

DRIP FERTIGATION AND ITS PHYSIOLOGICAL IMPACT IN AEROBIC RICE
(*Oryza sativa* L.)

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COIMBATORE 641 003

2008

**DRIP FERTIGATION AND ITS PHYSIOLOGICAL IMPACT IN AEROBIC
RICE (*Oryza sativa* L.)**

Thesis submitted in part fulfillment of the requirements for the award of the degree of
Master of Science (Agriculture) in Crop Physiology to the
Tamil Nadu Agricultural University, Coimbatore 641 003

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CERTIFICATE

This is to certify that the thesis entitled “**DRIP FERTIGATION AND ITS PHYSIOLOGICAL IMPACT IN AEROBIC RICE (*Oryza sativa* L.)**” submitted in part fulfillment of the requirement for the degree of **MASTER OF SCIENCE (Agriculture) in CROP PHYSIOLOGY** to the Tamil Nadu Agricultural University, Coimbatore, is a bonafide record of research work carried out by **Miss K. VANITHA** under my supervision and guidance and that no part of this thesis has been submitted for the award of any other degree, fellowship or other similar titles of prizes and that the work has not been published in part or full in any scientific or popular journal or magazine.

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ACKNOWLEDGEMENT

*First and foremost, I accost omnipotent for giving me the strength, courage and grace to compete the task. I always associate pleasant memories with **Tamil Nadu Agricultural University**, which has nurtured me during my UG & PG programmes.*

*I gratefully submit my special ardency and deep sense of gratitude to my beloved parents, **Mr. P. Koothan and Mrs. K. Sagunthala**.*

*With immense pleasure, I humbly wish to avail this opportunity to acknowledge the financial assistance rendered by **International Plant Nutrition Institute (IPNI)**, Georgia, USA, for granting **Scholar Award** for my pioneering research work. My special thanks are due to **Drs. Adrian Johnston, K.N. Tiwari and T.N. Rao** of IPNI.*

*I am mirthful to portney my deep sense of gratitude and generous thanks to my beloved Chairman **Dr. S. Mohandass**, Professor (Crop physiology) for his adroit guidance, meticulous care and mellifluous help all along with an everlasting heart. Life blessed me with the opportunity to meet him. The creativity, determination and sense of joy with which he respond to life's challenges have led me to seek this in others. This thesis is a small tribute to an exceptional man from a student still anxious to learn from him. His technical and expert guidance, sustained interest, consistent encouragement, pragmatic view and constructive criticism made the formidable work to be an easier one.*

*With deep respect and esteem regends, I owe my indebtedness to the members of my advisory committee **Dr. H. Vijayaraghavan** Professor and Head (Crop physiology), **Dr. SP. Sundaram**, Professor and Head (Agricultural Microbiology) and **Dr. P. Govindaraju** Professor (Biochemistry) for their valuable guidance and suggestions during the course of my study. I am grateful in acknowledging the constant encouragement by **Dr. M. V. Ranghaswami**, Director (WTC) and **Dr. S. Natarajan**, Director (SCMS), TNAU, Coimbatore. My thanks are due to **Drs. K. Appavu**, Professor (SS & AC) and **K.M. Sellamuthu**, Assistant Professor (SS & AC) for the technical expertise.*

*I profusely express my sincere and grateful thanks to **Dr. S. Ramasamy**, Professor of Agronomy for sparing his expertise in crop modelling and for the constructive and useful suggestions at the time of study. My heart feels pleasure in acknowledging the help rendered by **Dr. V.M. Duraisamy**, Professor and Head (Agricultural Farm Machinery Research Centre) for his expertise in designing and fabricating 'Root Auger' and **Dr. Ayyanar**, Associate Professor (Plant Breeding) for sharing his expertise on Quantitative Genetics. I place my sincere and profound thanks to **Dr. N. Thavaprakash**, Farm Manager (Wetlands) for his kind and timely help rendered*

during the field trial. I profusely thank **Dr. K. Senthil**, Assistant Professor, Micro Analytical Lab, Faculty of Horticulture for his invaluable and timely help in analysing the plant samples for various nutrients during the course of study. I acknowledge the help rendered by **Mr. R. Thulasimani**, Agricultural Assistant, and Water Technology Centre in the lay out of drip fertigation system and rendering his valuable service through out the course of my field experiment.

I am grateful to all the Scientists, administrative and laboratory staff members of the Department of Crop Physiology for their moral support and encouragement to carry out my research work.

My heartfelt thanks are due to my friends **Lux, Suma, Hema, Mahe, Kavi, Viji, Sathya,, Sakthi and others** for their help and pleasant company during my study and stay here. Ineffable and glowing gratitude is due to my affectionate seniors and well-wishers (**Mr. Ramesh & Mr. Rajkumar**) and my junior friends.

I gratefully owe gratitude to my sister **Mrs. S. Punitha**, my brother **Mr. K. Sureshkumar**, my uncle **Mr. N. Sekar** and my sister-in-law **Mrs. S. Thenmozhi** for their life long affection, blessings, care, indispensable encouragement and prayers in the pursuit of my educational ambitions. I express my special loves to **Sonu, Pradeep, Madhu, Lathika, Goutham, Ajit and Dharshan**.

I acknowledge with thanks M/s **Sree Kumaran Computers**, TNAU campus for their help in neat execution of the thesis materials.

(**K. VANITHA**)

ABSTRACT

DRIP FERTIGATION AND ITS PHYSIOLOGICAL IMPACT IN AEROBIC RICE

(*Oryza sativa* L.)

By

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YEAR : 2008

Investigations were carried out during dry season of 2007 in the Department of Crop Physiology, Agricultural College and Research Institute, Tamil Nadu Agricultural University Campus, Coimbatore to study the physiological impact of drip fertigation in aerobic rice.

There is a great scope of growing aerobic rice under the fertigated micro-irrigation system. Grain yield of drip fertigation was better placed than the conventional method of irrigation and fertilizer application owing to favourable root characters, source capacity and translocation efficiency in the former.

The morphological parameters such as tiller production, root volume, root mass density, LAI, LAD, CGR and NAR were favourably influenced by the drip fertigation system.

