SOIL-WATER RELATIONS AFFECTING RICE ROOT POROSITY, TRANSPIRATION AND ION UPTAKE

A thesis
submitted to the
Uttar Banga Krishi Viswavidyalaya
in partial fulfilment of the requirements for the Degree of
Master of Science (Agriculture)

in

SOIL SCIENCE & AGRIL. CHEMISTRY

By

JYOTISH CH. TARAFDAR

DEPARTMENT OF SOIL SCIENCE & AGRIL. CHEMISTRY
Faculty of Agriculture
UTTAR BANGA KRISHI VISWAVIDYALAYA
Pundibari, Cooch Behar, West Bengal

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Dedicated
to my beloved
Parents

UTTAR BANGA KRISHI VISWAVIDYALAYA
FACULTY OF AGRICULTURE
DEPARTMENT OF SOIL SCIENCE & AGRIL. CHEMISTRY
P.O. Pundibari, Cooch Behar, West Bengal 736165, India

From :
Dr. Arun Kr. Saha
Reader & Head

Ref No. .... **Date** ...7:7:03.....

CERTIFICATE

This is to certify that the work recorded in the thesis entitled '**SOIL-WATER RELATIONS AFFECTING RICE ROOT POROSITY, TRANSPIRATION AND ION UPTAKE**' submitted by Shri Jyotish Ch. Tarafdar in partial fulfillment of the requirements for the degree of Master of Science (Agriculture) in Soil Science & Agril. Chemistry of the Uttar Banga Krishi Viswavidyalaya, is the faithful and bonafide research work carried out under my personal supervision and guidance. The results of the investigation reported in the thesis have not so far been submitted for any other Degree or Diploma. The assistance and help received from various sources during the course of investigation have been duly acknowledged.

A. K. Saha

(Arun Kr. Saha)
Chairman
Advisory Committee

APPROVAL OF EXAMINERS FOR THE AWARD OF THE DEGREE OF MASTER OF SCIENCE (AGRICULTURE) IN SOIL SCIENCE & AGRIL. CHEMISTRY

We, the undersigned, having been satisfied with the performance of Shri Jyotish Ch. Tarafdar, in the Post-submission Seminar on Final Evaluation of thesis, conducted today, the .... 2003, recommended that the thesis be accepted for the award of the degree of Master of Science (Agriculture) in Soil Science & Agril. Chemistry.

Name	Signature
1. Dr. A. K. Saha Chairman Advisory Committee	A. K. Saha ....
2. Dr. A. K. Saha Head of the Department	A. K. Saha ....
3. Dr. A. K. Ghosh Member Advisory Committee	....
4. Prof. (Dr.) A.K. Singha Roy Member Advisory Committee	....
5. Dr. D. Mukhopadhyay Member Advisory Committee	....

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Place: Pundibari, Cooch Behar
Date:

Jyotish Ch. Tarafdar
(Jyotish Ch. Tarafdar)

CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF PLATES

ABSTRACT

A pot experiment was conducted on a clay loam soil within the Glass house at Teaching and Instructional farm of Uttar Banga Krishi Viswavidyalaya, Pundibari, Cooch Behar, (Terai region of West Bengal) to investigate the influence of soil water regimes on Root Porosity, Transpiration, Nutrient uptake, Dry matter production and Yield of rice (*Oryza sativa* L.) varieties of MW 10 and IR 50 grown under flooded condition and field capacity.

A variations in soil moisture regimes from field capacity to flooding resulted in a great increase in the total root porosity, transpiration, nutrient uptake and dry matter production. Dry matter production and nutrient uptake showed a high positive correlation with the total amount of water transferred. The amount of water transferred per day per pot was positively correlated with the total root porosity per pot. More nutrient uptake as a results of increased availability of nutrients, together with greater transpirational transfer of water and ions facilitated by increased root porosity, resulted in an increase in the growth and yield of rice plant grown under flooded condition.

— Chapter-I —

INTRODUCTION

INTRODUCTION

Water is the principal factor limiting the plant growth. Water stress is commonly the most severe constraint to rice production (Widawsky and O'Toole, 1990). Only a fraction of about 1% of the total amount of water taken up by plant is retained in the plant tissue; yet this minute fraction is very important as because a small variation of it can make a great difference in the growth and yield of a crop. Water stress reduces the nutrient uptake which may be due to less absorption of water and nutrients by plant roots. Rice (*Oryza sativa* L.), being a semi-aquatic plant, is markedly influenced by the environment in which it is grown. Root growth in rice plant is frequently inhibited by adverse physiological environment resulting from soil water stress in rainfed farming and in upland conditions (Kar *et al.*, 1974). Unlike other plants, rice plant thrives well under submerged conditions (Chaklader, 1946; Jana and Ghildyal, 1969). Submergence brings a series of changes in physical, chemical and microbiological properties of soil which ultimately influence the nutrient uptake and yield of rice (Ponnamperuma, 1972; Tadano and Yoshida, 1978; Ponnamperuma , 1978, Ponnamperuma, 1984; Roger, 1996). The vegetative growth and grain yield of rice (*Oryza sativa* L.) are considerably higher when the crop is grown in flooded than in unsaturated fields, probably because of increased availability of nutrients, better soil-water-plant relationship (Clark *et al.*, 1957; Chaudhary and Mc Lean, 1963; Enyi, 1965; Ghildyal and Tomar, 1976) or because of better root growth and more transport of water through roots (Tomar and Ghildyal, 1975). The growth of rice under flooded condition may also increase be due to increase in evapo-transpiration (ET) as because a strong relationship exists between evapo-transpiration (ET) and dry matter production. Thus flooding results higher growth and yield of rice than field capacity or any other lower soil moisture regimes.

Though enormous amount of research was done on the growth of rice under different soil moisture condition, the mechanism of better growth under flooded condition is not fully understood. The better growth of rice plant under flooded condition may be due to increased availability of nutrient together with the anatomical changes in root tissue (e.g. root porosity) and physiological process (e.g. transpiration). But a very little work has been done to find out the effect of flooded condition on root porosity and transpiration which may contribute to the better growth of rice plant through more transfer of water and nutrients. The present investigation was therefore initiated to develop better understanding of the effect of soil moisture regimes on root porosity, transpiration, nutrient uptake, dry matter production at different stages of growth and finally marketable yield of rice plant. The objectives of the present investigate are :

i) To investigate the influence of soil-moisture regimes on root porosity and transpiration of IR50 and MW10 (Annanda) varieties of paddy at different stages of growth and at harvest,

ii) The effect of soil moisture regimes on uptake of plant nutrients with special reference to nitrogen (N), phosphorus (P), potassium (K), calcium (Ca) and magnesium (Mg) by IR 50 and MW 10 (Annanda) varieties of paddy and

iii) To investigate the influence of soil moisture regimes on growth and yield of IR 50 and MW 10 (Annanda) varieties of paddy.

Chapter-II

REVIEW OF LITERATURE

REVIEW OF LITERATURE

Water is the most important factor in rice cultivation. Water is a major constituent of tissue, a reagent in chemical reaction, a solvent for and mode of translocation for metabolites and minerals within plant and is essential for cell enlargement through turgor pressure. With the occurrence of water deficits many of the physiological processes associated with growth are affected and under severe deficits, death of plants may results. Submergence of the soil create the chemical and biological basis for a continuous renewal of the system's soil fertility (Ponnamperuma, 1984, Roger, 1996). Concentration of phosphorus, potassium, iron, manganese and silicon increases under submerged situation and increases the uptake of these nutrients elements.

This chapter deals with the review of literature regarding the effect of soil moisture regimes on root porosity, transpiration and nutrient uptake.

2.1 Root porosity of plants as influenced by soil-moisture regimes :

Root porosity may be defined as the volume of gas space per unit volume of root. It is one of the factors used in assessing internal aeration. Growth of plant roots require a supply of oxygen and an escape mechanism for liberation of carbon dioxide during respiration. The internal transfer of O_2 from shoots to roots within aerenchymatous cortical tissue is an important mechanisms for complete or partial avoidance of O_2-deficiency in many cereal species. Rice, being a semi-aquatic plant, the system of interconnected gas space or lacunae is very well developed (Armstrong, 1979), but the demand for O_2 is just as great as in non wetland species (Armstrong and Webb, 1985).

Studies have pointed out that aeration for rice roots can occur within the plant and without need of aeration through the soil. Norris (1913) observed that gas spaces were invariably present in the roots of *Zea mays* when cultured in water, but these were found to be reduced when the roots are grown in porous soil. Juliano and Aldama (1937) observed air channels in cortex of roots, stems and leaf blades of rice plant. Mepherson (1939) observed an increase in gas space of maize root tissue due to the death and decay of the protoplasm in root cells. He explained that below the critical oxygen pressure, in anaerobic respiration the cells used up food material more rapidly than they were being supplied by the conducting system and then destroyed themselves by autolysis, a common occurrence among starving cells. Boeke (1940) working with strongly developed adventitious roots of cultivated rice (*Oryza sativa* L.) was in agreement with Mepherson's (1939) openion that formation of air cavities could not be accounted by the action of mechanical forces during growth.

Barber *et al.* (1962) studied the movement of O^{15} through barley and rice plants and found that the movement of oxygen through rice and barley plants from the shoot to the root was simple gaseous diffusion processes through intercellular spaces. Gas spaces in rice plants contributed 5 to 30 per cent of the root tissue where as that of barley were below 1 percent.

Luxmoore and Stolzy (1969) in nutrient solution experiment with rice and maize plants reported that adventitious roots were more porous than primary roots indicating that adventitious roots had considerable significance in internal aeration. No effect of solution O_2 concentration on root porosity was observed by them which suggested that space development might be less dependent on oxygen supply. Jensen *et al.* (1967) also did not observe any significant effect of oxygen treatment on root porosity.

Luxmoore *et al.* (1970) in pot experiment with rice and maize plants reported that the root tip segment was characterized by the highest maximum respiration rate, highest permeability and lowest porosity. Both respiration rate and permeability decreased with distance from the root tip, whereas porosity increased. They stated that the linear increase in the porosity in first 6 cm from the root tip was indicative of a cumulative increase in the development of gas spaces resulting from differential cellular growth and from the decay of cells.

Saha *et al.* (1973) conducted a pot experiment to investigate the effect of soil water regimes on root porosity of two rice varieties grown under flooded and field capacity. They showed that a variation in the soil moisture regimes from field capacity to flooded condition resulting in a great increase in the total root porosity. The varietal differences of percent root porosity was observed and showed that root porosity (%) was more for 'IR-8' than for 'Jaya'. Root porosity (%) varied significantly with the stage of growth. Under flooded condition, it reached a peak on 20th day and subsequently there was a gradual decrease with the age of the plant. Under irrigation to field capacity, root porosity attained the maximum values on the 40th day and then decreased rapidly. They further showed that the total root porosity was parallel to the growth of the root and increased with an increase in the level of soil moisture and it also varied greatly with the stage of growth.

In submerged soils, the availability of water to roots was more owing to higher root porosity and lower root resistance to water transport (Sahu *et al.*, 1973; Tomar and Ghildyal, 1975), increasing the transpiration losses (Patel *et al.*, 1979). Under unsaturated soil-water regimes, limited supply of water, less root porosity and higher resistance might have resulted in lower rate of water uptake. As a result, the amount of water transpired was less under saturated and unsaturated soil water regimes than under submergence. Drenth *et al.* (1991) also reported the similar results that root porosity was higher in anaerobic soil than in aerobic soil, and that younger roots were more porous than older roots.

Justin and Armstrong (1991) carried out a study on two rice cultivars and reported that cavity formation in roots is controlled by endogenous levels of ethene and also showed that root porosity varied with root length and the inhibitory effect of the silver ion on aerenchyma development appeared to be greater. They also concluded that ethene had increased root porosity and $AgNO_3$ had decreased it and aerenchyma development in both cultivars was also enhanced by flooding, with percentage porosities 12 units higher in flooded than in drained soil.

A study was conducted by Sekhon *et al.* (1993) on the influence of soil redox conditions on root and shoot growth characteristics in rice and the results show that submergence alone increased (plant height, leaf area) root porosity, root, straw and grain weight. They also shows that root density tended to increase in surface layers with increase in reduction status of soil. Neue *et al.* (1997) reported that during ripening and maturity root exudation, root porosity and root oxidation power of rice may control methane emission rates.

2.2 Nutrient uptake as influence by soil moisture regimes :

Waterlogging causes changes in the properties of soils which profoundly affect the nutrition of low land rice. The root zone is changed from aerobic to anaerobic environment as a result of drastic decrease in the oxygen supply in the soil. Chaudhary and McLean (1963) reported that in a green house experiment with poorly drained mineral soil, rice plants grown under flooded conditions contained higher concentrations of phosphorus and manganese in shoots than those grown under unflooded condition. The concentration of iron in shoots did not change significantly due to flooded or unflooded conditions of soil. He explained that due to the lack of adequate supply of phosphorus and manganese in available form for rice might have contributed to the poor performance of rice plants under unflooded conditions. Workers of IRRI (1964) reported that phosphorus, potassium, calcium, magnesium, iron and manganese contents were more in rice plants grown under flooded condition than under unflooded condition. Enyi (1965) found that concentration of nitrogen, phosphorus, manganese, zinc, copper, molybdenum and boron in upland rice plants grown under flooded condition was higher than that of the plants grown under unflooded condition. In a green house experiment with two varieties paddy noted that uptake of potassium was unaffected by flooding, where as phosphorus uptake was lower at field capacity suggesting that phosphorus availability was higher under flooded condition. Cherian *et al.* (1968) in pot experiment with rice observed that uptake of iron, manganese and phosphorus was increased, but the uptake of calcium, magnesium, potassium and zinc was decreased by flooding the soil. Pande and Singh (969) reported that nitrogen, phosphorus, iron and manganese contents were more under continuous submerged conditions than under field capacity. In a pot experiment, the results shows that concentration of potassium, calcium & magnesium in shoots of rice plant decreased with the increase in soil moisture from field capacity to flooding but the case was reversed for iron and manganese (Sharma, 1970). Saha *et al.* (1973) reported that a variation in the soil moisture regimes from field capacity to flooded condition resulted in a great increase in nutrient uptake. They explained that the more nutrient uptake as a result of increase availability of nutrients, together with greater transpirational transfer of water and ions facilitated by increase root porosity. The increase in soil pH in acid soils under waterlogged condition has been reported by Mohanty and Patnaik (1975), which might be due to ferrous-ferric equilibrium (Ponnamperuma, 1972). Earlier laboratory experiments on submerged soils indicated increased availability of NH^{4+}-N (Mohanty and Patnaik, 1975), phosphorus (Mandal, 1964; Mohanty and Patnaik, 1977), iron and manganese (Ponnamperuma, 1977; Mohanty & Patnaik, 1977). Singh and Ram (1976) reported that the general trend of transformation of applied phosphorus was identical under field capacity and submergence in certain soils of Uttar Pradesh, the rate as well as the magnitude of transformation being higher under waterlogged conditions but Mandal and Khan (1976) did not find significant effect of water treatments on the phosphate transformation pattern in rice soils. Pillai and De (1979) reported that nitrogen uptake was more under continuous submergence than under alternate submergence. The uptake of phosphorus by rice in submerged soil was three to four times higher than in non-submerged soil and the high phosphorus content in the shoot tissue of plants grown under water logging might help the plants to elongate during submergence period (Bora and Goswami, 1980). The total nutrient uptake of nitrogen, phosphorus, potassium, calcium and magnesium under lowland situation were reported to 78.20, 22.14, 103.52, 10.23 and 27.18 kg/ha respectively under normal doses (60, 40, 40) of fertilizer application (Pande *et al.*, 1985). Saikia and Dutta (1989) conducted a two years field experiment and showed that the nitrogen uptake by grain and straw were significantly higher under continuous submergence and also increased with increasing levels of nitrogen.

