynthetic efficiency under drought. The less delay in flowering of Kranti and Mahamaya under drought was also related with maintenance of high water potential. These evidences suggest that the capacity to maintain high internal plant water status during 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/or water conservation by the plant and also internal plant water conductance during drought stress (Pantuwan *et al.* 2001).

Membrane stability has been associated with water drought tolerance in various crop plants (Sairam *et al.* 1999). It was noted that Kranti and Mahamaya showed higher membrane stability under drought. Higher membrane stability can be related with the maintenance of higher plant water status under drought. Lower membrane stability or higher injury reflects the extent of lipid peroxidation which in turn is a consequence of higher oxidative stress due to various environmental stresses (Leibler *et al.* 1986). The result shows that membrane stability can be used as indicator of drought tolerance. Premchandra *et al.* (1990) also reported that membrane stability can be used as a selection criteria to screen the germplasm for drought tolerance.

Biomass production under drought is a function of extractable soil water and can be related to the rooting pattern of the varieties. The results on root dry weight shows that Kranti and Mahamaya increases the root dry weight under drought conditions. Such an increase in root dry weight can be very helpful in water extraction from deeper soil layers in drying soil. Puckridge and O'Toole (1981) reported that crop growth and grain yield under drought strongly influenced by water extraction capability by deeper roots. The higher partitioning of dry matter into roots under drought in Kranti and Mahamaya can be responsible for maintenance of higher water potential, higher transpiration rate, higher membrane stability, higher photosynthetic stability which ultimately reflects in yield stability.

The studies showed that post flowering dry matter production under drought ranges from 10.12 g (R-827-287) to 424.12 g (Mahamaya). Kranti and Mahamaya showed lowest reduction in post flowering dry matter production under drought compare to other varieties. The stability in post flowering dry matter production was associated with photosynthetic stability, maintenance of higher water potential and higher membrane stability under drought. The delay in flowering due to drought was also related with low post flowering dry matter production.

Average apparent translocation rate from stem was observed higher under drought conditions as compare to irrigated controls. The increase in apparent translocation rate from stem under drought can be because of the lower availability of current photosynthates. Under such conditions plant is forced to depend on pre anthesis stored assimilates from stem. The increase in apparent translocation rate from stem under drought compare to irrigated conditions was highest in Kranti. The higher stem apparent translocation rate can be associated with yield stability in Kranti. Higher rate of dry matter translocation from stem under drought was also reported by Lu *et al.* (1998) in rice. Such a transfer of assimilates from stem were not observed in R 405-A-4, Shyamla and Mahamaya. The reduced translocation of stem reserves to panicle in R 405-A-4 and Shyamla under drought may probably the cause of its low grain yield. In Mahamaya higher current photosynthesis and post flowering dry matter production under drought compensate the low translocation of stem reserves to panicle and shows yield stability. An increase in stem apparent translocation rate under drought was related with yield stability particularly under reproductive stage drought (Kumar *et al.* 2000).

The results on grain yields shows that R-405-A-4 produces highest grain yields under irrigated conditions. Higher photosynthetic rate, higher stomatal conductance alongwith higher transpiration rate helps R-405-A-4 in achieving maximum grain yield under irrigated conditions. Significant varietal variation were observed among varieties in terms of yield stability under drought. The per cent yield reduction under drought ranges from 26 per cent (Kranti) and 72 per cent (Indira A-9). The lowest yield reduction in Kranti under drought can be associated with low reduction in photosynthetic rate due to drought, higher remobilization of stored assimilates from stem, less delay in flowering under drought, maintenance of higher leaf water potential and membrane stability. The results also indicates that genotypes with larger plant size were disadvantaged because they use more water and experienced higher water deficit than did smaller plant size varieties. The varieties like R-405-A-4 and Indira-A-9 could not maintain higher leaf water status under drought at flowering because they losses higher amount of water from its larger canopy. Wade *et al.* (2000) also reported that the effect of plant size before stress imposition was large. On the other hand Mahamaya maintained higher leaf water potential inspite of its big plant size at flowering possibly through higher water uptake by better root system. This enables Mahamaya to produce significantly highest amount of post flowering dry matter through higher current photosynthesis under drought. The small plant size of Shyamla favours the maintenance of higher leaf water potential and photosynthetic stability at flowering. However, Shyamala could not achieve the yield stability equal to Kranti due to delay in flowering and absence of assimilate translocation from stem to grains. R-827-287 increases the apparent translocation from stem under drought, but, failed to stabilize the yield due to very low post flowering dry matter production, delay in flowering and low leaf water status.

On the basis of above studies it can be concluded that a combination of several morpho-physiological traits confers drought resistance and may be used as indirect selection criteria to improve grain yield under reproductive stage drought.

Summary, Conclusion & Suggestions for Future Work

CHAPTER-VI

SUMMARY, CONCLUSION AND SUGGESTIONS FOR FUTURE WORK

It was noticed that dry matter production ability decreases as the drought progresses from flowering to maturity. Kranti showed highest dry matter production stability under drought. Maintenance of higher leaf water status and photosynthetic stability was related with dry matter production stability under drought. The accumulation of dry matter in stem at flowering was higher in Kranti under drought conditions compare to irrigated conditions. At maturity the reduction in stem dry matter under drought was also higher in Kranti. Such a higher accumulation of dry matter in stem at flowering and its subsequent reduction at maturity under drought shows that Kranti translocate higher amount of dry matter from stem to developing grains.