The reduction in physiological parameters, such as chlorophyll content, photosynthetic efficiency (F_v / F_m) and growth parameters were also evident under limited water supplying environment. The effect of water stress in the given growing environment showed a substantial decline in the biochemical constituents. Regarding the biochemical aspects, drip fertigation also promoted increased rate of proline accumulation, enhanced content of endogenous cytokinins, negated activities of NRase, IAA oxidase, SOD and increased activities of peroxidase under the water stress situations.

Similarly, drip fertigation system could alleviate water deficit situations for the parameters of plant water relations such as leaf water potential, transpiration rate, diffusive resistance, leaf and canopy temperature, RWC, CSI and MSI with inadequate water supply. The uptake of essential nutrients, both macro and micro elements, were more favoured with the biofertigation practice.

The yield components viz., number of panicles, number of grains, spikelet fertility, grain filling rate, Panicle Harvest Index, Grain Harvest Index and TDMA, which were affected due to water deficit situation, could be improved substantially with the biofertigation practice thus ultimately resulting in significant improvement in grain yield even with inadequate water supply.

Molecular studies revealed the expression of putative proteins for the leaf protein profile and specific PO isoforms as observed with low and moderate water and fertilizer levels of the drip fertigation treatments indicating its drought tolerant behaviour.

The values of water productivity also showed significant improvement with the drip fertigation system in the aerobic environment.

Thus, the overall study revealed that the mean yield reduction of rice to the tune of 22.2 as observed with the limited water supply could be improved to + 16.0 per cent with the drip fertigation system. In this context, a special reference could be made to the biofertigation with the composite biofertilizer, *Azophosmet* for its effectiveness with the higher benefit: cost ratio of 2.41 in the aerobic environment.

To conclude, scheduling of drip fertigation at 125 % PE + 100 % RDF + Biofertigation (*Azophosmet*) performed better than the conventional practice.

Simulation analysis with well calibrated and validated dynamic model ORYZA2000 using present data inputs of drip fertigation system indicated that temperature-induced yield alterations in future climates could be favourably mitigated with the CO₂ fertilization along with biofertigation practice.

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CHAPTER I

INTRODUCTION

Rice is the most important staple crop in Asia, providing 35 -80 per cent of total calorie intake (IRRI, 1997). Asia's present and future food security depends largely on the irrigated rice production system. Food security in Asia is challenged by increasing food demand and threatened by dwindling water resources. Despite the constraints of water availability, rice production must, however, rise dramatically over the next generation to meet the food needs in the Asian continent. Producing more rice with less water is, therefore, a formidable challenge for food, economic, social and water security.

Water is one of the most vital natural resource of the world. According to UNO, water crisis is the major threat for mankind in 21st century (as quoted by Meghanatha Reddy *et al.*, 2007). From the total available water, 85 per cent is used by agriculture sector alone, of which 75 per cent is used for rice cultivation (Kirloskar, 2003). Irrigated lowland rice requires lot of water; about 3000-5000 litre of water is used to produce one kg of grain (IRRI, 2001). In such ecosystem, seepage and percolation losses account for 50 to 80 per cent of total water outflow from the field (Sharma, 1989). Evaporation makes up about 30 per cent leaving only 13-33 per cent of total water flow as consumptive water use by transpiration. Therefore, to mitigate the increasing water scarcity, it is necessary to develop a new way of growing rice using less water while maintaining higher yields.

Aerobic rice is a newer concept to decrease the water requirements in rice production. It is commercially grown in Brazil and also being pioneered by the rice farmers in Northern China. In India, innovative farmers have begun to grow rice aerobically under furrow irrigation in raised-bed systems. Thus, the water-saving irrigation practices shift away from conventional method of continuous anaerobic conditions to continuous aerobic conditions. However, this shift will have major consequences for both soil as well as plant nutrient dynamics.

Aerobic rice cultivation requires aerobic soil conditions with intermittent irrigation in non-puddled and non-flooded conditions (Wang *et al.*, 2002). The International Rice Research Institute (IRRI) had identified some existing improved upland and lowland cultivars for aerobic conditions (Laffitte *et al.*, 2002).

In the aerobic rice culture, the amount of irrigation water applied should match evaporation from the soil and also transpiration by the plant. Since, it is not possible to apply irrigation water to the root zone only as in the case of surface irrigation, some of it is lost by deep percolation and thus is unavailable for uptake by the crop. Recent studies also indicated that rice could be successfully grown completely under aerobic conditions thereby continuous submergence and seepage and percolation losses are eliminated (Bouman, 2001). This could be easily achieved using sprinkler / drip irrigation with their field application efficiencies of more than 90 per cent in comparison with only 60-70 per cent in the case of surface irrigation (Bouman and Tuong, 2001). Besides cutting down the seepage and percolation losses, evaporation from water surface in the rice fields can also be reduced significantly with the drip system, since there is no continuous standing water layer.

Aerobic rice cultivation might also lead to unknown challenges with respect to productivity, weed infestation, availability of nitrogen, micronutrients and pest and disease incidences (Belder *et al.*, 2005; Zhao *et al.*, 2006).

Thus, the aerobic rice will benefit the rice-growing community because it can be grown in environments where there is not enough rain for lowland production, in pump irrigated areas where water is expensive and also in areas where drought is common in the first part of the growing seasons but where flooding is typical in the second part.

The wasteful and harmful system of flood irrigation practiced widely in rice growing countries must be replaced with furrow, drip or sub-irrigation systems (Aujla *et al.*, 2005; Buttar *et al.*, 2006).

Drip irrigation has the greatest potential for the efficient use of water as well as fertilizers. The limited area of wetting under drip irrigation reduces the active root zone and also the foraging area of plants to draw more water and nutrients from the soil on per unit volume basis. For minimizing cost of irrigation and fertilizers, adoption of drip irrigation with fertigation is felt essential which will maximize the Nutrient Use Efficiency with optimum use of water and fertilizer.