Subramanian and Gopalswamy (1991) conducted an incubation study for a period of 45 days to study the influence of moisture, organic matter, phosphate and silicate on the availability of silicon and phosphorus in four rice soils. They observed that continuous submergence of soil and addition of organic matter resulted in an increase in the availability of silicon and phosphorus. The addition of silicon significantly increased the availability of silicon in all soils and available silicon and phosphorus increased initially and subsequently decreased with passage of time. Phosphorus transformation in four rice soils under different soil water regimes under laboratory conditions was studied by Kumaraswamy and Sreeramula (1992) and their results reviewed that in all soils solid phosphorus disappeared even in the early stages of incubation and most of added P was fixed initially as Al-P. Transformation of phosphorus into different inorganic -P fractions followed almost similar pattern under both soil water regimes. With passage of time, a portion of the Al-P was transformed into Fe-P in soils originally preponderant in this fraction and into Ca-P in the soil originally preponderant in Ca-P. Transport of the more soluble nutrient ions, such as NH^{4+} and K^{+} to the root surfaces is rapid enough in well-puddled flooded soils so that they do not limit uptake rates. But if the soil is not well-puddled or if it is dried and re-flooded, transport rates may become limiting (Kirk and Solvas, 1994). Patra *et al.* (1995) studied the effect of variable moisture treatments, namely air drying, 50 per cent water holding capacity, 100 per cent water holding capacity, continuous submergence and alternate and drying on the available potassium of five tarai soils have shown that the highest level of available potassium was maintained by 50% water holding capacity and lowest level of alternate wetting and drying. Continuous submergence was not found favourable for potassium availability.

Alam and Ladha (1997) pointed out that the P deficiency aggravates the drought effect by retarding the growth and delaying maturity of rice. This severity may be due to the alternate wetting and drying cycles in rainfed lowlands that may offset the increased P availability by submergence. Field experiment at the International Rice Research Institute (IRRI), during dry season was conducted by Castillo *et al.* (1998) and their results shows that in all fertilizer and crop establishment treatments, straw nitrogen concentrations of the stressed plants were higher than those of the well-watered plants. They explained that the high straw nitrogen concentration in the stress treatment could be attributed to the lack of complete senescence of the plants. They farther showed that grain nitrogen uptake in the stressed plants was lower than in the well-watered plants, mainly because of the significantly higher yield of the flooded treatment but the total nitrogen uptake in the stressed treatment was similar to that of the flooded treatment.

Zhang *et al.* (2000) showed that flooding strongly increased phosphorus adsorption and decreased phosphorus desorption in the paddy soil while simulated oxygen secretion from rice root significantly reduced phosphorus adsorption and enhanced both phosphorus desorption in rhizosphere and phosphorus uptake by ion-exchanger. They explained that the effect of oxygen secretion from rice root should be one of the important mechanisms for rice take up of phosphorus, normally under the conditions of phosphorus availability reduction by flooding. Phosphorus availability in the soil reduced by flooding should be one related to the transformation of phosphorus fractions because of Al-P fraction increased by phosphorus amendment in the soil was almost transformed into the Fe-P fraction by two week flooding.

2.3 Nutrient uptake at different stages of growth :

The process of nutrient uptake in rice at different stages of growth is the function of climate, soil properties, amount of fertilizers applied, variety and the method of cultivation (Ishizuka, 1964).

Dion *et al.* (1949) pointed out that the main absorption of phosphorus occurred before maturity. Tanaka *et al.* (1959) observed that uptake of phosphorus steadily increased and almost reached the maximum during the active tillering phase and thereafter absorption was negligible. Gama and Mellow (1960) found that phosphorus absorption increased until maturity and suggests that there would be an advantage in applying split amount of phosphatic fertilizers to rice. Bhumbla and Rana (1965) found that rice plant continued to take up phosphorus from soil even after the boot stage. But phosphorus applied at later stages of growth resulted in increasing phosphorus content of straw, and a very small percent of it was utilized for grain formation. Patnaik *et al.* (1965) conducted solution culture experiments with early and medium duration Indica and reported that phosphorus absorbed after tillering stage tended to be accumulated in straw and root with no advantage to grain yield. This result suggested that an early application of phosphorus is desirable. Sims and Place (1968) in a field experiment with rice reported that percent content of phosphorus did not differ with respect to plant age. As total uptake of phosphorus is closely related with dry matter production, it increased with plant age. They also reported that percentage content of potassium decreased with age of the plant but total potassium uptake increased with age of the plant.

Workers of IRRI (1964) flooded the rice field after 20 days of sowing and measured nutrient content at a regular interval of 3 weeks after flooding. They observed that the contents of phosphorus and potassium were high on the 3rd week after flooding and decreased with plant age while calcium, magnesium, iron and manganese contents continued to increase upto the 6th week and then decreased. Ishizuka (1964) reported that percentage of potassium and calcium in rice plant decreased after transplanting from the value obtained at seedling stage, then again increased and reached a high percentage after flowering until complete ripening while percentage magnesium was high from transplanting to middle of tillering.

2.4 Transpiration in relation to the soil moisture content, nutrient uptake and age of the rice plant :

The relationship between the rate at which water, rubidium and phosphorus ions are absorbed by intact plants and transferred to their shoots was investigated by Russel and Shorrocks (1959) in water culture under varying conditions of transpiration and nutrient supply. They reported that when the external concentration and the nutrient status of the plants were low, transpiration rate had little effect on the transportation of nutrients to shoots when the external concentration and the nutrient status of the plants are high the rate of transfer of ions to shoots varied closely with the rate of transpiration. Russel and Barber (1960) reported that when ions were transferred from the outer medium to the shoot, the movement of ions could be accelerated by increasing the rate of transpiration. Slatyer (1962) stated that transpiration could increase the uptake of nutrients specially when the requirements of the plant was high.

The workers of IRI (1965) reported that transpiration ratio (dry matter produced/water transpired) increased with the plant age possibly because of an increased ratio of respiration to photosynthesis. They compared the transpiration between flooded and unflooded condition and reported that under flooded condition, the water supply from roots to leaves was ample and the transpiration was parallel to the energy input of solar radiation. Under unflooded condition, the soil water supply was limited and the rate of water supply to the leaves could not match the rate of evapotranspiration from the leaves. Because of this transpiration was less under unflooded condition than under flooded condition. They also reported that increased light intensity caused increase of transpiration under flooded condition, but transpiration decreased with increase of light intensity under unflooded conditions.

Jana and Ghildyal (1969) reported that the atmospheric, soil and plant factors were involved in the process of evapo-transpiration. They found that water use by rice crop depends not only upon soil water regime and plant growth phase, but also on the environmental conditions of evaporative demand. Ghidyal (1971) observed that the amount of water transpired during its growth period and also the rate of transpiration per unit leaf area per time increased with increased in soil moisture regimes from unsaturation to flooding. He explained that the increased growth and dry matter production, where the transpirational transfer of water was more may also be due to the increased nutrient uptake as a result of mass transfer of ions through the transpiration stream. In a pot experiment Saha *et al.* (1973) showed that the amount of water transpired varied with the soil water regime and the stages of growth. They observed that under flooded condition, the increased availability of water to roots tends to increased transpirational losses than field capacity and the amount of water transpired under flooded condition was about twice that under field capacity.

Patel *et al.* (1976) reported that the cumulative evapotranspiration (ET) was very high under treatments where continuous submergence was maintained followed by altenate flooding and drainage and unsaturated soil-water regimes. The cumulative ET increased with crop growth and the rate of increase was maximum upto 62 days after transplanting. The evaporation decreased as the soil-water regimes were changed from submergence to saturation and then to unsaturation. Similar results were reported by Sahu *et al.* (1973), Ueki and Shanmugeratnam (1973) and Nair *et al.* (1973). In a lysimetery study, Patel *et al.* (1979) showed that the total ET was found to be very high under the soil water regimes in which continuous 5 cm submergence was maintained and they also reported that varieties of rice differed in their cumulative ET, water use and water use efficiency.

Sen and Jana (1987) reported that the evapotranspiration rate gradually increased with the age of the crop and it was maximum during 40 to 50 days after sowing and then slowly decreased. They also reported that this trend was observed under different soil moisture tensions during both the seasons and evapotranspiration rate was different under different soil moisture tensions. It was always higher under lower soil moisture tension than higher soil moisture tension. They explained that low evapotranspiration rate under high soil moisture tension was mainly due to higher resistance to the flow water vapour through soil (Ritchie, 1971). Evapotranspiration of direct seeded rice was determined by a floating type lysimeter during wet season and the value of ET was found to be 47.7 cm (Taha *et al.*, 1988). In a field trails with rice comparison was made between the panicle and flag leaf in their transpiration characteristics. Transpiration rate in the panicle reached a maximum at heading and decreased with aging. Transpiration rate in the panicle increased linearly as vapour pressure difference increased (Ishihara *et al.*, 1990). A series of green house and growth studies were conducted in 1985-86 and showed that by using the Poiseuille-Hagen law for water movement in capillaries, rice root axial resistance explained differences in leaf water potential and transpiration when only one cultivar was used, but did not explain differences among cultivars (Yambao, 1992). Thus it was concluded that increasing root xylem vessel radii profably will not directly increase drought resistance. Field experiment study on 8 rice cultivars at different soil-moisture regimes showed that transpiration decreased with crop age and was highest in plants continuously flooded and lowest in rainfed plants (Singh *et al.*, 1992). Transpiration rate of rice (*Oryza sativa*) were measured in a closed chamber and showed that transpiration rate increased until the heading stage and thereafter decreased (Saito *et al.*, 1996). They also showed that transpiration rate increased exponentially and at heading stage, it was maximum.

Sharma and Bhushan (1999) reported that the evapo-transpiration (ET) with time, irrespective of cultivar and water regime, followed the sigmoidal curve and ET in two cultivars behaved differently as the soil water regime changed from flooded condition saturation to 50 K Pa matric suction due to some physiological reasons. Varietal differences in rice for daily ET were minimal (Sugimoto, 1975) but only under adequate soil water regime. But the same is not true under deficient water conditions.

2.5 Growth of rice plant as influenced by soil moisture regimes :

Morphologically rice is a non-aquatic plant. Yet in submerged condition, rice plants behave their maximum growth. This fact has been established by Chaklader (1946), Workers of IRRI (1963, 1964, 1965), Halm (1967), Jana and Ghildyal (1969), Luxmoore and Stolzy (1969) and many other workers. Cherian *et al.* (1968) reported that the rice plants grown under flooded condition produced more fresh and dry weight than plants grown under field capacity. Pande and Singh (1969) found that yields, leaf area, number of effective tillers and ratio of sound to unsound grains were more under continuous submerged condition than under field capacity. Jana and Ghildyal (1969) reported that plants grown under flooded soil had greater dry weights of shoots and roots than those of the plants grown under non-flooded condition. Rao and Venkaleswarlu (1989) observed that moisture stress at reproductive and ripening stage is crucial for growth and productivity of rice. Mandal *et al.* (1991) reported that best growth and highest yield was obtained under continuous submergence than alternative wetting and drying methods and growth characters like plant height, tillering, straw yield were significantly influenced by continuous submergence. However, in Japan it has been reported that continuous ponding in the first half of the growing season and alternate drying and ponding in the later half enhance productivity of the rice crop (Watanabe, 1992). Budi and Suprihanto (1992) found that moisture stress imposed from panicle initiation to heading reduced grain yield upto 50% and when the moisture stress was imposed from heading to maturity, yield reduction was around 70%. Reports by Sekhon *et al.* (1993) suggested that the submergence increased shoot height, root, straw and grain weight. Significant differences in tiller numbers was observed due to cultivars, water regimes and soil type. They observed that the tiller number reduced due to stress in 10-47.1%. Observation of Misra and Panda (1994) showed that under shallow water table conditions, continuous saturation or intermittent ponding during the vegetative stages does not generally affect the significant grain yield of rice. Early cessation of rainfall and limited availability soil moisture lead to terminal stress and results in fewer grain number and poor grain filling (Krupp *et al.*, 1972). Similarly, root system and its development are strongly influenced by soil edaphic factors (Mambani *et al.*, 1990; Thangaraj *et al.*, 1990 and Sharma *et al.*, 1994) and large genotypic differences have been reported (Klepper *et al.*, 1984 and Yamanchi *et al.*, 1996) in their response to soil moisture stress. Chauhan *et al.* (1996) investigated the effect of soil moisture stress on growth and development of upland rice at 100, 80, 60 and 40% water holding capacity in pots and reported that the rice cultivars "Vandana" transpired less water than the rice cultivars "Brown gora" under stress conditions. They also reported that the effects of moisture stress become more apparent with age, particularly at 60 and 40% of water holding capacity. Chaudhary (1997) reported that the rice crop has specific plant development phases and characteristics when the crop water requirement is high and response pattern do change with differential irrigation regimes. Singh and Sharma (1997) found that higher grain yield under continuous ponding and under submergence two days after the disappearance of ponded water may be due to continuous readily available soil water that enhanced root growth, resulting in increased water and nutrient uptake. Besides this roots can markedly influence the activities of shoot (Torey, 1976) thus affecting the coordinated development of plant. Kondo *et al.* (2000) reported that in rice, water uptake, dry matter production in shoot and root length were largely suppressed under severe moisture stress compared to the mild moisture stress condition. Sarkar (2001) studed a field experiment to assess the performance of a common rice (IET 4786) under stressed (intermittent ponding) and non-stressed (continuous ponding) conditions and his results revealed that the highest grain yield was attained under continuous ponding, followed by under intermittent ponding in early.