The higher photosynthetic in R-405-A-4 was related with higher dry matter and grain yield under irrigated conditions. Drought significantly reduces the photosynthetic rate. Significant varietal difference were observed in terms of photosynthetic stability under drought. Kranti and Mahamaya showed higher photosynthetic rate under drought upto fifteen days of flowering. The stability of photosynthesis under drought was related with maintenance of higher turgor due to the higher water potential of the leaves. Stomatal control was also found responsible for photosynthetic efficiency under irrigated and drought conditions. The transpiration rate decreases under drought conditions. Higher stomatal conductance was associated with higher transpiration rate. Regular flow of water seems to be supported by higher rate of transpiration under water deficit conditions.

Drought delayed the flowering. The maximum delay in flowering due to drought was observed in Indira A-9. The delay in flowering under drought was related with drought susceptibility. Drought significantly reduces the plant height at maturity. Kranti showed lowest reduction in plant height due to drought. The stability of flag leaf area under drought was also related with yield stability. Significant varietal variation were observed for maintenance of water potential under drought. Kranti and Mahamaya maintain relatively higher water potential compare to other varieties at both the stages. The delay in flowering due to drought can also be related with lower leaf water status.

Membrane stability was found higher in Kranti and Mahamaya compare to other varieties under drought. Lower membrane injury was related with maintenance of higher leaf water status under drought. The results showed that an increase dry matter partitioning into roots under drought can be very helpful in water extraction from deeper soil layers. Such a higher partitioning into roots was related with building higher leaf water status, membrane stability and photosynthetic stability. The translocation of dry matter from stem increases under drought possibly due to the reduction in current photosynthesis. The dry matter translocation from stem was recorded highest in Kranti compare to other varieties. The ability to translocate higher dry matter from stem was associated with reproductive stage drought resistance. The results also indicates that genotypes with larger plant size were disadvantaged because they use more water and experienced higher water deficit than did smaller plant size varieties.

Yield stability under drought was associated with less delay in flowering, maintenance of higher leaf water status, higher membrane stability, photosynthetic stability and higher translocation of stem dry matter to developing grains.

Conclusions:

1. Significant varietal variation were observed among varieties in terms of dry matter production capacity under irrigated and drought conditions.
2. The dry matter production stability was related with photosynthetic stability and higher leaf water status under drought.
3. The maintenance of higher transpiration rate by maintaining the higher stomatal conductance during drought was associated with an efficient root and conductance system.
4. Drought tended to delay flowering and larger delay in flowering was associated with higher reduction in grain yield, panicle, harvest index and percentage of filled grains.
5. The less reduction in plant height at maturity was related with maintenance of higher leaf water status which favours the shoot growth.
6. Flag leaf contribute significantly to grain yield. The stability in flag leaf area under drought contributes to drought resistance.
7. Maintenance of higher water potential under drought helps in maintaining the membrane integrity and photosynthetic efficiency.
8. Membrane stability can be used as indicator of drought.

9. The higher partitioning of dry matter into roots under drought was related with maintenance of higher water potential alongwith higher transpiration.

10. The stability in post flowering dry matter production under drought was associated with photosynthetic stability, maintenance of higher water potential and higher membrane stability.

11. An increase in stem apparent translocation rate under drought was related with yield stability at reproductive stage drought.

12. The results also indicates that genotypes with larger plant size were disadvantaged because they use more water and experienced higher water deficit than did smaller plant size varieties.

Suggestions for future work:

On the basis of results obtained from the present studies the future line of work are suggested:

1. Rice germplasm should be screened for different traits, associated with drought resistance.

2. Rapid and reliable screening techniques should be developed for screening the rice for drought resistance.

3. Quantitative trait loci should be identified for various traits responsible for drought resistance in rice.

4. Marker aided selection based introgression of major quantitative trait loci should be followed.

Abstract

Effect of reproductive stage drought on rice physiology

by

Robinson Sudhir Kujur

ABSTRACT

The present studies entitled "Effect of reproductive stage drought on rice physiology" was conducted at the Instructional Farm of IGAU, Raipur during wet season of 2000. The objectives of the study was to find out the effect of reproductive stage drought on dry matter production and its partitioning into various plant parts, photosynthetic stability, membrane stability, phenology, root growth, ability to maintain leaf water potential, contribution of stem to built grain yield, transpiration rate and yield of different rice varieties. Varieties were staggered in the nursery to match the phenological stages during experiment. Drought was imposed by stopping irrigation from fifteen days after panicle stage to maturity. Rain out shelters were used to protect the drought plots from rains.

Dry matter production capacity reduced under drought as the drought progress from flowering to maturity. The ability to maintain higher leaf water potential and photosynthetic stability was related with stability in dry matter production under drought. Drought tended to delay the flowering. The delay in flowering due to drought was associated with higher yield reduction. It was noticed that membrane stability contributes significantly to the drought resistance at reproductive stage drought. Crop growth and grain yield under drought was strongly influenced by the root growth. The varieties with good root system keeps the aerial parts well supplied with water. Such a regular flow of water was also reflected in higher transpiration rate. Translocation of dry matter from stem increases under drought conditions and was related with yield stability. The reproductive stage drought resistance in rice was related with photosynthetic stability, maintenance of higher leaf water potential, higher remobilization of stored assimilates to grain, higher root growth and less delay in flowering.

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