Horie *et al.* (2005) opined that intermittent irrigation (similar aerobic rice) would reduce the adverse effects of low redox potential on rice roots and allow them to

penetrate deeper into the soil, which would greatly depend on the timely availability of nitrogen (N). Current recommendations of split applications at specified growth stages did not result in a better match of the N supply from the applied fertilizer with crop demand because of large variations in crop N requirement and soil N supply. A tool, which helps the researchers to manage the N as well as other nutrient supply-demand balance is **Drip-Fertigation**, which envisages an urgent need for a more dynamic and systematic research to guide and schedule nutrient management especially for the aerobic rice. Applying fertilizers through the irrigation system (drip-fertigation) has several advantages as furnished below:

- Nutrients can be applied at any time during the season and according to plant requirements.
- Placement of mobile nutrients such as nitrogen can be regulated in the soil profile by the amount of water applied.
- Applied nutrients are readily available for rapid uptake by the plants.
- Nutrients are applied uniformly over the field.
- Ground water contamination is likely to be less since nitrogen may be applied at any given time. It is often applied when crop uptake and utilization are at their peak.
- Crop damage during fertilizer application is minimized.

Besides, under limited water delivery system, as in aerobic rice, it is not surprising that the contents of phytohormones are also changed. It is very important because plant hormones are the main signals in root-to-shoot communication and *vice versa*. Consequently, the hormonal imbalance might play a key role in the sequence of events induced by limited water supply situations.

In recent years, realization of good number of plant growth promoting phyllosphere bacteria harbouring on the leaf surfaces and also contributing substantially to plant growth resulted in the discovery of facultative methylotrophic bacteria (FMs) belonging to the genus *Methylobacterium* and also the microbial culture, **Azophosmet**, consisting of mixture of *Azospirillum*, *Phosphobacterium* and *Methylobacterium* species, which are found promising especially under limited water resource conditions.

Keeping these in view, the present investigation is aimed at raising the yield plateau of aerobic rice grown under drip-fertigation system in order to increase the efficiencies of applied inputs such as water and fertilizer (both inorganic and biofertilizer) for realizing higher monetary returns to the poor and stressed rice farmers.

To achieve this, following objectives were set out for the present study:

1. To evaluate the compatibility of drip fertigation for aerobic rice culture under the scenario of limited water availability situations
2. To standardise crop management inputs such as water and fertilizers for enhancing aerobic rice productivity under drip- fertigation technology and to elucidate physiological / chemical bases of performance of aerobic rice in the drip-fertigation system, and
3. To validate ORYZA2000 dynamic simulation model using weather, soil and crop characteristics of the present study and to simulate grain yield for future climate change scenarios with special reference to the drip fertigation system in aerobic rice.

CHAPTER II

REVIEW OF LITERATURE

Irrigated agriculture is by far the biggest user of freshwater, accounting for more than 70 per cent of water withdrawals world wide (Rosegrant, 1997). In Asia, more than 50 per cent of all water used for agriculture is shared to irrigate rice (Barker *et al.*, 1999). The irrigated rice ecosystem covers about 79 million ha, which is about half of the world's total of 147 million ha under rice production. Irrigated rice in Asia produces about 75 per cent of the worldwide rice production of 530 million tonnes (IRRI, 1997). In Asia, rice is the most important staple food, providing 35-80 per cent of total calorie uptake. Thus, the present and future food security of Asia depends largely on the irrigated rice production system. This ecosystem is, however, threatened by water shortage. Therefore, there is a pressure to find ways to reduce water use and increase water productivity in rice production, while maintaining higher yields.

Conventional lowland rice fields have considerable so-called “non-productive” water losses such as percolation, seepage and evaporation. It has been estimated that seepage and percolation accounted for 50-80 per cent of the total water outflow from the field (Sharma, 1989). Estimating that evaporation makes up about 30 per cent of combined evapo-transpiration, then about 13-33 per cent of total water outflow is consumptive or “physiological” water use by transpiration. Thus, many technologies to save water focus on the reduction of non-productive water losses (Tabbal *et al.*, 2002).

A new water saving technology is to grow rice aerobically, that is, in non-puddled and nonflooded aerobic soil with supplementary irrigation (Bouman, 2001).

In this chapter, attempts have been made to illustrate the relationship between water stress and rice crop and the possible role of water saving irrigation and fertilizer supplying system strategies for providing broad perspective necessary to the present study.

2.1. Irrigation practices in rice

Traditionally, rice is grown under a continuously flooded condition and hence most conventional water management practices aim at maintaining a standing depth of water in the field throughout the season. Excessive ponded water conditions inhibited air

exchange between soil and the atmosphere, resulting in oxygen deficiency ([IRRI, 1964](#)). The degree of crop susceptibility depended on plant species and its development stage, soil and air temperature and duration of water logging ([Yamada, 1968](#); [Furuki, 1983](#); [Tabuchi, 1992](#)). Recently, effects of deeper ponded water depth on plant growth received renewed attention because of the subsurface irrigation and water table conditions in large sized paddy fields ([Murugaboopathi et al., 1991](#); [Anbumozhi et al., 1994](#)).

To identify the optimal water environment for improving plant yield, [De Datta \(1981a\)](#) reported that extremely deep water resulted in poor growth and yield. He further reiterated that rice might be grown under continuous submergence or intermittent or variable ponded conditions depending on the farmer's choice and also on the water resources. However, under continuous submergence in a loamy soil of puddled paddy field surrounded by bunds, about 60 to 70 per cent of the total water requirement was lost through deep percolation and only a small proportion (30-40 per cent) was utilized consumptively ([Koga, 1992](#)). The utility of keeping the field under continuous ponded condition had been questioned by several researchers. Hence, an intermittent or variable ponding of water was of practical importance in the place of continuous ponding. However, Biswas and Dravid (2001) observed inhibition of growth under saturation level than under submerged moisture level due to poor root growth or reduction of internal water potential.

Besides, application of fertilizer in irrigation water, i.e., fertigation, resulted in water and fertility stresses due to the sub-optimal ponded water depth at different places within the field. Many scientists studied the interactive effects in terms of nitrate-N and water supply, assuming that the stress was evenly distributed through out the field and the crop season. But this assumption did not hold, if the field was not perfectly leveled.

To conclude, the changes brought out by different ponded water depths in different water regimes such as continuous ponding, intermittent ponding and variable ponding and also under different fertigation levels on rice crop production and water use needs thorough investigation. This aspect forms the basis of the present study to explore the possibility of growing aerobic rice under drip fertigation system mainly to minimize the non-productive water losses.