Chapter-III

MATERIALS AND METHODS

MATERIALS AND METHODS

Pot experiment was conducted within the Glasshouse at Teaching and Instructional Farm of Uttar Banga Krishi Viswavidyalaya, Pundibari, Cooch Behar, Terai Region of West Bengal in the year 2002 (Feb to July) for studying "Soil-Water Relations Affecting Rice Root Porosity, Transpiration and Ion Uptake". The farm is situated at $26^0$19'N latitude and $89^0$23'E longitude and at an altitude of 43 m above mean sea level. This chapter deals with the materials used and the method followed to conduct this studies.

3.1 Meteorological Feature of the Experimental Site :

The climate of the terai zone is sub-tropical in nature with distinctive characteristics of high rainfall, high humidity and prolonged winter. There are practically two dominant seasons in a year – an extended winter or dry rabi season and a long rainy season. The wet or rainy season is characterized by hot and humid weather, heavy precipitation by South-West monsoon with cloudy overcast days and fewer hours of bright sunshine. The details of the meteorological parameters pertaining to the period of experimentation are presented in the table -1.

Table-1: Meteorological monthly mean data pertaining to the periods of experimentation. (2002-03)

Months	Temperature (Within glass house)	
	Max (^{0}C)	Min (^{0}C)
Feb	28.4	15.3
March	34.12	18.04
April	33.78	20.25
May	37.42	23.31

3.2 Collection of Soil :

Plough layer soil (0-15 cm depth) from Teaching and Instructional Farm of Uttar Banga Krishi Viswavidyalaya, Pundibari, was collected. Some physical and chemical properties of soil used in this investigation are given in the Table -2.

Table -2 : Physical and chemical properties of the soils

Properties of the soil	Value	Method of Determination
A. Physical :		International Pipette Method, Kilmer and Alexander (1949).
1. Mechanical Composition :		
a) Coarse sand	13%	
b) Fine Sand	10%	
c) Silt	48%	
d) Clay	28%	
2. Texture	Clay loam	
3. Single Value soil Constants :		Keen-Rackzowski Box measurement, Keen-Racksowski, (1921)
a) Maximum water holding capacity	70%	
b) Volume expansion	5.025%	
c) Bulk density of processed soil	0.932 gcm^{-3}	
d) Particle density of processed soil	2.296 gcm^{-3}	
e) Total Porosity	59.4%	
4. Saturated Hydraulic conductivity	1.053 x 10^{-4} cm sec^{-1}	Constant Head Permeameter as described by Baruah & Brathakur, 1997.
B. Chemical		
1. pH	5.76	Systronic glass-electrode pH meter using 1 : 2.5 soil-water ratio (Jackson, 1967)
2. Oxidizable organic carbon	1.02%	Modified Walkely & Black method as described in Jackson (1967)
3. Available Nitrogen (kg/ha)	210.5	Alkaline potassium permanganate method of Subbiah and Asija (1956)
4. Available Phosphorus (kg/ha)	23.53	Ascorbic acid reductant Method as described by Watanabe and Olsen (1965)
5. Available Potassium (kg/ha)	142.5	Flame photometer method – Black (1965)

3.3 Processing of soil and filling up pots :

The soil was air dried in the shade at room temperature. The air dry soil was crushed gently with the help of wooden-roller and passed through a 2 mm sieve. Nitrogen as urea @ 80 kg/ha, phosphorus as single super phosphate (SSP) @ 40 kg/ha and potassium as potassium chloride (MOP) @ 40 kg/ha were applied as basal dose and were mixed thoroughly with entire soil. 6 kg soil (on oven dry weight basis) was potted in polythene pot (30 cm height and 25 cm diameter) and then glasshouse studies were conducted.

3.4 Treatment and experimental design :

The treatments were 2 varieties of paddy, viz. IR50 and MW10 (Ananda); two moisture levels, viz. Flooding And Field capacity and different stages of growth starting from transplanting and 4 stages at a regular interval of 20 days after transplanting (DAT) and at harvesting. The analysis of variance was done using three factor C.R.D. considering, Factor 1= variety, Factor 2 = moisture levels and Factor 3 = stages of growth. All treatments were replicated 3 times. Thus in all, there were 60 planted pots. Besides these, there were 6 pots without any plants in which 3 pots were under flooded condition and remaining 3 pots were at field capacity.

3.5 Glasshouse studies :

Seedlings were grown in the nursery bed very near to the field from which the soil was collected. Treated seeds were soaked in water and were sown in the seed bed on 25th January, 2002. The percentage moisture retain in the soil at field capacity was determined by redistribution process after infiltration of ponding water for several hours. Measured amount of water was added in the pots to maintain field capacity and flooding condition of soil. Three seedlings in a hill of 31 days old were transplanted in all the pots on 25th Feb, 2002. Moisture levels were maintained by adding the amount of water which was lost due to evapo-transpiration (ET). Evapo-transpiration (ET) was measured by weighing the pots on every alternate days during the initial stages, afterwards, the weight has been taken every day. Evaporation from pots without any plant and having the other conditions similar as those of planted pots were also measured.

3.6 Sampling and preparation for analysis :

At the time of transplanting seedlings of the two varieties were taken separately. Plants samples were taken at a regular interval of 20 days after transplanting (DAT) in 4 stages and at harvest. For different stages and at harvest a set of 12 different pots were chosen. At the time of sampling plants were removed from each pot separately. The roots were washed to removed the adhering soils and the root portion were detached. Root porosity were then determined by Pycnometer method as describe in section-3.7. The shoots were air dried in shade and were placed in brown paper bags which was dried in an electric oven for 24 hours and the dry weight was recorded.

3.7 Measurement of root porosity :

Root porosity (volume of gas space/unit volume of root) was determined by Pycnometer method as given by Jensen *et al.* (1969).

The weight of root sample alone (W_r); the weight of root sample in a pycnometer bottle filled with water (W_{r+w}); the weight of ground root in Pycnometer bottle filled with water (W_h) and the weight of the bottle filled with water only (W_w) were taken and the root porosity in percentage (%) was calculated with the following formula,

$$\text{Percent root porosity} = \frac{W_h - W_{r+w}}{W_w + W_r - W_{r+w}}$$

3.8 Growth study :

At different stages and time of harvesting average number of tillers, height of plants, number of leaves and fresh weight of plant samples were measured. Dry weight of shoot were also recorded.

3.9 Determination of total nitrogen (N) :

Total nitrogen of plant sample was determined by modified Kjeldhal method as described by (Jackson, 1967). In this method plants samples were digested in H_2SO_4 at a temperature between 360 and 410^{0}C. The rate of digestion was accelerated by using K_2SO_4, $CuSO_4$ and selenium powder in the ratio of 100 : 10 : 1 and mercury oxide was also added. On completion of digestion 40% NaOH was added to the digested material for distillation. The distil ammonia was quantitatively absorbed in boric acid and titrated with standard sulfuric acid.

3.10 Wet digestion of plant tissues :

Oxidation of organic matter of plant tissue and release of mineral elements was done by means of solution of di acid mixture (Conc. HNO_3 and 60% $HClO_4$ mixed in a volume ratio of 3 : 1 respectively). Pre-digestion of plant tissue in HNO_3 prior to the addition of acid mixture were done first. The residue of the digested materials was dissolved in conc. HCl. The volume of digested materials was made up by double distilled water into the volumetric flasks. These solution were used for determination of inorganic elements such as P, K, Ca and Mg present in the plant tissue.

3.11 Determination of potassium (K) content :

Potassium content of the digested materials was estimated by Flame-Photometer (Systronic type -128) as described by Black (1965).

3.12 Determination of Calcium (Ca) and Magnesium (Mg) :

Calcium (Ca) and Magnesium (Mg) was determined by Complexometric titration using EDTA as described by Tucker and Kurtz (1961). EDTA forms a stable metal complex with many metals at different pH. The interference of metals other than Ca & Mg was removed by adding other chealiting compounds, like hydroxyl amine hydrochloride, potassium ferrocyanide etc.

3.13 Determination of phosphorus :

Phosphorus was determined by Vanadomolybdo-phosphoric yellow colour method in nitric acid system and the intensity of colour was read in UV-vis Spectrophotometer (Systronic type - 117) at 420 nm as described by Jackson (1967).

3.14 Symbols used :

F → Flooding

F.C → Field capacity

V_1M_1 → MW 10, Flooding

V_1M_2 → MW 10, Field capacity

V_2M_1 → IR 50, Flooding

V_2M_2 → IR 50, Field capacity

H → Harvest

Chapter-IV

RESULTS

RESULTS

4.1 Root porosity :

Rice root porosity under different soil water regimes at different stages of growth.

Percent root porosity and total root porosity for two varieties of paddy viz. MW 10 and IR 50 grown under two soil water regimes viz. flooding and field capacity at different stages of growth are shown in Table - 3 and Table - 4 respectively.

4.1.1 Percent root porosity :

The variation of percent root porosity with stages of growth are shown in Fig-1(a).

Percent root porosity varied with variety being more for MW 10 but variation between two varieties was insignificant. It also varied significantly with stages of growth. At seedling stage percent root porosity was 18.69 for MW 10 and 19.87 for IR 50. Under flooding it reached peak values of 27.33 for MW 10 on 60th day and 25.52 for IR 50 on 40th day after transplanting followed by subsequent decrease with plant age. Under field capacity it was minimum on 20th day and attained a maximum value of 20.97 for MW 10 and 18.05 for IR 50 on 60th day after transplanting and then decreases with plant age.

The difference of percent root porosity between two soil moisture regimes was significant at all stages. It was more under flooding than field capacity. Under flooding it ranged between 11.16 to 27.33 for MW 10 and 17.10 to 25.53 for IR 50. Under field capacity it varied within a limit of 11.16 to 20.97 for MW 10 and 12.70 to 18.05 for IR 50.

4.1.2 Total root porosity :

The variation of total root porosity with stage of growth are presented in Fig.-1(b).

Total root porosity tended to be more for MW 10 than for IR 50. It also varied greatly with stages of growth. At seedling stage it was 0.1338 cm^3/pot for MW 10 and 0.1324 cm^3/pot for IR 50. Total root porosity for MW 10 and IR 50 reached a peak values of 180.88 cm^3/pot and 144.83 cm^3/pot respectively under flooding and 46.27 cm^3/pot and 35.41 cm^3/pot under field capacity on 60th day after transplanting and then decreased with plant age. Under flooding the increase was gradual from the day after transplanting to 20th day and sharp from 20th to 60th day but under field capacity the increase was negligible from the day after transplanting to 20th day and gradual from 20th to 60th day .

Total root porosity also varied greatly with soil moisture regimes, being more under flooding. Under flooding it ranged from 9.92 cm^3/pot to180.88 cm^3/pot for MW 10 and 6.73 cm^3/pot to 144.83 cm^3/pot for IR 50. Under field capacity it varied between 1.30 cm^3/pot to 46.27 cm^3/pot for MW 10 and 1.08 cm^3/pot to 35.41 cm^3/pot for IR 50.

Table -3. Percentage root porosity under different soil water regimes at different stages of growth.

Days after transplanting	Root porosity (%)			
	MW 10		IR 50	
	F	Fc	F	Fc
0	18.69		19.87	
20	21.03	12.39	17.10	12.86
40	22.96	16.75	25.52	13.01
60	27.33	20.97	23.51	18.05
80	11.16	11.66	17.66	12.70

C.D. at 5%

a) For two variety : 0.668
b) For two moisture levels : 0.668
c) For 4 stages of growth : 0.944

Table-4. Total root porosity under different soil water regimes at different stages growth

Days after transplanting	Total root porosity (cm^3)			
	MW 10		IR 50	
	F	Fc	F	Fc
0	0.133		0.132	
20	9.923	1.304	6.737	1.089
40	72.245	28.578	66.330	19.114
60	180.881	46.273	144.835	35.417
80	75.273	24.885	107.836	20.730

4.2 Water relation under varies soil water regimes at different stages of growth

4.2.1 Transpiration :

It is the process through which soil water passes into the atmosphere through the tissues of a aerial parts of living plant such as leaves, green shoot etc. The variation of water transpired per day per pot (3 plants) with stages of growth are presented in the Fig.-2 and the experimental results are shown in Table - 5.

Table-5. Transpiration under varying soil water regimes at different stages of growth

Days after transplanting	Transpiration (ml/day/pot)			
	MW 10		IR 50	
	F	Fc	F	Fc
20	20.33	18.00	18.08	16.83
40	44.90	16.33	23.75	15.91
60	117.26	18.61	54.02	16.94
80	172.52	19.43	155.87	18.50
Harvest	164.48	15.36	145.13	11.39

The amount of water transpired per day per pot tended to be more for MW 10 than for IR 50 under flooded condition. Under field capacity it was almost same for both the varieties. It varied greatly with stages of growth. Under flooding it increased rapidly to the values of 172.52 ml for MW 10 and 155.87 ml for IR 50 on 80th day after transplanting and then decreased slightly with plant age . Under field capacity it remained almost constant upto 80 days and then decreased slightly with plant age. As soil water regimes varied from field capacity to flooding, the amount of water transpired per day per pot increased greatly. Under flooding it ranged between 20.33 ml to 172.52 ml for MW 18.08 to 155.87 ml for IR 50. Under field capacity the corresponding values were 18.0 ml to 19.48 ml for MW 10 and 16.83 ml to 18.50 ml for IR 50.

4.2.2 Transpiration ratio :

It is the amount of water transpired for production of unit amount of dry matter. The variation of transpiration ratio are presented graphically in Fig.-3 and the experimental results are shown in Table - 8.