2.1.1. Irrigation regimes on nutrient transformation

Irrigation influenced mineralization of soil N and was enhanced both under aerobic and flooded conditions (Sahrawat, 1981). De Datta (1981b) brought out the significance of alternate flooding and drying on nitrification and denitrification process causing heavy loss of ammoniacal N. Christopher Lourduraj and Rajagopal (1999) could not find any influence of irrigation regimes on soil N and K dynamics but the P status was higher with irrigation scheduled three days after the disappearance of water due to reduced P loss through water outlet and low solubility under the given irrigation regime. Irrigating the rice crop to 5 cm depth one day after the disappearance of ponded water recorded increased nitrogen availability during both *kharif* and *rabi* seasons (Balasubramanian and Krishnarajan, 2001). Uphoff (2002) observed that major share of the rice roots stayed in the top 6 cm of soil and most of them degenerated at the time of panicle initiation because of continuous flooding.

Iruthayaraj and Morachan (1980) reported increased P availability due to flooding; while Mali and Varade (1981) recorded decreased P availability with increased availability of calcium (Ca), magnesium (Mg), iron (Fe) and manganese (Mn) under similar conditions. The contents of P, Fe and Mn were higher under submerged conditions than under upland conditions (Padihar and Dikshit, 1985).

2.1.2. Irrigation regimes on nutrient uptake

Non-flooded conditions during the entire grain filling period increased both N uptake and yield in rice (Miyasaka, 1970). Waterlogging resulted in significantly higher N content in the plant at dough stage (1.12 %) and in total uptake (157.7 kg ha^{-1}) at harvest in comparison with the alternate wetting and drying practice (Biswas and Mahapatra, 1980). Well-drained soils helped in greater N uptake under higher percolation rate (Khind and Kazibwe, 1983; Yamamuro, 1983). Irrigation scheduled one day after the disappearance of ponded water recorded higher N and K uptake than irrigation given three days after the disappearance of water (Christopher Lourduraj and Rajagopal, 1999).

According to Krishnakumar and Subramonian (1992), draining and reflooding the field caused a marked decrease in N uptake by the rice crop due to lower N supply to the crop by the soil as a result of denitrification brought out by draining and reflooding.

Greater P uptake was recorded under alternate submergence and saturation till maximum tillering and continuous submergence resulted in considerable uptake of P at harvest stage (Dikshit and Padihar, 1988). Biswas and Dravid (2001) noticed higher P uptake in rice under saturation than under submergence while the uptake of Mg and zinc (Zn) was higher under submergence than at saturation moisture regime.

Longer the duration of soil water submergence lower was the content of dissolved oxygen in the soil water; but water saving irrigation supplied enough oxygen to the rice roots and induced an oxidized condition (Zhang *et al.*, 1994).

Higher uptake of Fe and Mn by rice was noticed under waterlogged conditions while a reverse trend in the uptake of Zn and copper (Cu) was found under moisture deficit situations (Thiyagarajan and Selvaraju, 2001).

2.1.3. Irrigation regimes on water use and water productivity

At Central Luzon province in the Philippines, wet seeded rice system used 1747 mm³ of water compared to 2195 mm³ for the transplanted rice without significant reduction in yield (Bhuiyan *et al.*, 1995). Alternate wetting and drying reduced the water requirement with increased yield (SWIM, 1997). Yang *et al.* (2002) observed minimized water use in aerobic rice.

Castañeda *et al.* (2002) showed that the water use decreased relatively more than the grain yield under aerobic cultivation with increased water productivity by 20-40 per cent (even 80 % in one case) over that under flooded conditions. Nieuwenhuis *et al.* (2002) observed that under pot culture experiments, the water productivity was higher (0.96-1.24 g grains kg⁻¹ water) under aerobic conditions with flooding during the reproductive phase. Nevertheless, Yang *et al.* (2002) indicated that the water productivity of the aerobic rice varieties under aerobic conditions were 164-188 per cent higher than that under the lowland situations.

2.1.4. Irrigation regimes on yield components

Ramasamy *et al.* (1997) found that drained field conditions raised the number of filled spikelets per panicle by 13 to 17 per cent with higher fraction of white or brown coloured roots due to increased root oxidizing power.

Christopher Lourduraj and Rajagopal (1999) reported that all the yield components viz., panicle number m^{-2} , number of filled grains per panicle and filled grain percentage were comparable between continuous submergence and irrigation given one day after the disappearance of water with significant reduction when irrigation was scheduled three days after the disappearance of ponded water.

Raju (1980) observed that maintenance of saturation level at vegetative and flooded irrigation during reproductive stage had higher HI and vice-versa. On the other hand, continuous irrigation to 5 cm depth gave higher grain yield but lowered the HI. The HI also showed a consistent association with grain yield in rice (Reuben and Katuli, 1990).

2.1.5. Irrigation regimes on grain productivity

Rangamanner *et al.* (1979) observed that grain yield under continuous submergence was significantly higher than the saturation treatment. Mohankumar and Singh (1983) reported that continuous flooding gave significantly higher yield than alternate wetting and drying due to increased nutrient availability, regulation of soil temperature and its pH. Similar findings were reported by Mandal and Chatterjee (1984).

Sandhu *et al.* (1980) and Ramamoorthy *et al.* (1993) noticed that the intermittent application of irrigation water 1-5 days after the disappearance of ponded water saved 25-50 per cent of irrigation water in comparison with the continuous submergence without any adverse effects on rice yields.

However, continuous submergence (5 cm) resulted in higher grain yield, followed by the irrigation given immediately after the disappearance of ponded water (Nayak *et al.*, 1981; Prasad and Sharma, 1984; Wahab and Daniel, 1992). But, Agarwal *et al.* (1995) reported that continuous shallow submergence throughout the crop period proved to be the best one and produced significantly higher grain yield.

Patjoshi and Lenka (1998) observed inhibition of tillering and reduction in grain yield with continuous submergence of ponded water at active tillering stage. Although alternate wetting and drying resulted in water saving, yield losses by 0-70 per cent was inevitable as compared to the flooded treatments depending on the number of days between irrigation and existing soil conditions (Bouman, 2001).

2.2. Water saving irrigation in rice cultivation

Recently, the term ‘water-saving irrigation techniques’ has been introduced (Guerra *et al.*, 1998) to denominate irrigation strategies that aim at reducing seepage and percolation (SP) rates by: i) reducing the depth of ponded water; ii) keeping the soil just saturated or iii) alternate wetting / drying, i.e., allowing the soil to dry out to a certain extent before re-applying the irrigation water.