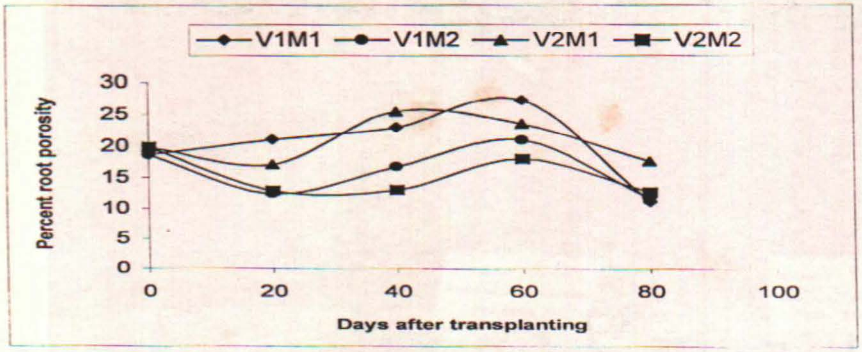

Fig. 1(a) : Changes in percent root porosity of rice under varying soil moisture regimes at different stages of growth

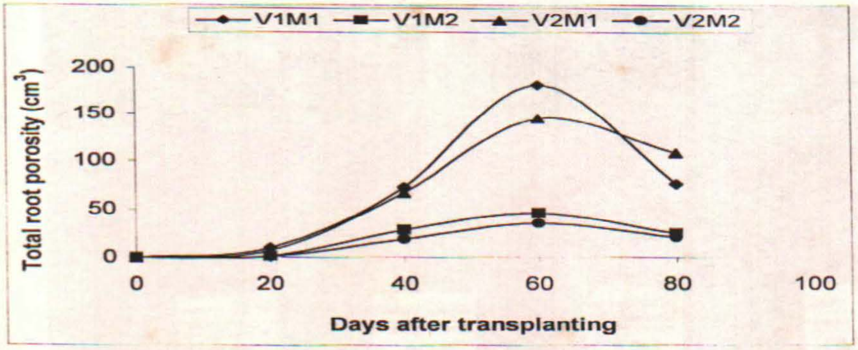

Fig. 1(b) : Changes in total root porosity of rice under varying soil moisture regimes at different stages of growth

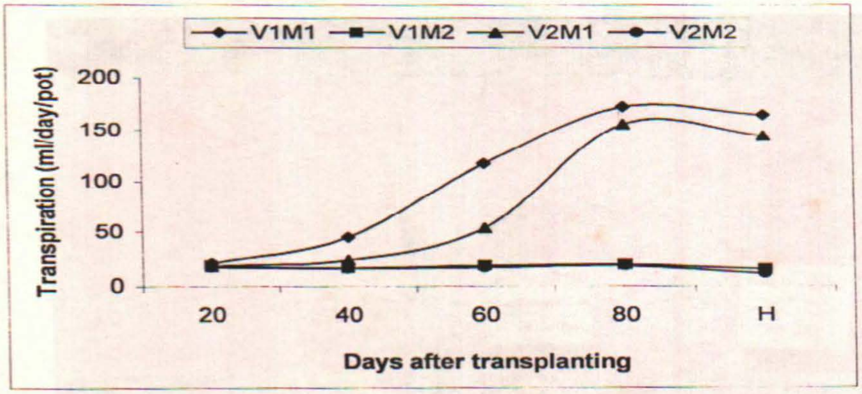

Fig. 2 : Transpiration under varying soil water regimes at different stages of growth

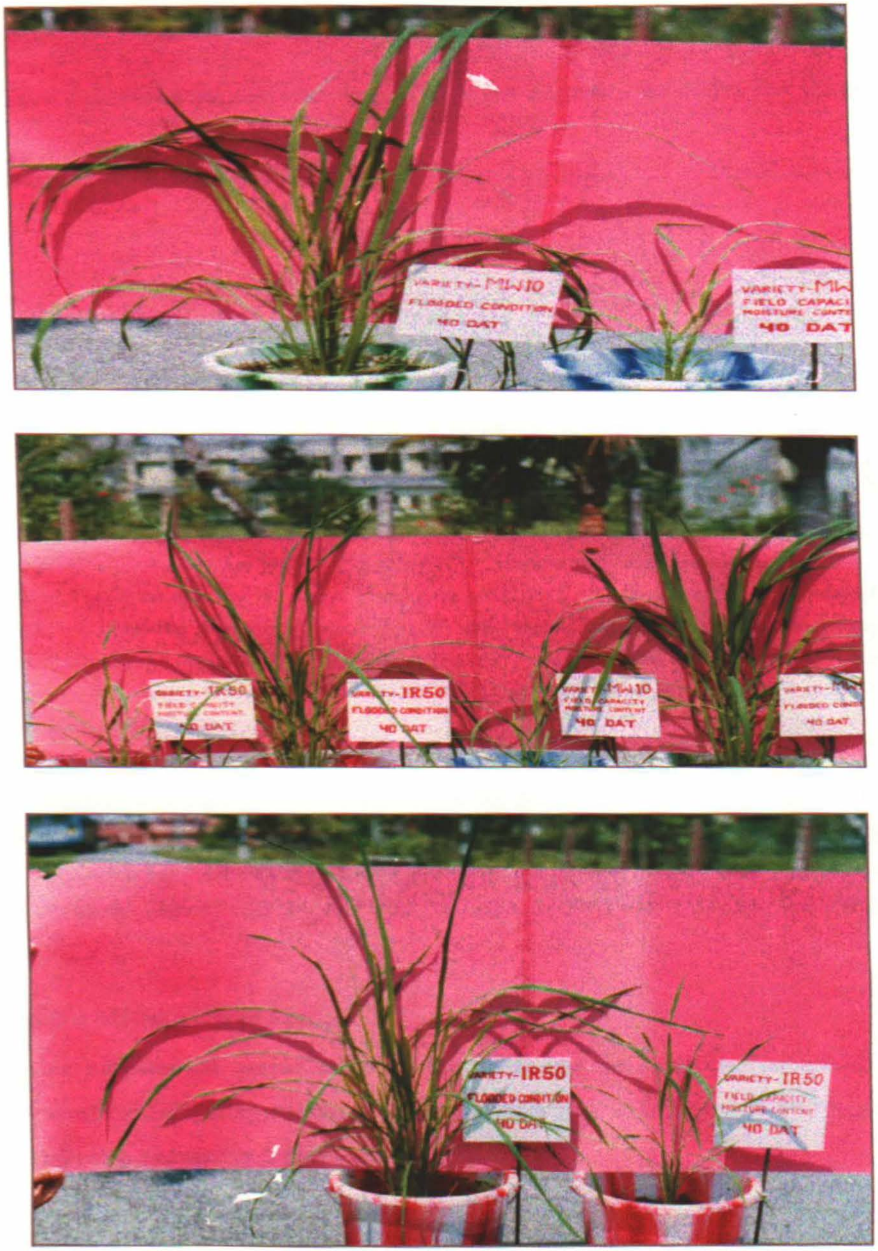

Plate 1: Plant height and growth at 40 days after transplanting

Table - 8. Water relations under varying soil water regimes at different stages of growth.

Days after transplanting	MW10					
	Transpiration ratio		Transpiration efficiency		Transpiration (ml)	
	F	Fc	F	Fc	F	Fc
20	677.71	900.00	0.0014763	0.0011116	406.66	360.00
40	311.94	893.45	0.0032153	0.0011210	1796.00	653.33
60	632.04	482.85	0.0015816	0.0020843	7035.66	1116.66
80	646.46	271.70	0.0015520	0.0036833	13802.33	1559.00
H	516.70	163.34	0.0019133	0.0061570	18915.33	2258.33

IR50

Days after transplanting	Transpiration ratio		Transpiration efficiency		Transpiration (ml)	
20	641.67	930.58	0.0015646	0.0010851	361.66	336.66
40	229.36	921.28	0.0043700	0.0010967	950.00	636.66
60	378.28	899.98	0.0026500	0.0011126	3241.66	1016.66
80	793.58	386.35	0.0012636	0.0026110	12470.00	1480.66
H	586.05	168.59	0.0017100	0.0059340	16690.00	1675.00

Transpiration ratio was very much affected with variety. It tended to more for IR50. Under flooding it was more for MW10 upto 60^{th} while the condition became reversed from 80^{th} day .But under field capacity it was more for IR 50. The variation in transpiration ratio at different stages of growth were noteworthy. Under flooding it decreased to a minimum value on 40^{th} day ,then increased to maximum value on 80^{th} day again decreased with plant age .Under field capacity it remained almost same upto 40^{th} day for MW10 and 60^{th} day for IR50 and then decreased sharply with plant age

The difference in transpiration ratio for two moisture levels was significant, being more under field capacity .Transpiration ratio was more under field capacity upto 40^{th} day for MW 10 than under flooding but the condition became reversed afterwards. Under flooding it ranged between 311.94 to 677.77 for MW 10 and 229.36 to 793.58 for IR 50. The corresponding values under field capacity were 163.34 to 900.00 and 168.59 to 930.58 for MW 10 and IR 50 respectively.

4.2.3. Transpiration efficiency :

It is the amount of water used in transpiration for production of unit amount of dry matter. The variation of transpiration efficiency with stages of growth were presenting in Fig-4. and the results being shown in Table - 8.

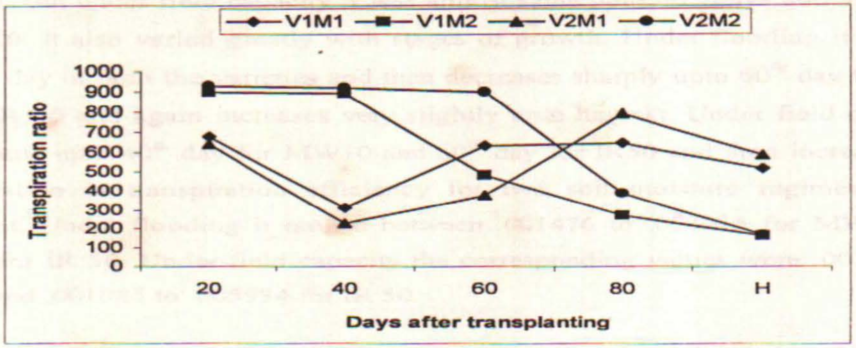

Fig. 3 : Transpiration ratio under varying soil moisture regimes at different stages of growth

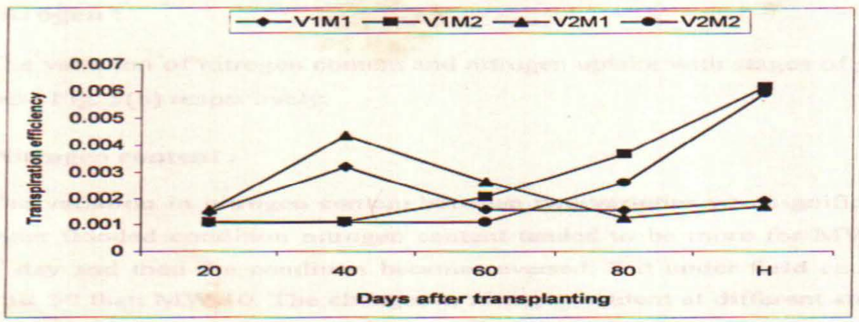

Fig. 4 : Transpiration efficiency under varying soil moisture regimes at different stages of growth

The variation in transpiration efficiency for the two varieties varied greatly with stages of growth. Under flooding it was more for IR 50 upto 60th days and for rest of the period it was less for IR 50. But under field capacity it was almost same upto 40th days and then it be came more for MW10. It also varied greatly with stages of growth. Under flooding it increased gradually upto 40th day in both the varieties and then decreases sharply upto 60th day for MW 10 and 80th day for IR 50 and again increases very slightly upto harvest. Under field capacity it remained almost same upto 40th day for MW10 and 60th day for IR50 and then increased with plant age. The variation in transpiration efficiency for two soil moisture regimes was found to be significant. Under flooding it ranged between .001476 to .003215 for MW 10 and .00126 to .004370 for IR 50. Under field capacity the corresponding values were .001111 to .006157 for MW 10 and .001085 to .005934 for IR 50.

4.3 Nutrient content and nutrient uptake by shoot under different soil moisture regimes at different stages of growth.

At different stages of growth the nitrogen, phosphorus, potassium, calcium and magnesium content and uptake for MW 10 and IR 50 varieties of paddy, grown under flooding and field capacity are given in Table-6 and Table-7 respectively.

4.3.1 Nitrogen :

The variation of nitrogen content and nitrogen uptake with stages of growth are shown in Fig5(a). and Fig. 5(b) respectively.

4.3.1.1 Nitrogen content :

The variation in nitrogen content between two varieties was significant, being more for IR50. Under flooded condition nitrogen content tended to be more for MW 10 than for IR 50 upto 40th day and then the condition became reversed. But under field capacity it was always more for IR 50 than MW 10. The changes in nitrogen content at different stages of growth were noteworthy. At seedling stage percent nitrogen content for MW 10 and IR 50 was 2.8 and 2.82 respectively. Under flooding it increased to the maximum values of 3.720 for MW 10 and 3.738 for IR 50 on 20th day after transplanting and then decreased continuously to a value of 1.16 for MW 10 and 0.96 for IR 50. Similar results was also obtained under field capacity and its value ranged from 1.78 to 3.323 for MW 10 and 1.843 to 3.297 for IR 50. The variation in percent nitrogen content for the two moisture levels was significant. It increased as the soil moisture regimes varied from flooding to field capacity. Under flooding it varied from a maximum of 3.72 to a minimum of 1.16 for MW 10 and from maximum of 3.728 to a minimum of 0.96 for IR 50 whereas under field capacity the corresponding values were 3.323 to 1.780 for MW 10 and to 1.843 for IR 50.

Table -6. Nutrient content of shoot under different soil water regimes at different stages of growth

Days after transplanting	MW10 (%)									
	N		P		K		Ca		Mg	
	F	Fc	F	Fc	F	Fc	F	Fc	F	Fc
0	2.8		0.32		2.86		0.38		0.36	
20	3.720	3.323	0.455	0.341	3.147	3.290	0.500	0.403	0.374	0.364
40	2.743	3.117	0.329	0.217	2.150	2.197	0.442	0.360	0.413	0.401
60	2.173	2.763	0.218	0.183	1.517	1.647	0.262	0.227	0.290	0.283
80	1.373	2.133	0.203	0.141	1.300	1.287	0.390	0.310	0.310	0.330
Harvest	1.160	1.780	0.179	0.118	1.133	1.150	0.405	0.390	0.378	0.360

Days after transplanting	IR50 (%)									
	N		P		K		Ca		Mg	
	F	Fc	F	Fc	F	Fc	F	Fc	F	Fc
0	2.82		0.41		2.94		0.36		0.37	
20	3.738	3.297	0.456	0.375	3.071	3.240	0.450	0.390	0.383	0.352
40	3.057	3.257	0.374	0.249	2.210	2.190	0.413	0.350	0.399	0.400
60	1.803	3.060	0.295	0.203	1.663	1.480	0.253	0.217	0.257	0.257
80	1.300	2.547	0.261	0.162	1.283	1.253	0.357	0.332	0.292	0.330
Harvest	0.960	1.843	0.240	0.138	1.170	1.120	0.392	0.401	0.377	0.370

CD. at 5%	N	P	K	Ca	Mg
a) For two variety	0.043	0.004	0.022	0.006	0.028
b) For two moisture levels	0.043	0.004	0.022	0.006	0.028
c) For five stages of growth	0.068	0.006	0.035	0.010	0.406

Table -7. Nutrient uptake by shoot under different soil water regimes at different stages of growth. (mg/pot)

Days after transplanting	MW10									
	N		P		K		Ca		Mg	
	F	Fc	F	Fc	F	Fc	F	Fc	F	Fc
0	1.92		0.219		1.961		0.260		0.240	
20	22.293	13.267	2.728	1.393	18.880	13.160	3.000	1.611	2.240	1.353
40	158.247	21.800	18.958	1.588	123.963	16.073	25.443	2.637	23.833	2.937
60	241.213	64.400	24.307	4.251	168.767	38.667	29.177	5.273	32.320	6.427
80	293.333	122.293	41.396	8.100	269.747	73.773	83.527	18.787	66.273	18.40
Harvest	321.463	137.360	46.641	10.409	286.313	91.167	95.373	29.467	92.537	28.873
Days after transplanting	IR50									
	N		P		K		Ca		Mg	
	F	Fc	F	Fc	F	Fc	F	Fc	F	Fc
0	2.658		0.386		2.772		0.339		0.348	
20	21.167	14.267	2.583	1.374	17.397	11.870	2.550	1.433	2.163	1.290
40	124.733	23.183	15.220	1.743	89.833	14.200	16.787	2.457	16.193	2.797
60	155.100	36.033	25.350	2.305	142.740	17.840	21.720	4.447	22.060	3.013
80	198.787	90.633	41.057	5.840	201.987	47.227	56.080	12.380	45.877	12.560
Harvest	221.657	114.967	48.777	8.416	228.677	59.840	73.847	20.333	70.123	19.947

C.D. at 5%	N	P	K	Ca	Mg
a) For two variety	3.72	0.422	2.433	1.086	0.975
b) For two moisture levels	3.72	0.422	2.433	1.086	0.975
c) For five stages of growth	5.881	0.667	3.847	1.718	1.542

4.3.1.2 Nitrogen uptake :

Nitrogen uptake was more for MW 10 than for IR 50. At seedling stage it was 1.92 mg/pot for MW10 and 2.658 mg/pot for IR 50. It increased with increase of plant age. Under field capacity the rate of uptake was slow up to 40^{th} day for MW10 & 60^{th} day for IR50; rapide upto 80^{th} & gradual afterwards. Under flooding for MW 10 the rate uptake was slow upto 20^{th} day, very sharp from 20^{th} day to 60^{th} day, rapid from 60^{th} to 80^{th} day and gradual from 80^{th} day to harvest; but for IR 50 it was slow upto 20^{th} day, sharp upto 40^{th} day and gradual afterwards.

Nitrogen uptake increased greatly with increase of soil moisture regimes. Under flooding nitrogen uptake /pot ranged between 22.29 mg to 321.46 mg for MW 10 and 21.17 mg to 221.66 mg for IR 50, while the corresponding values ranged for field capacity 13.27 mg to 137.36 mg for MW 10 and 14.27 mg to 114.97 mg for IR 50.

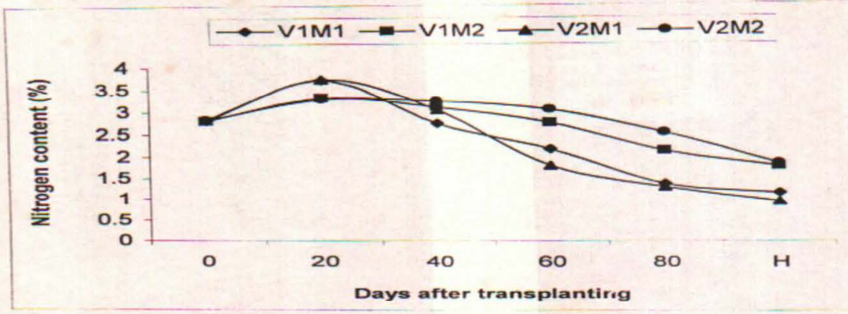

Fig. 5(a). : Changes in nitrogen content (%) of rice at different stages of growth

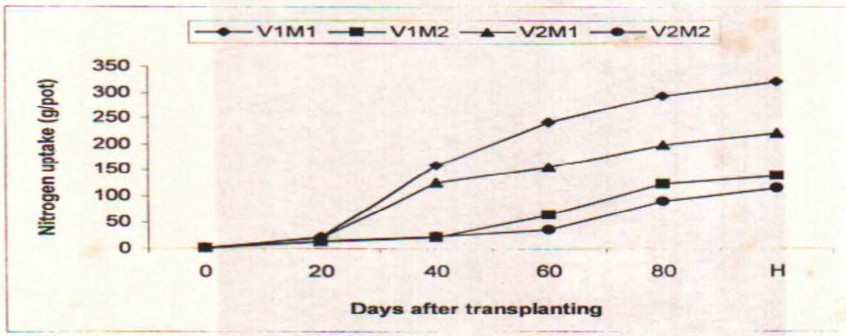

Fig. 5(b). : Changes in nitrogen uptake of rice at different stages of growth

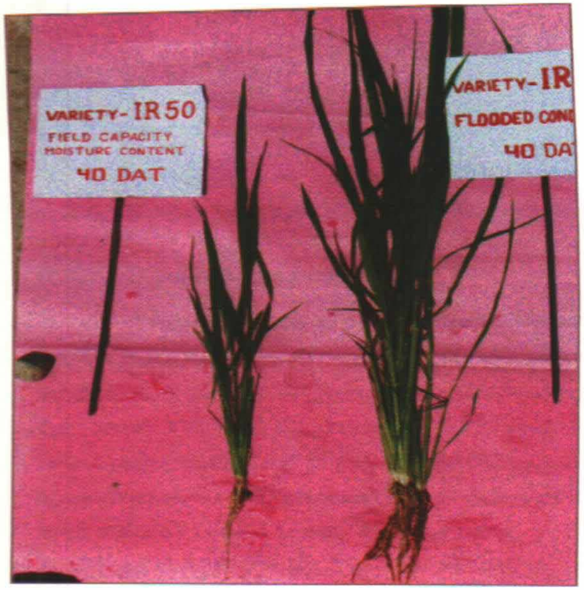

Plate 2: Plant height and root growth at 40 days after transplanting

4.3.2 Phosphorus :

The variation of phosphorus content and phosphorus uptake with stages of growth are shown in Fig. 6(a) and Fig. 6 (b) respectively.

4.3.2.1 Phosphorus content :

The variation in phosphorus content for the two varieties was significant. It was more for IR 50 than for MW 10 under both the soil moisture regimes. The changes in phosphorus content at different stages of growth were noteworthy. At seedling stage percentage phosphorus content for MW 10 and IR 50 was 0.32 and 0.41 respectively. Under flooding it increase to the maximum values of 0.455 for MW 10 and 0.456 for IR 50 on 20th day after transplanting and then decreases continuously to a value of 0.179 for MW 10 and 0.240 for IR 50. Similar results was also obtained under field capacity and its value ranged from 0.118 to 0.341 for MW 10 and 0.138 to 0.375 for IR 50. The variation in percentage phosphorus content for the two moisture levels was significant. It increased as the soil moisture regimes varied from field capacity to flooding. Under flooding it varied from a maximum value of 0.455 to a minimum value of 0.179 for MW 10 and from a maximum of 0.456 to a minimum of 0.24 for IR 50. Whereas under field capacity the corresponding values were 0.341 to 0.118 for MW 10 and 0.375 to 0.138 for IR 50.

4.3.2.2 Phosphorus uptake :

Phosphorus uptake was more for MW 10 than for IR 50. At seedling stage it was 0.219 mg/pot for MW 10 and 0.386 mg/pot for IR 50. It increased with increase of plant age. The rate of uptake was slow upto 20th day under flooding but for field capacity it was upto 40th day after wards. Under flooding it became rapid from 20th day to 80th day and slow. Under field capacity the rate of uptake was gradual from 40th to harvesting stage.

Phosphorus uptake varied significantly with variation of soil moisture regimes. It was much more under flooding than field capacity. Under flooding phosphorus uptake per pot ranged between 2.728 mg to 46.641 mg for MW 10 and 2.583 mg to 48.777 mg for IR 50. While the corresponding values for field capacity ranged from 1.393 mg to 10.409 mg for MW 10 and 1.374 mg to 8.416 mg for IR 50.

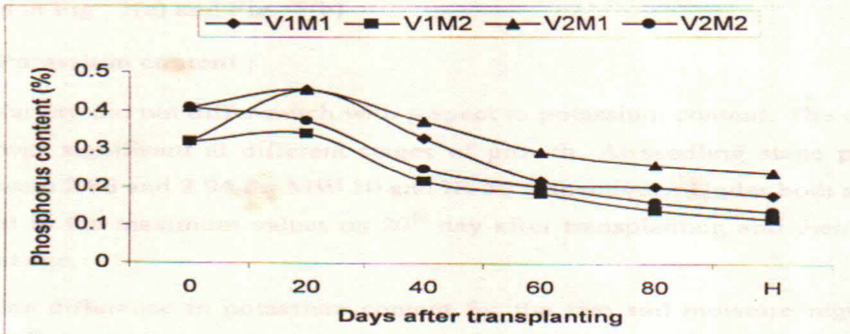

Fig. 6(a). : Changes in phosphorus content (%) of rice at different stages of growth

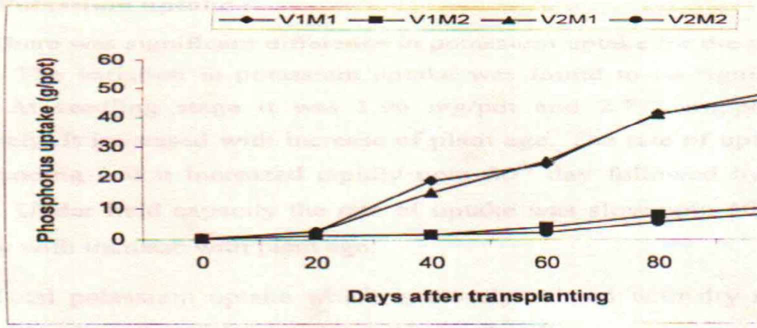

Fig. 6(b). : Changes in phosphorus uptake of rice at different stages of growth

4.3.3 Potassium :

The variation of potassium content and potassium uptake with stages of growth are presented in Fig. 7(a) and Fig. 7(b)

4.3.3.1 Potassium content :

Variety did not differ much with respect to potassium content. The changes in potassium content was significant at different stages of growth. At seedling stage percentage potassium content were 2.86 and 2.94 for MW 10 and IR 50 respectively. Under both soil moisture regimes it reached to the maximum values on 20th day after transplanting and then decreased gradually with plant age.

The difference in potassium content for the two soil moisture regimes was significant only on 20th day after transplanting; the content being more under field capacity. On 20th day the values were 3.147% for MW 10 and 3.071% for IR 50 under flooding and 3.29% for MW 10 and 3.24% for IR 50 under field capacity. Rest of the growth period the values were insignificant between the soil water regimes. Under flooding the variation of percent potassium content was from 1.133 to 3.147 for MW 10 and 1.170 to 3.071 for IR 50. The corresponding variations under field capacity were from 1.150 to 3.290 for MW 10 and 1.12 to 3.240 for IR 50.

4.3.3.2 Potassium uptake :

There was significant difference in potassium uptake for the two varieties, being more for MW 10. The variation in potassium uptake was found to be significant at different stages of growth. At seedling stage it was 1.96 mg/pot and 2.772 mg/pot for MW 10 and IR 50 respectively. It increased with increase of plant age. The rate of uptake was slow upto 20th day under flooding and it increased rapidly upto 80th day followed by a reduction in the rate of increase. Under field capacity the rate of uptake was slow upto 40th day and then it increased gradually with increase with plant age.

Total potassium uptake which is closely related with dry matter production increased with increase in soil moisture regimes. Under flooding potassium uptake per pot varied between 18.88 mg to 286.313 mg for MW 10 and 17.397 mg to 228.677 mg for IR 50. Under field capacity the corresponding values were 13.16 mg to 91.167 mg for MW 10 and 11.87 mg to 59.84 mg for IR 50.

Chapter-II

REVIEW OF LITERATURE

REVIEW OF LITERATURE

Water is the most important factor in rice cultivation. Water is a major constituent of tissue, a reagent in chemical reaction, a solvent for and mode of translocation for metabolites and minerals within plant and is essential for cell enlargement through turgor pressure. With the occurrence of water deficits many of the physiological processes associated with growth are affected and under severe deficits, death of plants may results. Submergence of the soil create the chemical and biological basis for a continuous renewal of the system's soil fertility (Ponnamperuma, 1984, Roger, 1996). Concentration of phosphorus, potassium, iron, manganese and silicon increases under submerged situation and increases the uptake of these nutrients elements.

This chapter deals with the review of literature regarding the effect of soil moisture regimes on root porosity, transpiration and nutrient uptake.

2.1 Root porosity of plants as influenced by soil-moisture regimes :

Root porosity may be defined as the volume of gas space per unit volume of root. It is one of the factors used in assessing internal aeration. Growth of plant roots require a supply of oxygen and an escape mechanism for liberation of carbon dioxide during respiration. The internal transfer of O_2 from shoots to roots within aerenchymatous cortical tissue is an important mechanisms for complete or partial avoidance of O_2-deficiency in many cereal species. Rice, being a semi-aquatic plant, the system of interconnected gas space or lacunae is very well developed (Armstrong, 1979), but the demand for O_2 is just as great as in non wetland species (Armstrong and Webb, 1985).

Studies have pointed out that aeration for rice roots can occur within the plant and without need of aeration through the soil. Norris (1913) observed that gas spaces were invariably present in the roots of *Zea mays* when cultured in water, but these were found to be reduced when the roots are grown in porous soil. Juliano and Aldama (1937) observed air channels in cortex of roots, stems and leaf blades of rice plant. Mepherson (1939) observed an increase in gas space of maize root tissue due to the death and decay of the protoplasm in root cells. He explained that below the critical oxygen pressure, in anaerobic respiration the cells used up food material more rapidly than they were being supplied by the conducting system and then destroyed themselves by autolysis, a common occurrence among starving cells. Boeke (1940) working with strongly developed adventitious roots of cultivated rice (*Oryza sativa* L.) was in agreement with Mepherson's (1939) openion that formation of air cavities could not be accounted by the action of mechanical forces during growth.

Barber *et al.* (1962) studied the movement of O^{15} through barley and rice plants and found that the movement of oxygen through rice and barley plants from the shoot to the root was simple gaseous diffusion processes through intercellular spaces. Gas spaces in rice plants contributed 5 to 30 per cent of the root tissue where as that of barley were below 1 percent.