According to Paurd *et al.* (1989), rice is not an aquatic plant. Achieving economy in water use without affecting the crop yield seemed to be the hit world in rice cultivation considering the fact that the farmers over irrigate their paddy crop more than its requirement (Ganesh, 2000). It is reaffirmed that flooding was not the best practice to produce rice (Amischan Gani, 2001).

2.3. Drip irrigation

Lowland rice in Asia has relatively higher water inputs. As water is becoming a scarce commodity nowadays, it is necessary to find ways and means of using the available water resources in a judicious manner to attain maximum productivity per unit quantity of water.

In drip irrigation, water is provided most efficiently at right time and practically near the root zone of the crop. Generally, between 15 to 60 per cent of the fraction of the soil alone is wetted. It enables precise application of water and nutrients at precise zone avoiding soil erosion and drain of water by deep percolation (Herman, 1982). Drip irrigation could also be used for close spaced row crops of high return wherever water scarcity would be the major constraint. Though the initial cost would be more, the pay back period for many commercial crops like sugarcane, banana, vegetables, cotton, etc., was within two years (Selvaraj *et al.*, 1997).

With the advancement in designing and reduced cost of materials, drip irrigation is becoming popular and acceptable for most of the field crops. It is now realized that drip irrigation not only boosts up the production but also reduces the water requirement, when it is practiced along with fertigation (Sivanappan, 2004).

2.3.1. Moisture distribution under drip irrigation

Water movement and distribution in the soil largely varies depending upon several parameters such as soil type, rate of infiltration, rate of discharge, quantity of water applied, antecedent moisture content, depth of water table and certain climatic factors. Plant growth and ultimate yield of any crop is influenced by availability of water in the root zone. Soil moisture exercises its influence on plant physiological processes which in turn govern the yield and quality of the crop.

Slow and frequent watering eliminated wide fluctuation of soil moisture under drip irrigation resulting in better growth and yield (Sivanappan, 1998). Study conducted at Coimbatore revealed that surface irrigation showed steep decline in the available soil moisture from 90 to 24 per cent; whereas in drip irrigation system, the available soil moisture was consistent throughout the irrigation cycle (about 87 per cent) and it was always nearer to field capacity under the irrigation schedule of once in two days (Bobade, 1999). Suresh Kumar (2000) also established that available soil moisture was almost consistent and nearer to field capacity under drip irrigation system as against wide fluctuation under surface irrigation.

2.4. Fertigation

Fertigation is the application of fertilizers through irrigation. By definition, fertigation is the precise application of soluble fertilizers through sprinkler and drip irrigation (Bill Segars, 2003). When fertilizers were applied along with water through drip irrigation system, there was considerable saving of fertilizers besides increasing the yield, quality and saving of water compared to surface method of irrigation. It also helped to achieve higher fertilizer use efficiency and water use efficiency.

Drip fertigation provided an efficient method of fertilizer delivery and if properly managed, it reduced overall fertilizer application rate and minimized the adverse environmental impact (Hake *et al.*, 1992).

In this context, fertigation through the trickle irrigation system offered several advantages like: i) increased use efficiency of both water and fertilizer, ii) optimization of nutrient balance by supplying nutrient directly to active root zone in the available forms, iii) flexibility of fertilizer application in accordance with crop nutrient demand,

iv) reduced labour, v) reduction in groundwater pollution by minimizing leaching below the rooting depth and vi) reduced soil erosion (Hagin and Lowengart, 1996).

On the other hand, there might be some disadvantages like unequal distribution of nutrients in the field, the possibility of over-irrigation or leaching and the possibility of chemical reaction in the irrigation system (Haynes, 1985).

2.4.1. Fertilizers suitable for fertigation

Fertigation practice is becoming more popular because of the availability of completely water-soluble fertilizer materials of high grade. These fertilizers are made of same chemical compound as those of normal fertilizers, but they are devoid of neutral insoluble materials such as earth, gypsum, dolomite, clay etc. Therefore, these water soluble fertilizers are 100 per cent soluble in water with pure nutrients in the manufactured products without leaving any sediment in fertigation or clogging the sprayers when applied as foliar spray or as fertigation along with the irrigation water.

Venkateshamurthy (1997) also opined that the water soluble fertilizers were the better source for fertigation than the normal fertilizers as they resulted in less clogging.

2.4.1.1. Nitrogenous fertilizers

Different sources of nitrogen (N) that could be used for fertigation are anhydrous ammonia, ammonium phosphate, urea, ammonium nitrate and calcium nitrate. Careful consideration might be given to pH in the irrigation water since some of the N sources increased the pH leading to precipitation of calcium and magnesium and thereby clogging the drip system. While using soluble fertilizers, N use efficiency could be as high as 90 per cent in comparison with 40-60 per cent in the conventional method of fertilizer application. Careful evaluation of soil type, crops and irrigation management would be necessary in selecting most appropriate source of N for fertigation (Paryea, 1992).

2.4.1.2. Phosphatic fertilizer

Application of phosphatic fertilizers along with irrigation water might cause precipitation problems. Phosphoric acid, which is the concentrated form of phosphate, containing 20 to 32 per cent of phosphorus (P) could be used in fertigation as a source of P, which would also aid in cleaning the system of chemical deposits.

If irrigation water is low in calcium and magnesium, few problems would be encountered in applying phosphoric acid in fertigation. In such situations, ammonium or potassium dihydrogen phosphate could also be used. Other soluble fertilizers available as P sources are ammonium polyphosphates and nitrophosphates. However, Mikkelsen (1989) opined that fertilizer compatibility test with the irrigation water should be conducted before injecting the soluble P fertilizer in the trickle irrigation system.

2.4.1.3. Potassic fertilizers

The common sources of potassium (K) such as potassium chloride, potassium nitrate and potassium sulphate, were readily available and did not cause any precipitation problem in the drip fertigation system.

2.4.2. Movement of nutrients in soil by fertigation

Under fertigation method, movement of nutrients in the soil is largely determined by the Cation Exchange Capacity (CEC) of the soil and then electrostatic charge of the particular nutrient, water flow through the soil and plant nutrient uptake. The charged nutrient ions such as ammonium, potassium, calcium and magnesium are dependant on the degree of saturation and exchange capacity of the soil. Thus, the nutrient movement in the sandy soils occurs more rapidly than loamy or clayey soils mainly because of lesser exchange sites available in the case of sandy than the loamy soils.