Luxmoore and Stolzy (1969) in nutrient solution experiment with rice and maize plants reported that adventitious roots were more porous than primary roots indicating that adventitious roots had considerable significance in internal aeration. No effect of solution O_2 concentration on root porosity was observed by them which suggested that space development might be less dependent on oxygen supply. Jensen *et al.* (1967) also did not observe any significant effect of oxygen treatment on root porosity.

Luxmoore *et al.* (1970) in pot experiment with rice and maize plants reported that the root tip segment was characterized by the highest maximum respiration rate, highest permeability and lowest porosity. Both respiration rate and permeability decreased with distance from the root tip, whereas porosity increased. They stated that the linear increase in the porosity in first 6 cm from the root tip was indicative of a cumulative increase in the development of gas spaces resulting from differential cellular growth and from the decay of cells.

Saha *et al.* (1973) conducted a pot experiment to investigate the effect of soil water regimes on root porosity of two rice varieties grown under flooded and field capacity. They showed that a variation in the soil moisture regimes from field capacity to flooded condition resulting in a great increase in the total root porosity. The varietal differences of percent root porosity was observed and showed that root porosity (%) was more for 'IR-8' than for 'Jaya'. Root porosity (%) varied significantly with the stage of growth. Under flooded condition, it reached a peak on 20th day and subsequently there was a gradual decrease with the age of the plant. Under irrigation to field capacity, root porosity attained the maximum values on the 40th day and then decreased rapidly. They further showed that the total root porosity was parallel to the growth of the root and increased with an increase in the level of soil moisture and it also varied greatly with the stage of growth.

In submerged soils, the availability of water to roots was more owing to higher root porosity and lower root resistance to water transport (Sahu *et al.*, 1973; Tomar and Ghildyal, 1975), increasing the transpiration losses (Patel *et al.*, 1979). Under unsaturated soil-water regimes, limited supply of water, less root porosity and higher resistance might have resulted in lower rate of water uptake. As a result, the amount of water transpired was less under saturated and unsaturated soil water regimes than under submergence. Drenth *et al.* (1991) also reported the similar results that root porosity was higher in anaerobic soil than in aerobic soil, and that younger roots were more porous than older roots.

Justin and Armstrong (1991) carried out a study on two rice cultivars and reported that cavity formation in roots is controlled by endogenous levels of ethene and also showed that root porosity varied with root length and the inhibitory effect of the silver ion on aerenchyma development appeared to be greater. They also concluded that ethene had increased root porosity and $AgNO_3$ had decreased it and aerenchyma development in both cultivars was also enhanced by flooding, with percentage porosities 12 units higher in flooded than in drained soil.

A study was conducted by Sekhon *et al.* (1993) on the influence of soil redox conditions on root and shoot growth characteristics in rice and the results show that submergence alone increased (plant height, leaf area) root porosity, root, straw and grain weight. They also shows that root density tended to increase in surface layers with increase in reduction status of soil. Neue *et al.* (1997) reported that during ripening and maturity root exudation, root porosity and root oxidation power of rice may control methane emission rates.

2.2 Nutrient uptake as influence by soil moisture regimes :

Waterlogging causes changes in the properties of soils which profoundly affect the nutrition of low land rice. The root zone is changed from aerobic to anaerobic environment as a result of drastic decrease in the oxygen supply in the soil. Chaudhary and McLean (1963) reported that in a green house experiment with poorly drained mineral soil, rice plants grown under flooded conditions contained higher concentrations of phosphorus and manganese in shoots than those grown under unflooded condition. The concentration of iron in shoots did not change significantly due to flooded or unflooded conditions of soil. He explained that due to the lack of adequate supply of phosphorus and manganese in available form for rice might have contributed to the poor performance of rice plants under unflooded conditions. Workers of IRRI (1964) reported that phosphorus, potassium, calcium, magnesium, iron and manganese contents were more in rice plants grown under flooded condition than under unflooded condition. Enyi (1965) found that concentration of nitrogen, phosphorus, manganese, zinc, copper, molybdenum and boron in upland rice plants grown under flooded condition was higher than that of the plants grown under unflooded condition. In a green house experiment with two varieties paddy noted that uptake of potassium was unaffected by flooding, where as phosphorus uptake was lower at field capacity suggesting that phosphorus availability was higher under flooded condition. Cherian *et al.* (1968) in pot experiment with rice observed that uptake of iron, manganese and phosphorus was increased, but the uptake of calcium, magnesium, potassium and zinc was decreased by flooding the soil. Pande and Singh (969) reported that nitrogen, phosphorus, iron and manganese contents were more under continuous submerged conditions than under field capacity. In a pot experiment, the results shows that concentration of potassium, calcium & magnesium in shoots of rice plant decreased with the increase in soil moisture from field capacity to flooding but the case was reversed for iron and manganese (Sharma, 1970). Saha *et al.* (1973) reported that a variation in the soil moisture regimes from field capacity to flooded condition resulted in a great increase in nutrient uptake. They explained that the more nutrient uptake as a result of increase availability of nutrients, together with greater transpirational transfer of water and ions facilitated by increase root porosity. The increase in soil pH in acid soils under waterlogged condition has been reported by Mohanty and Patnaik (1975), which might be due to ferrous-ferric equilibrium (Ponnamperuma, 1972). Earlier laboratory experiments on submerged soils indicated increased availability of NH^{4+}-N (Mohanty and Patnaik, 1975), phosphorus (Mandal, 1964; Mohanty and Patnaik, 1977), iron and manganese (Ponnamperuma, 1977; Mohanty & Patnaik, 1977). Singh and Ram (1976) reported that the general trend of transformation of applied phosphorus was identical under field capacity and submergence in certain soils of Uttar Pradesh, the rate as well as the magnitude of transformation being higher under waterlogged conditions but Mandal and Khan (1976) did not find significant effect of water treatments on the phosphate transformation pattern in rice soils. Pillai and De (1979) reported that nitrogen uptake was more under continuous submergence than under alternate submergence. The uptake of phosphorus by rice in submerged soil was three to four times higher than in non-submerged soil and the high phosphorus content in the shoot tissue of plants grown under water logging might help the plants to elongate during submergence period (Bora and Goswami, 1980). The total nutrient uptake of nitrogen, phosphorus, potassium, calcium and magnesium under lowland situation were reported to 78.20, 22.14, 103.52, 10.23 and 27.18 kg/ha respectively under normal doses (60, 40, 40) of fertilizer application (Pande *et al.*, 1985). Saikia and Dutta (1989) conducted a two years field experiment and showed that the nitrogen uptake by grain and straw were significantly higher under continuous submergence and also increased with increasing levels of nitrogen.

Subramanian and Gopalswamy (1991) conducted an incubation study for a period of 45 days to study the influence of moisture, organic matter, phosphate and silicate on the availability of silicon and phosphorus in four rice soils. They observed that continuous submergence of soil and addition of organic matter resulted in an increase in the availability of silicon and phosphorus. The addition of silicon significantly increased the availability of silicon in all soils and available silicon and phosphorus increased initially and subsequently decreased with passage of time. Phosphorus transformation in four rice soils under different soil water regimes under laboratory conditions was studied by Kumaraswamy and Sreeramula (1992) and their results reviewed that in all soils solid phosphorus disappeared even in the early stages of incubation and most of added P was fixed initially as Al-P. Transformation of phosphorus into different inorganic -P fractions followed almost similar pattern under both soil water regimes. With passage of time, a portion of the Al-P was transformed into Fe-P in soils originally preponderant in this fraction and into Ca-P in the soil originally preponderant in Ca-P. Transport of the more soluble nutrient ions, such as NH^{4+} and K^{+} to the root surfaces is rapid enough in well-puddled flooded soils so that they do not limit uptake rates. But if the soil is not well-puddled or if it is dried and re-flooded, transport rates may become limiting (Kirk and Solvas, 1994). Patra *et al.* (1995) studied the effect of variable moisture treatments, namely air drying, 50 per cent water holding capacity, 100 per cent water holding capacity, continuous submergence and alternate and drying on the available potassium of five tarai soils have shown that the highest level of available potassium was maintained by 50% water holding capacity and lowest level of alternate wetting and drying. Continuous submergence was not found favourable for potassium availability.

Alam and Ladha (1997) pointed out that the P deficiency aggravates the drought effect by retarding the growth and delaying maturity of rice. This severity may be due to the alternate wetting and drying cycles in rainfed lowlands that may offset the increased P availability by submergence. Field experiment at the International Rice Research Institute (IRRI), during dry season was conducted by Castillo *et al.* (1998) and their results shows that in all fertilizer and crop establishment treatments, straw nitrogen concentrations of the stressed plants were higher than those of the well-watered plants. They explained that the high straw nitrogen concentration in the stress treatment could be attributed to the lack of complete senescence of the plants. They farther showed that grain nitrogen uptake in the stressed plants was lower than in the well-watered plants, mainly because of the significantly higher yield of the flooded treatment but the total nitrogen uptake in the stressed treatment was similar to that of the flooded treatment.

Zhang *et al.* (2000) showed that flooding strongly increased phosphorus adsorption and decreased phosphorus desorption in the paddy soil while simulated oxygen secretion from rice root significantly reduced phosphorus adsorption and enhanced both phosphorus desorption in rhizosphere and phosphorus uptake by ion-exchanger. They explained that the effect of oxygen secretion from rice root should be one of the important mechanisms for rice take up of phosphorus, normally under the conditions of phosphorus availability reduction by flooding. Phosphorus availability in the soil reduced by flooding should be one related to the transformation of phosphorus fractions because of Al-P fraction increased by phosphorus amendment in the soil was almost transformed into the Fe-P fraction by two week flooding.

2.3 Nutrient uptake at different stages of growth :

The process of nutrient uptake in rice at different stages of growth is the function of climate, soil properties, amount of fertilizers applied, variety and the method of cultivation (Ishizuka, 1964).

Dion *et al.* (1949) pointed out that the main absorption of phosphorus occurred before maturity. Tanaka *et al.* (1959) observed that uptake of phosphorus steadily increased and almost reached the maximum during the active tillering phase and thereafter absorption was negligible. Gama and Mellow (1960) found that phosphorus absorption increased until maturity and suggests that there would be an advantage in applying split amount of phosphatic fertilizers to rice. Bhumbla and Rana (1965) found that rice plant continued to take up phosphorus from soil even after the boot stage. But phosphorus applied at later stages of growth resulted in increasing phosphorus content of straw, and a very small percent of it was utilized for grain formation. Patnaik *et al.* (1965) conducted solution culture experiments with early and medium duration Indica and reported that phosphorus absorbed after tillering stage tended to be accumulated in straw and root with no advantage to grain yield. This result suggested that an early application of phosphorus is desirable. Sims and Place (1968) in a field experiment with rice reported that percent content of phosphorus did not differ with respect to plant age. As total uptake of phosphorus is closely related with dry matter production, it increased with plant age. They also reported that percentage content of potassium decreased with age of the plant but total potassium uptake increased with age of the plant.

Workers of IRRI (1964) flooded the rice field after 20 days of sowing and measured nutrient content at a regular interval of 3 weeks after flooding. They observed that the contents of phosphorus and potassium were high on the 3rd week after flooding and decreased with plant age while calcium, magnesium, iron and manganese contents continued to increase upto the 6th week and then decreased. Ishizuka (1964) reported that percentage of potassium and calcium in rice plant decreased after transplanting from the value obtained at seedling stage, then again increased and reached a high percentage after flowering until complete ripening while percentage magnesium was high from transplanting to middle of tillering.

2.4 Transpiration in relation to the soil moisture content, nutrient uptake and age of the rice plant :

The relationship between the rate at which water, rubidium and phosphorus ions are absorbed by intact plants and transferred to their shoots was investigated by Russel and Shorrocks (1959) in water culture under varying conditions of transpiration and nutrient supply. They reported that when the external concentration and the nutrient status of the plants were low, transpiration rate had little effect on the transportation of nutrients to shoots when the external concentration and the nutrient status of the plants are high the rate of transfer of ions to shoots varied closely with the rate of transpiration. Russel and Barber (1960) reported that when ions were transferred from the outer medium to the shoot, the movement of ions could be accelerated by increasing the rate of transpiration. Slatyer (1962) stated that transpiration could increase the uptake of nutrients specially when the requirements of the plant was high.

The workers of IRI (1965) reported that transpiration ratio (dry matter produced/water transpired) increased with the plant age possibly because of an increased ratio of respiration to photosynthesis. They compared the transpiration between flooded and unflooded condition and reported that under flooded condition, the water supply from roots to leaves was ample and the transpiration was parallel to the energy input of solar radiation. Under unflooded condition, the soil water supply was limited and the rate of water supply to the leaves could not match the rate of evapotranspiration from the leaves. Because of this transpiration was less under unflooded condition than under flooded condition. They also reported that increased light intensity caused increase of transpiration under flooded condition, but transpiration decreased with increase of light intensity under unflooded conditions.

Jana and Ghildyal (1969) reported that the atmospheric, soil and plant factors were involved in the process of evapo-transpiration. They found that water use by rice crop depends not only upon soil water regime and plant growth phase, but also on the environmental conditions of evaporative demand. Ghidyal (1971) observed that the amount of water transpired during its growth period and also the rate of transpiration per unit leaf area per time increased with increased in soil moisture regimes from unsaturation to flooding. He explained that the increased growth and dry matter production, where the transpirational transfer of water was more may also be due to the increased nutrient uptake as a result of mass transfer of ions through the transpiration stream. In a pot experiment Saha *et al.* (1973) showed that the amount of water transpired varied with the soil water regime and the stages of growth. They observed that under flooded condition, the increased availability of water to roots tends to increased transpirational losses than field capacity and the amount of water transpired under flooded condition was about twice that under field capacity.

Patel *et al.* (1976) reported that the cumulative evapotranspiration (ET) was very high under treatments where continuous submergence was maintained followed by altenate flooding and drainage and unsaturated soil-water regimes. The cumulative ET increased with crop growth and the rate of increase was maximum upto 62 days after transplanting. The evaporation decreased as the soil-water regimes were changed from submergence to saturation and then to unsaturation. Similar results were reported by Sahu *et al.* (1973), Ueki and Shanmugeratnam (1973) and Nair *et al.* (1973). In a lysimetery study, Patel *et al.* (1979) showed that the total ET was found to be very high under the soil water regimes in which continuous 5 cm submergence was maintained and they also reported that varieties of rice differed in their cumulative ET, water use and water use efficiency.