2.4.2.1. Nitrogen

The initial distribution of N added to the soil from the micro irrigation system (MIS) is likely to differ markedly depending upon the source and rate of N application. As the concentration of applied ammonium increased sufficiently to overcome the CEC of the soil, then the ammonium would move further. Thus, the extent of movement would, therefore, depend on the soil CEC and the rate of ammonium application.

The highly mobile nitrate ions moved with the wetting front of the irrigation application and tended to accumulate at periphery of the wetted soil volume and at the soil surface midway between emitters (Dalbro and Dorph Peterson, 1976). In well-aerated soils, nitrification occurred, thus mobility of N was not restricted and was equal to that of the wetted front (Haynes, 1985). In over-irrigation, leaching of nitrate would occur if N was present in surface and underground water resources (Magen, 1995).

Gratez *et al.* (1978) suggested that the faster discharge rates might improve the distribution of soluble nutrients particularly for surface rooting crops.

2.4.2.2. Phosphorus

In the case of fertigation practice, mobility of P was restricted due to its strong retention by soil oxides and clay minerals; but continuous application of orthophosphate through fertigation proved to be superior to applying P as basal dress (Bar-Yosef, 1982).

2.4.2.3. Potassium

Potassium ion is normally adsorbed at the cation exchange sites of the soil colloids, but was shown lateral and downward mobility of K when applied through drip fertigation (Haynes, 1985). Magen (1995) showed that the distribution of K was more uniform than that of either nitrates or phosphates.

2.5. Effects of water stress and fertilizer on rice

Water-saving irrigation techniques often run the risk of yield reduction because of possible drought-stress effects on the crop. Drought effects on lowland rice can occur when soil water content drops below saturation. Therefore, relationship between water input and rice yield needs to be established to find out how far water can be reduced without compromising the economic yield for optimizing scarce water in rice production.

Therefore, in the following pages, attempts have been made to review the effects of deficit water supply on growth and yield of rice that might be incurred by water-saving irrigation techniques, involving both irrigation and fertilizer as external inputs, with special reference to the morpho-physiological and biochemical basis in order to develop management strategies for successful aerobic rice production.

2.5.1. Morphological characters

2.5.1.1. Plant height

In general, moisture stress resulted in reduced plant height and the susceptible lowland types were more sensitive than upland varieties (Basu Raychaudhuri and Das Gupta, 1981). However, plant height was higher in rice when irrigation was given two days after subsidence of ponded water at vegetative phase and four days of subsidence at reproductive phase (Uppal *et al.*, 1991). Tomar and Prasad (1996) reported that plant

height in rice was associated with thick and deep root system. Lower amount of water supplied in the aerobic method reduced plant growth and prolonged the cycle duration in different cultivars (Russo, 2000).

It was often observed that the plant height increased with increase in nitrogen (N) supply (De Datta, 1981b). Nevertheless, application of N at different levels had insignificant difference in the non-flooded situation (Salvatore and Iside, 1998).

2.5.1.2. Root characters

Especially under water deficit situations, the most effective defense mechanism available for the rice plant is the presence of well developed root system, consisting of deeper and mostly thicker roots enabling the plant to absorb moisture from the deeper soil layers for avoiding adverse effects of water stress (Chang *et al.*, 1972). Cruz *et al.* (1986) observed that a mild water stress at vegetative phase decreased total root dry mass and total root length and density. Though genetically controlled, the root characters of rice crop could be strongly influenced by soil conditions and crop management practices (Hasegawa *et al.*, 1984). Increased yield was often associated with well developed rice roots owing to the oxidized condition resulting from alternate wet and dry irrigation practice (Fang *et al.*, 1996).

Deep root system ensured greater extraction of water held deep in the soil profile and maintained higher leaf water potential during the drought period (Fukai and Cooper, 1995).

Yield efficiency was noted for upland rice varieties having relatively high root / shoot ratio (R/S ratio) under moisture stress conditions (O'Toole and Chang, 1979). The R/S ratio was high in drought resistant upland rice cultivars (Namuco *et al.*, 1993; Lu and Hua, 1994). Henry *et al.* (1997) also stated that the R/S dry matter ratio increased due to drought stress. The ratio was negatively correlated with membrane thermal stability under osmotic stress (Dhanda *et al.*, 2004). Higher R/S ratio under drought contributed significantly to drought tolerance in rice especially at flowering stage (Kumar and Kujur, 2003).

With the supply of N, increased root length (Dhurander and Tripathi, 1999) and root volume (Khanda and Dixit, 1996) were observed in rice.

2.5.1.3. Tiller production

A mild plant water stress at vegetative growth stage decreased tiller number (Cruz *et al.*, 1986). Such reduction was marginal in the tolerant types as compared to the susceptible rice varieties under drought situations (Vijayalakshmi and Nagarajan, 1994)

However, the tiller production could be generally increased due to N application as observed by Shanmugam (1983), Sankaranarayan (1985) and Krishnakumar (1986). On the contrary, Salvatore and Iside (1998) could not find any substantial influence of N applied at various levels for the non-flooded rice.

2.5.1.4. Total Dry Matter Accumulation (TDMA)

Simane *et al.* (1993) reported that the rate of TDMA varied in drought resistant and susceptible cultivars. Lilley and Fukai (1994) reported that the degree of TDMA reduction depended upon the severity of moisture stress. In rice, dry matter was reduced by 11-37 per cent and 30-65 per cent under mild and severe moisture stress respectively (Yang *et al.*, 1995a). Chauhan *et al.* (1996) reported that cultivars differed in their ability to produce dry matter under stress. The total biological yield was higher in continuous irrigation than the lower biomass observed in irrigation given at eight-day interval after tillering initiation (Surek and Beser, 1999). Aerobic treatment with flooding in the reproductive stage exhibited 14 per cent lower biomass production than continuous flooded treatment; but, continuous aerobic situation produced 32 per cent lower biomass than continuously flooded treatment (Nieuwenhuis *et al.*, 2002).

Venkitaswamy (1986) and Rajeswari (1990) reported that N application increased TDMA in rice. As opined by Belder *et al.* (2005), the TDMA of aerobic rice could be improved by the N application as compared to the flooded rice.