Sen and Jana (1987) reported that the evapotranspiration rate gradually increased with the age of the crop and it was maximum during 40 to 50 days after sowing and then slowly decreased. They also reported that this trend was observed under different soil moisture tensions during both the seasons and evapotranspiration rate was different under different soil moisture tensions. It was always higher under lower soil moisture tension than higher soil moisture tension. They explained that low evapotranspiration rate under high soil moisture tension was mainly due to higher resistance to the flow water vapour through soil (Ritchie, 1971). Evapotranspiration of direct seeded rice was determined by a floating type lysimeter during wet season and the value of ET was found to be 47.7 cm (Taha *et al.*, 1988). In a field trails with rice comparison was made between the panicle and flag leaf in their transpiration characteristics. Transpiration rate in the panicle reached a maximum at heading and decreased with aging. Transpiration rate in the panicle increased linearly as vapour pressure difference increased (Ishihara *et al.*, 1990). A series of green house and growth studies were conducted in 1985-86 and showed that by using the Poiseuille-Hagen law for water movement in capillaries, rice root axial resistance explained differences in leaf water potential and transpiration when only one cultivar was used, but did not explain differences among cultivars (Yambao, 1992). Thus it was concluded that increasing root xylem vessel radii profably will not directly increase drought resistance. Field experiment study on 8 rice cultivars at different soil-moisture regimes showed that transpiration decreased with crop age and was highest in plants continuously flooded and lowest in rainfed plants (Singh *et al.*, 1992). Transpiration rate of rice (*Oryza sativa*) were measured in a closed chamber and showed that transpiration rate increased until the heading stage and thereafter decreased (Saito *et al.*, 1996). They also showed that transpiration rate increased exponentially and at heading stage, it was maximum.

Sharma and Bhushan (1999) reported that the evapo-transpiration (ET) with time, irrespective of cultivar and water regime, followed the sigmoidal curve and ET in two cultivars behaved differently as the soil water regime changed from flooded condition saturation to 50 K Pa matric suction due to some physiological reasons. Varietal differences in rice for daily ET were minimal (Sugimoto, 1975) but only under adequate soil water regime. But the same is not true under deficient water conditions.

2.5 Growth of rice plant as influenced by soil moisture regimes :

Morphologically rice is a non-aquatic plant. Yet in submerged condition, rice plants behave their maximum growth. This fact has been established by Chaklader (1946), Workers of IRRI (1963, 1964, 1965), Halm (1967), Jana and Ghildyal (1969), Luxmoore and Stolzy (1969) and many other workers. Cherian *et al.* (1968) reported that the rice plants grown under flooded condition produced more fresh and dry weight than plants grown under field capacity. Pande and Singh (1969) found that yields, leaf area, number of effective tillers and ratio of sound to unsound grains were more under continuous submerged condition than under field capacity. Jana and Ghildyal (1969) reported that plants grown under flooded soil had greater dry weights of shoots and roots than those of the plants grown under non-flooded condition. Rao and Venkaleswarlu (1989) observed that moisture stress at reproductive and ripening stage is crucial for growth and productivity of rice. Mandal *et al.* (1991) reported that best growth and highest yield was obtained under continuous submergence than alternative wetting and drying methods and growth characters like plant height, tillering, straw yield were significantly influenced by continuous submergence. However, in Japan it has been reported that continuous ponding in the first half of the growing season and alternate drying and ponding in the later half enhance productivity of the rice crop (Watanabe, 1992). Budi and Suprihanto (1992) found that moisture stress imposed from panicle initiation to heading reduced grain yield upto 50% and when the moisture stress was imposed from heading to maturity, yield reduction was around 70%. Reports by Sekhon *et al.* (1993) suggested that the submergence increased shoot height, root, straw and grain weight. Significant differences in tiller numbers was observed due to cultivars, water regimes and soil type. They observed that the tiller number reduced due to stress in 10-47.1%. Observation of Misra and Panda (1994) showed that under shallow water table conditions, continuous saturation or intermittent ponding during the vegetative stages does not generally affect the significant grain yield of rice. Early cessation of rainfall and limited availability soil moisture lead to terminal stress and results in fewer grain number and poor grain filling (Krupp *et al.*, 1972). Similarly, root system and its development are strongly influenced by soil edaphic factors (Mambani *et al.*, 1990; Thangaraj *et al.*, 1990 and Sharma *et al.*, 1994) and large genotypic differences have been reported (Klepper *et al.*, 1984 and Yamanchi *et al.*, 1996) in their response to soil moisture stress. Chauhan *et al.* (1996) investigated the effect of soil moisture stress on growth and development of upland rice at 100, 80, 60 and 40% water holding capacity in pots and reported that the rice cultivars "Vandana" transpired less water than the rice cultivars "Brown gora" under stress conditions. They also reported that the effects of moisture stress become more apparent with age, particularly at 60 and 40% of water holding capacity. Chaudhary (1997) reported that the rice crop has specific plant development phases and characteristics when the crop water requirement is high and response pattern do change with differential irrigation regimes. Singh and Sharma (1997) found that higher grain yield under continuous ponding and under submergence two days after the disappearance of ponded water may be due to continuous readily available soil water that enhanced root growth, resulting in increased water and nutrient uptake. Besides this roots can markedly influence the activities of shoot (Torey, 1976) thus affecting the coordinated development of plant. Kondo *et al.* (2000) reported that in rice, water uptake, dry matter production in shoot and root length were largely suppressed under severe moisture stress compared to the mild moisture stress condition. Sarkar (2001) studed a field experiment to assess the performance of a common rice (IET 4786) under stressed (intermittent ponding) and non-stressed (continuous ponding) conditions and his results revealed that the highest grain yield was attained under continuous ponding, followed by under intermittent ponding in early.

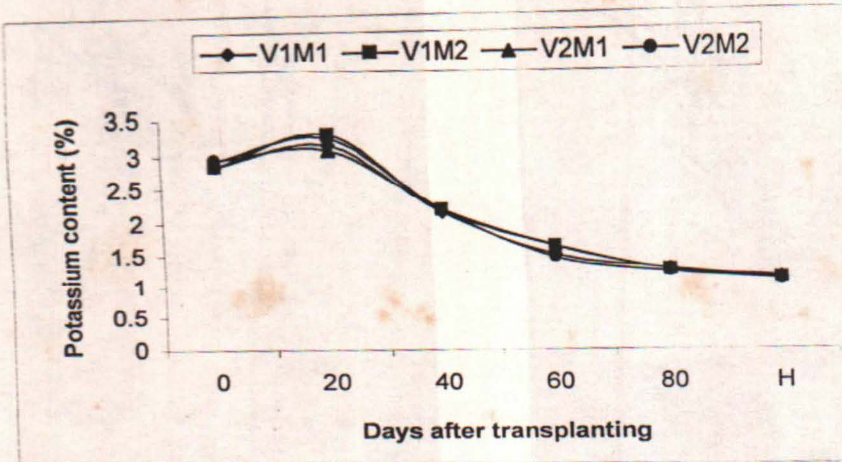

Fig. 7(a). : Changes in potassium content (%) of rice at different stages of growth

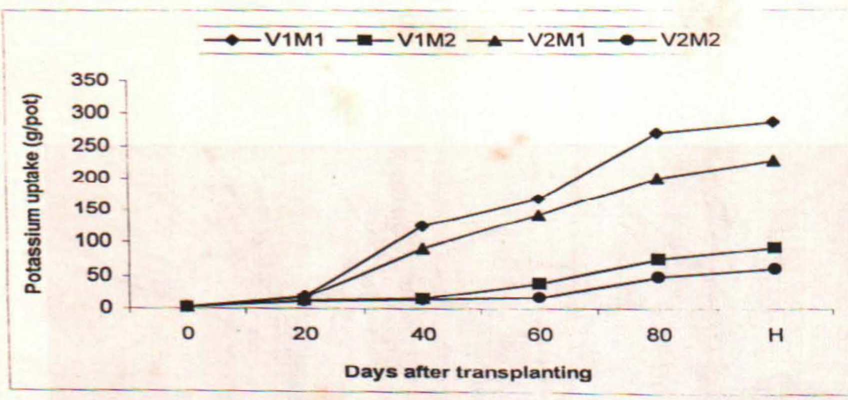

Fig. 7(b). : Changes in potassium uptake of rice at different stages of growth

Plate 3: Plant height and growth at 80 days after transplanting

4.3.4 Calcium :

The variations of calcium content and calcium uptake with stages of growth are presented in Fig. 8(a) and Fig. 8(b) respectively.

4.3.4.1 Calcium content :

The variation in calcium content for the two varieties was significant. It was more for MW10 than for IR 50. The difference in calcium content at different stages of growth was also significant. At seedling stage percent calcium content was 0.38 for MW 10 and 0.36 for IR 50. Under both the soil moisture regimes it increased upto the 20th day after transplanting and then decreased gradually upto 60th day and again increased gradually upto harvesting stage.

The calcium contents for the two soil moisture regimes differed significantly. Under flooding percent calcium content ranged between .262 to .500 for MW 10 and .253 to .450 for IR 50. The corresponding values under field capacity were .227 to .403 for MW 10 and .217 to .401 for IR 50.

4.3.4.2 Calcium uptake :

The difference in total uptake of calcium was found to be significant. It was greater for MW 10 than IR 50 under both the soil moisture regimes. At seedling stage it was 0.260 mg for MW 10 and 0.399 mg for IR 50. It continuously increased with the age of the plant. Under flooding the rate of increase was rapid after 20th day while that under field capacity was gradual after 60th day.

Calcium uptake per pot was more under flooding than under field capacity. Under flooding it varied between 3.00 mg to 95.37 mg for MW 10 and 2.55 mg to 73.84 mg for IR 50. Under field capacity the corresponding values were 1.61 mg to 29.46 mg for MW 10 and 1.43 mg to 20.33 mg for IR 50.

4.3.5 Magnesium :

Fig. 9(a) and Fig. 9(b) show the variations of magnesium content and magnesium uptake with stages of growth.

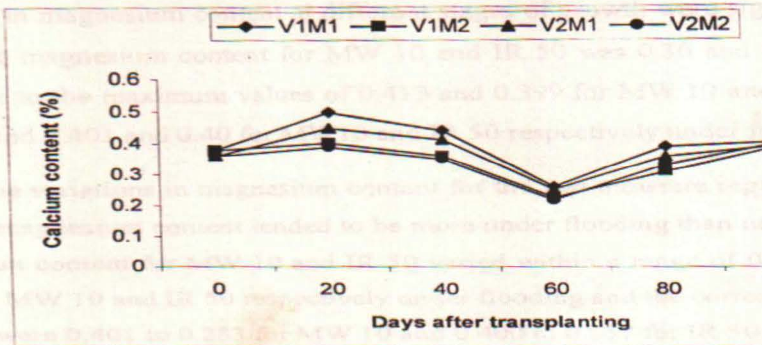

Fig. 8(a). : Changes in calcium content (%) of rice at different stages of growth

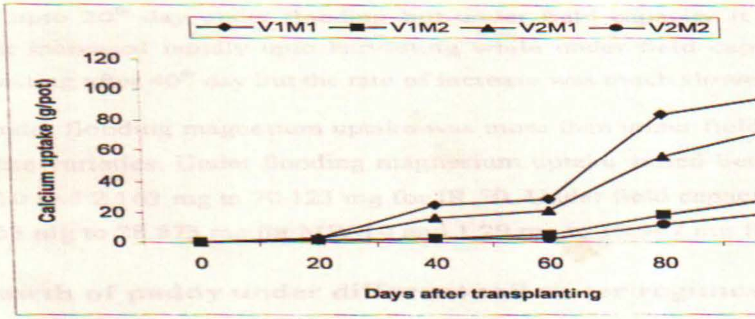

Fig. 8(b). : Changes in calcium uptake of rice at different stages of growth

4.3.5.1 Magnesium content :

The changes in magnesium content between the two varieties were insignificant. But the variations in magnesium content at different stages of growth were significant. At seedling stage percentage magnesium content for MW 10 and IR 50 was 0.36 and 0.37 respectively. On 40th day it rose to the maximum values of 0.413 and 0.399 for MW 10 and IR 50 respectively under flooding and 0.401 and 0.40 for MW10 and IR 50 respectively under field capacity.

The variations in magnesium content for the two moisture regimes was also insignificant although magnesium content tended to be more under flooding than under field capacity. Percent magnesium content for MW 10 and IR 50 varied within a range of 0.413 to 0.290 and 0.399 to 0.257 for MW 10 and IR 50 respectively under flooding and the corresponding values under field capacity were 0.401 to 0.283 for MW 10 and 0.400 to 0.257 for IR 50.

4.3.5.2 Magnesium uptake :

Significant difference of magnesium uptake was found between the two varieties of paddy being more for MW10. The difference was significant under flooding but it was insignificant under field capacity. At seedling stage magnesium uptake was 0.240 mg/pot for MW 10 and 0.348 mg/pot for IR50. It increased with increase of plant age. The rate of uptake was slow upto 20th day under flooding but under field capacity it was upto 40th day. Under flooding it increased rapidly upto harvesting while under field capacity although it increased upto harvesting after 40th day but the rate of increase was much slower than that under flooding.

Under flooding magnesium uptake was more than under field capacity moisture regimes for both the varieties. Under flooding magnesium uptake varied between 2.24 mg to 92.53 mg for MW 10 and 2.163 mg to 70.123 mg for IR 50. Under field capacity the corresponding values were 1.353 mg to 28.873 mg for MW 10 and 1.29 mg to 19.947 mg for IR 50.

4.4 Growth of paddy under different soil water regimes :

Tiller number, leave number, plant height and dry weight of shoot of rice plant grown under two soil moisture regimes viz. flooding and field capacity were measured on the day of transplanting, at regular interval of 20 days after transplanting and at harvest. The measurement are tabulated in Table - 9.