2.5.2. Growth attributes

2.5.2.1. Leaf area

Assimilatory system might be a key factor for realization of grain yield (Gautam and Sharma, 1993). Development of leaf area is an important factor that could influence the crop response to water availability (Aggarwal and Sinha, 1987). Lilley and Fukai (1994) reported that susceptible varieties showed decline in leaf elongation and greater leaf death. Marginal reduction in leaf area under water stress condition was observed in drought tolerant rice varieties (Vijayalakshmi and Nagarajan, 1994). Fukai and Cooper

(1995) observed possible causes for drought affected leaf area development as reduced leaf expansion, leaf rolling and early senescence and suppressed tillering. Leaf area was reported to be reduced as much as 54.3 per cent in a traditional upland rice variety when subjected to moisture stress for 35 days (Chauhan *et al.*, 1996). Baruah *et al.* (1998) also observed similar decrease in leaf area per seedling under stress condition.

During water stress period, the rice cultivar with a smaller canopy maintained higher plant water status as compared to the cultivar with larger canopy. However, the cultivar with smaller canopy could not fully recover from the stress (Prasertsak and Fukai, 1997). Mitchell *et al.* (1998) also reported that cultivars with larger leaf area tended to lose more green leaves during the stress period.

Higher leaf area was observed with N supply (Dhyani and Mishra, 1994). But, the N insufficiency often resulted in reduction in leaf area in sorghum as observed by Zhao *et al.* (2005).

2.5.2.2. Leaf Area Index (LAI)

Leaf Area Index (LAI) is an important plant factor in determining the dry matter accumulation and hence the crop yield. The LAI was directly related to grain yield irrespective of the variety in wheat and maintenance of high LAI at anthesis would be desirable for obtaining higher yield in the stressed plants (Aggarwal and Sinha, 1987). Moisture stress induced changes in leaf area was also noticed in LAI, which varied with different moisture levels duly reflecting in the biomass yield (Kerby *et al.*, 1990).

Jayabalan *et al.* (1995) and Wang *et al.* (1996) reported a decline in LAI of rice varieties due to moisture stress. DeSouza *et al.* (1997) observed reduction in LAI due to acceleration of senescence under drought. The LAI exhibited significant and positive correlation with grain number per panicle, panicle length, spikelet number and transpiration rate at 28th day of water stress (Maibangsa, 1998).

In both flooded as well as aerobic rice, the LAI showed an increased trend with the supply of N (Belder *et al.*, 2005).

2.5.2.3. Specific Leaf Weight (SLW)

Specific Leaf Weight (SLW) was reported to have a strong positive correlation with leaf photosynthesis in several crops (Bowes *et al.*, 1972; Dornhoff and Shibles, 1976; Lugg and Sinclair, 1980). Decrease in SLW values with the increase in water stress was noticed by Rajkumar (2001). Under aerobic conditions, the rice plants showed increased values for SLW (Gowri, 2005).

2.5.2.4. Crop Growth Rate (CGR)

Crop production was determined by the CGR as a function of light interception in crop canopy (Whigham, 1983). Jayabalan *et al.* (1995) reported reduction in CGR of rice cultivars due to moisture stress. Zhang *et al.* (1997) observed greater inhibition of CGR and physiological activities of five rice varieties under water stress condition. Rajkumar (2001) showed that the drought tolerant rice variety, PMK 2, recorded higher CGR than the susceptible CO 32 variety under water stress condition.

2.5.3. Physiological and biochemical characters

Duration of physiological activity was determined to a large extent by the ability of cultivars to extract water. Greater water extraction prolonged the physiological activity and crop growth (Lilley and Fukai, 1994). Effect of water stress on the physiological and biochemical aspects of crop growth was briefly enumerated in the following pages.

2.5.3.1. Chlorophyll content

Chlorophyll pigments play decisive role in plant productivity, as it is the only pigment responsible for photosynthesis. Water stress decreased chlorophyll content in rice leaves (Zhu and Huang, 1994; Sheela and Alexander, 1996). The chlorophyll content of drought tolerant upland varieties was higher than the transplanted paddy under water deficit conditions (Peng *et al.*, 1996). Thus, its destruction was more deleterious to plant productivity under water stress situations.

Nitrogen is a major component of chlorophyll (Stevens *et al.*, 2001). Zhao *et al.* (2005) observed reduction in chlorophyll content due to insufficient supply of N, which was often associated with the break down of chlorophyll (Martignone *et al.*, 1987).

2.5.3.2. SPAD Chlorophyll meter readings

The chlorophyll meter (SPAD meter) quantifies green colour in plants immediately and non-destructively measures the chlorophyll status (Watanabe *et al.*, 1980). It has the potential to provide insight into the N status of rice crops (Matsuzaki *et al.*, 1980; Inada, 1985).

Peng *et al.* (1993) observed improved correlation from adjusting SPAD values for SLW. Leaf chlorophyll (SPAD value) was positively and significantly correlated with filled grain percentage and grain number panicle⁻¹ (Maibangsa, 1998).

Besides, the SPAD chlorophyll meter had been used to estimate N concentration on a dry weight basis (N_{dw}) of rice leaves with the goal of predicting the need for fertilizer-N top dressing (Chubachi *et al.*, 1986; Takebe *et al.*, 1990). The SPAD readings were often influenced by N fertilization, cultivar and position of leaf on plant and location on leaf where reading was taken and the deficiencies of P, Zn, Fe and Mn (Turner and Jund, 1991).

2.5.3.3. Soluble protein content

Soluble protein was the first nitrogenous compound to loss under stress (Martignone *et al.*, 1987). Soluble protein content in rice leaves was reduced due to moisture stress (Jayabalan *et al.*, 1995). Foliage protein content was often correlated with plant growth rate, soil water holding capacity, tillering, LAI and panicle number (Jayabalan *et al.*, 1995). Jha and Singh (1997) reported higher soluble protein content of stressed seedlings of tolerant rice cultivars as compared to the susceptible types. Under the conditions of aerobic rice, the content of soluble protein decreased drastically (Gowri, 2005).