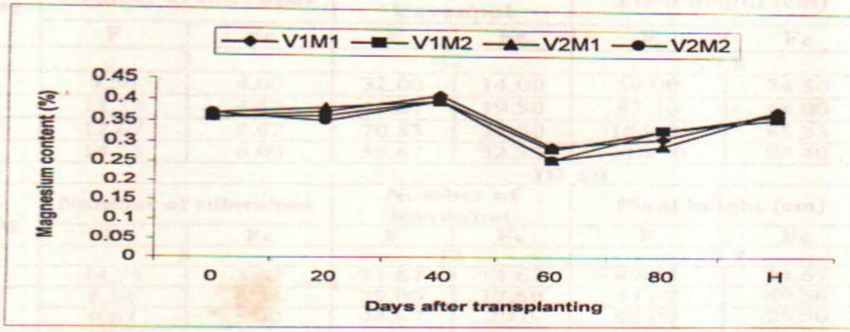

Fig. 9(a). : Changes in magnesium content (%) of rice at different stages of growth

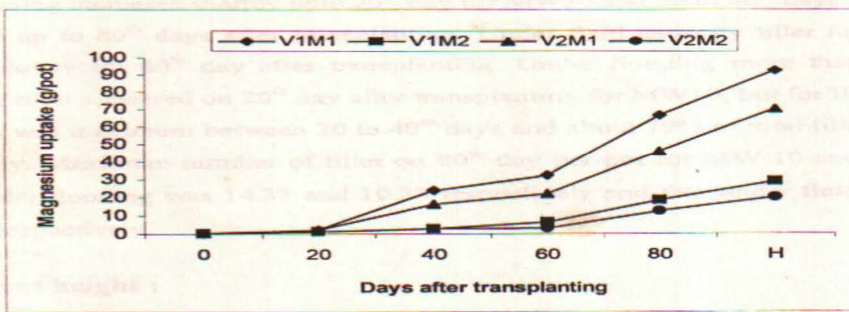

Fig. 9(b). : Changes in magnesium uptake of rice at different stages of growth

Table -9. Effect of soil moisture regimes on growth of paddy

Days after transplanting	MW 10							
	Number of tillers/pot		Number of leaves/pot		Plant height (cm)		Dry weight of shoot/pot (g)	
	F	Fc	F	Fc	F	Fc	F	Fc
0	3		12		27.8		0.068	
20	9.50	4.00	32.00	14.00	59.00	34.50	3.61	0.40
40	11.33	4.67	45.67	19.50	87.30	48.00	3.97	0.73
60	12.67	5.67	70.33	35.50	104.00	85.33	9.33	2.33
80	14.33	6.00	56.67	32.33	110.50	92.40	17.53	5.73
	IR 50							
Days after transplanting	Number of tillers/pot		Number of leaves/pot		Plant height (cm)		Dry weight of shoot/pot (g)	
	F	Fc	F	Fc	F	Fc	F	Fc
0	3		12		26.7		0.094	
20	14.75	3.67	21.67	13.67	49.83	24.67	0.57	0.37
40	8.34	4.33	29.00	17.50	57.67	49.50	4.06	0.70
60	9.67	5.00	48.67	29.0	93.00	75.50	8.60	1.13
80	10.5	5.00	46.5	22.5	103.34	77.00	15.73	3.87

4.4.1 The variation in tiller number are shown in Fig. 10.

The variation of effective tiller number between two varieties was remarkable. It was more for MW10 than IR50. The difference in effective tiller number per pot due difference in soil moisture regimes varied greatly from 20th day after transplanting. The effective tiller number under flooding increases sharply upto 20th day for MW10 and 20 to 40th days for IR50 and then it is gradual up to 80th days after transplanting. Under field capacity tiller number continued to increase slowly till 60th day after transplanting. Under flooding more than 65% of the total number of tiller appeared on 20th day after transplanting for MW10; but for IR50 the rate of tiller initiations was maximum between 20 to 40th days and about 79% of total tiller number appeared on 40th day. Maximum number of tiller on 80th day per pot for MW 10 and IR 50 varieties of paddy under flooding was 14.33 and 10.33 respectively and that under field capacity was 6.00 and 5.00 respectively.

4.4.2 Plant height :

The variation of plant height with stages of growth are presented in Fig. 11.

Plant height was measured on the surface of the soil to the highest leaf tip. There was a remarkable effect of soil water content on plant height. With the increase in soil moisture level

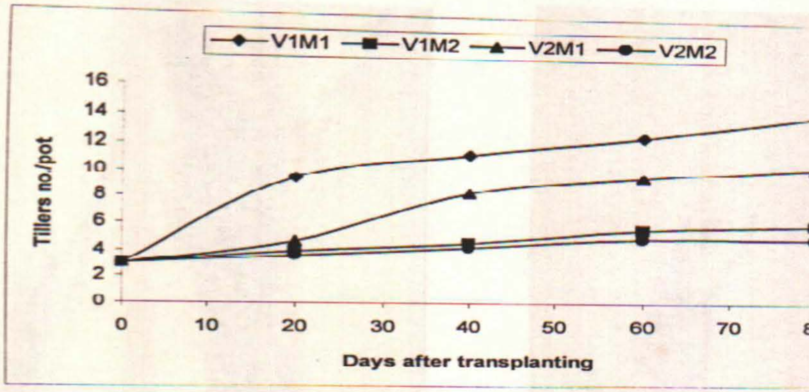

Fig. 10 : Changes in tillers number under varying soil moisture regimes at different stages of growth

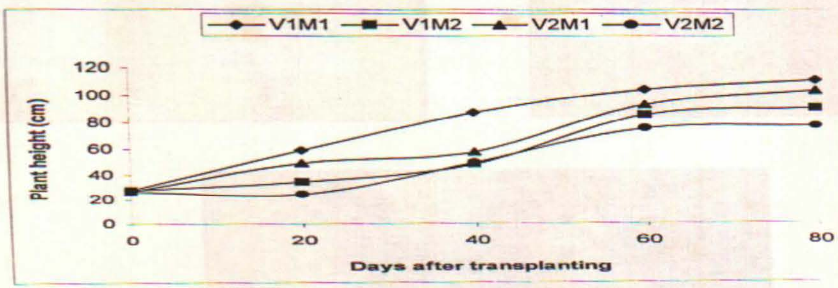

Fig. 11 : Changes in plant height at different stages of growth

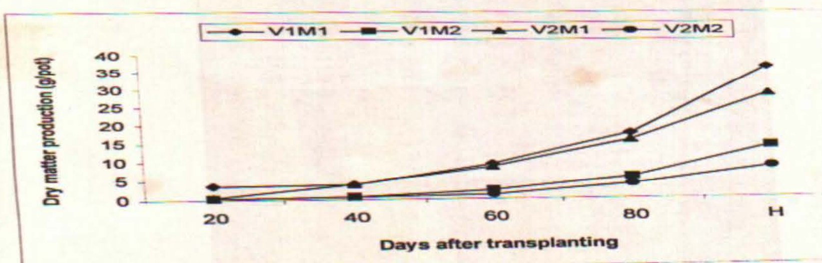

Fig. 12 : Changes in dry matter production at different stages of growth

Plate 4: Plant height and root growth at 80 days after transplanting

the height increased in both the varieties. On 40th day after transplanting plants attain 79 % for MW 10 and 55.8% for IR 50 of their final height under flooding and 51.9% for MW 10 and 64.3% for IR 50 of their final height under field capacity. In both the varieties and soil moisture regimes plant attain more than 90% of their final height on 60th day after transplanting. Finally plant attain height of 110.5 cm for MW 10 and 103.3 cm for IR 50 under flooding and 92.4 cm for MW10 and 77 cm for IR 50 under field capacity.

4.4.3 Dry weight of shoot :

The variation of dry weight of shoot with stages of growth under two soil water regimes are presented in Fig. 12.

Dry weight of shoot varied greatly with moisture regimes from 40th day after transplanting. It was more under flooding. The difference in dry weight of shoot between plants grown under flooding and field capacity become more and more pronounced with plant age. The rate of dry matter production of shoot was more after 20th day and it increased with increase in plant age. At harvest the dry weight (straw + grain) of shoots per pot for MW 10 and IR 50 was 36.20 g and 28.53 g respectively under flooding and 14.10 g and 8.437 g respectively under field capacity. The grain weight per pot for MW 10 and IR 50 was 13 g and 10.73 g under flooding and 6.01 g and 4.87 g under field capacity respectively.

Chapter-V

DISCUSSION

DISCUSSION

Root porosity, transpiration and nutrient uptake by rice plants were studied under varying soil water regimes viz. Flooding & Field capacity. The results show that nutrient uptake and dry matter production depend not only on soil water regimes but also on the amount of water transpired.

Dry matter production was significantly influenced by soil water regimes. As soil water regimes varied from field capacity to flooding, dry weight of shoot (grain + straw) at harvest varied from 14.01 g/pot to 36.2 g/pot for MW10 and 8.43 g/pot to 28.53 g/pot for IR 50. The results of transpiration studies show that with the variation of soil water regime from field capacity to flooding, total amount of water transpired from transplanting to the last harvest varied from 2.27 litres to 18.92 litres per pot for MW 10 and 1.68 litres to 16.70 litres per pot for IR 50. The rate of transpiration per unit time per unit pot also shows a variation from 15.36 ml/pot/day with field capacity to 172.53 ml/pot/day with flooding for MW10 and 11.39 ml/pot/day with field capacity to 155.83 ml/pot/day with flooding for IR50 during the maximum tillering stage. From the results it appeared that the amount of water transpired varies with soil water regimes, varieties and stages of growth. Transpiration ratio was influenced by soil water regimes, varieties and stages of growth (Table - 8).

Under flooding, increased availability of water to roots tends to increase the transpiration losses. Under field capacity limited supply of water in soil causes decrease in water availability to roots. As a result the amount of water transpired was less under field capacity than under flooding. The increased transpiration decreases the leaf water potential, thereby increasing the gradient between the plant root and soil. Under flooding due to saturated soil the hydraulic conductivity is high while under field capacity the condition is reversed. Lower unsaturated hydraulic conductivity under field capacity further limits the flow of water to the root zone.

The amount of water transpired appeared to be related with root porosity. A high positive correlation (r=.673 for MW 10 and .655 for IR 50) was obtained between total root porosity and the amount of water transpired per day per pot. The values of root porosity show that as soil water content varied from field capacity to flooding total root porosity per pot showed a variation of 46.27 cm^3 to 180.88 cm^3 per pot for MW 10 and 35.41 cm^3 to 144.83

cm^3 per pot for IR 50 during the flower initiation stage (60 days after transplanting). The greater total root volume under flooding increased total root porosity. It seems that the great root porosity facilitated greater transfer of water.

A high positive correlation (r=.924 for MW 10 and .957 for IR 50) was obtained between the total amount of water transpired and dry matter produced. Therefore, high transpirational transfer of water appears to be related to the increased growth and dry matter production. Thus increased transpiration due to the increased hydrostatic pressure of water in soil together with the increased root porosity seems to have favourably influenced rice growth under flooded conditions.

From nutrients uptake study it appeared that the total amount of water transpired is closely related with the nutrient uptake. A strong positive correlation was obtained between the total amount of water transpired and nutrients uptake (Table - 10). The results show that as soil water content varied from flooding to field capacity, absorption of nitrogen phosphporus, potassium, calcium and magnesium progressively increased.

Table – 10: Correlation coefficient between total amount of water transpired and nutrient uptake.

Correlation coefficent (r)	Nutrient Uptake				
	N	P	K	Ca	Mg
For MW 10	0.903	0.961	0.949	0.966	0.972
For IR 50	0.833	0.945	0.914	0.978	0.966

When a soil is flooded a series of reduction occurs, concentration of CO_2 increased and various physical, physico-chemical and biological reactions set in motion. Because of this, availability of nutrients increases. The increased availability of potassium, calcium and magnesium may be due to the solvent action of carbondioxide and cation exchange reactions. The increased availability of nitrogen under flooded condition may be due to accumulation of ammonium ions in soil which is favoured by rice plant; and rice plant prefer absorption of ammonium ions. The increased availability of phosphorus may be due to the reduction of ferric phosphate. Ponnamperuma (1965) and several other workers since confirmed these findings. The increased availability of the ions in soil together with greater transpirational transfer of ions might have increased their uptakes by the rice plant under flooding.

The content of all the nutrients reached a maximum peak during the initial stages of growth and then decreased. This means that the rate of photosynthesis increases more rapidly than nutrient uptake. The time of maximum content of nutrients in the plant body was different for different soil moisture regimes and for different types of ions.

The absorption of all the ions was rather slow upto the 20[th] day but subsequently became rapid due to the recovery from the damage caused by transplanting. Under flooding the quantity of uptake continued to increase upto the final stage while under field capacity the rate of increase of absorption became almost negligible after 80 days of transplanting.

The varietal difference had pronounced effects on nitrogen, phosphorus, potassium, calcium and magnesium uptake under both soil water regimes and nitrogen, phosphorus, potassium, calcium and magnesium uptake were more for MW 10 than IR 50. Variental difference with respect to dry matter production was significant being more for MW 10. It seems that the beneficial effect of nitrogen, phosphorus, potassium, calcium and magnesium nutrients increases in the growth and yield of MW 10.

Chapter-VI

SUMMARY AND CONCLUSION

SUMMARY AND CONCLUSION

Glass house studies were conducted on clay loam soil of Teaching and Instructional farm of Uttar Banga Krishi Viswavidyalaya to simulate the soil water relations on root porosity, transpiration and ion uptake by rice plant (*Oryza sativa* L.) and its growth pattern. Two varieties of paddy viz. MW 10 and IR 50 grown on two soil moisture regimes viz. Flooding And Field capacity were studied in Boro season. The results obtained can be summarized as follows :

1) Variation of soil moisture regimes was found to have significant effect on percentage root porosity as well as on total root porosity. Both percentage and total root porosity varied with stages of growth and varieties.

2) As soil water regimes varied from field capacity to flooding the amount of water transpired greatly increased while the transpiration ratio tended to be more under field capacity.

   The amount of water transpired, transpiration ratio and transpiration efficiency changed a lot with variety, stages of growth and moisture regimes.

3) Nitrogen, phosphorus, calcium and magnesium content of shoots were more while potassium content was almost same under flooding and field capacity. The contents of all the five ions reached a maximum peak during the initial stages of growth and then decreased. The time of maximum content of nutrients in the plant body was different for different soil moisture regimes and for different types of nutrient ions.

4) Flooding the soil showed remarkable increased in the uptake of nitrogen, phosphorus, potassium, calcium and magnesium. The absorption of all the ions was rather slow up to the 20th day but subsequently became rapid due to the recovery from the damage caused by transplanting. Under flooding and field capacity the quantity of uptake continued to increases upto the final stage, but the rate off uptake was much higher under flooding than field capacity.

5) Growth and dry matter production were more under flooding than under field capacity. MW10 was found to be superior than IR50.

So from results it seems quite logical to conclude that the increased growth and dry matter production of rice plant under flooding condition may be accounted for in the following way :

i) The increased transpiration due to increased hydrostatic pressure of water in soil together with the increased root porosity seems to have a favourable effect on growth and dry matter production of rice plant.

ii) More nutrient uptake as a result of increased availability of nutrients in soil together with greater transpirational transfer of water and ions facilitated by increased root porosity, may have increased growth and dry matter of rice plant.

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