RUBISCO (ribulose 1,5 - bisphosphate) accounted for more than 50 per cent of soluble protein content (Joseph *et al.*, 1981) and the drought stress led to a rapid decrease in the abundance of rubisco small sub unit transcripts, which might indicate decreased synthesis (Vu *et al.*, 1999). Soluble protein content was more affected in the susceptible CO 37 variety than the tolerant genotypes. The decline was associated with a concomitant increase in free aminoacid and decreased nitrate reductase activity (Rajkumar, 2001).

Break down of soluble protein due to N loss was reported by Martignone *et al.* (1987).

2.5.3.4. Peroxidase activity

Generation of activated oxygen species (AOS) might be responsible for most of the damage to cellular components under water stress (Allen, 1995; Willekens *et al.*, 1995). Photo-oxidation due to excess excitation of energy led to production of super-oxides, peroxides and hydroxyl radicals which were highly reactive and damaging to biological systems reacting quickly with membranes, proteins and DNA. This in turn had been linked to degenerative diseases and ageing (Shigenaga *et al.*, 1994).

Peroxidase (PO) activity was often associated with water stress in rice (Malik and Mehta, 1977). The PO catalysed the oxidation of many organic compounds in the presence of H₂O₂ (hydrogen peroxide) and was widely distributed in plant tissues. It is of great importance owing to its association with several physiological processes (Sharma and Mani, 1992). Boo and Jung (1999) reported that in rice plants (*Oryza sativa* L.) exposed to water stress, activities of ascorbate peroxidase (APX) and catalase decreased but levels of O₂⁻ did not change and H₂O₂ content decreased.

2.5.3.5. Superoxide dismutase (SOD)

A marked decrease in the activity of SOD was found in rice seedlings under moisture stress (Jiang *et al.*, 1991). Several SOD isoforms were found in the extracellular matrix. The APXs were the most important enzymes for protection against H₂O₂ in the cytosol and chloroplasts (Asada, 1992) particularly in the "Mehler reaction". Drought stress strongly induced in the transcript levels of cytosolic APX isoform mostly (Mittler and Zilinkas, 1994) and removed the H₂O₂ produced during dismutation of O₂⁻ by SOD. Under water stress, there was a potential increase in the SOD activities in wheat (Zhang and Kirkam, 1994) while it decreased in maize (Wang *et al.*, 1995).

It was postulated that decrease in antioxidant activity in water stressed tissue resulted in higher levels of AOS that might have contributed to injury in rice (Fadzillah *et al.*, 1996). On the contrary, antioxidant activity had increased under stress conditions, detoxified the heavy loads of AOS and provided protection (Prasad *et al.*, 1999).

2.5.3.6. IAA Oxidase

In comparison with huge information on auxin content during plant growth and development, relatively little information is available on the changes in auxin content induced by water stress (Pospisilova, 2003). Darbyshire (1971) found an increase in IAA

oxidase activity *in vitro* with decreasing water potential, and correlated it with an observed decrease in endogenous auxin in rice. Stressed situations led to sharp changes in the balance of phytohormones associated with not only accumulation of ABA, but also with a decline in the level of growth activating hormones such as IAA and cytokinins (Jackson, 1997).

Increased values of fresh and dry weight of two bromeliad species due to N supply in the form of urea was correlated with the IAA levels because of decreased IAA oxidase activity (Mercier *et al.*, 1997).

2.5.3.7. Nitrate Reductase activity (NRase activity)

Sinha and Rajagopal (1975) and Pal *et al.* (1976) observed that stability of enzyme activity under moisture stress might be associated with drought tolerance. Sairam and Dube (1984) reported that the stability of NRase activity under moisture stress was positively correlated with enzyme recovery with subsequent irrigation and was closely related to the relative water content and yield. In rice plants, the NRase activity decreased under drought stress (Rajkumar, 2001). However, the tolerant types maintained the NRase activity in their leaves during stress than the susceptible ones and the former also showed higher recovery upon drought relief (Saxena *et al.*, 1996; Jha and Singh, 1997).

The NRase activity increased with the supply of N in soybean (Harper and Cooper, 1971) and in *Phaseolus vulgaris* (Timpo and Neyra, 1983) with less appreciable differences in different levels of N for rice (Traore and Maranville, 1999).

2.5.4. Plant water relations

2.5.4.1. Relative Water Content (RWC)

The mechanism controlling internal plant water status might involve water uptake or water conservation by the plant and also internal plant water conductance during drought. As a result, the plant water status could differ significantly among cultivars exposed to the same period of water exclusion (O'Toole and Moya, 1978). Stressed rice plants possessed decreased leaf RWC as compared to the control plants (Sairam and Dube, 1984; Saxena *et al.*, 1996). Nevertheless, drought resistant varieties showed higher leaf water potential than the susceptible types under limited moisture supply (Thangaraj and Sivasubramanian, 1990; Nadarajan and Kumaravelu, 1993). The genotypes maintaining

higher RWC accumulated more osmolytes and had higher rate of photosynthesis (Krishnayya and Murty, 1991) coupled with higher recovery upon stress relief (Jha and Singh, 1997).

Moisture stress had an inhibitory effect on RWC as a result of soil dryness (Sarker *et al.*, 1999). Maintenance of plant water status more than plant functions controlled the crop performance under drought (Blum, 2002). Yield variation that was not related to plant water status might reflect variation in mechanisms such as the tolerance to root or leaf-sourced signals that reduced grain set (Kobata *et al.*, 1994) under stress or differences in the response of grain formation to varying levels of carbohydrate availability near flowering (Lafitte, 2002). Mean leaf RWC across the DH lines of rice declined to 68 per cent under stress (Babu *et al.*, 2003). Maintenance of higher water status under drought played crucial role in stabilizing various plant processes and yield (Kumar and Kujur, 2003).

2.5.4.2. Membrane Stability Index (MSI)

The leakage of solutes from tissue can be used as a dynamic measure of the damage to membranes incurred by stress experiences (Leopold *et al.*, 1981). The plasma membrane is generally protected from desiccation-induced damage by the presence of membrane-compatible solutes, such as sugars and amino acids (Schwab and Herber, 1984). Therefore, a link might exist between the capacity for osmotic adjustment and the degree of membrane protection from the effect of dehydration (Lilley and Ludlow, 1996).

Membrane stability was associated with drought tolerance in rice (Tyagi *et al.*, 1999). Higher membrane stability under drought contributed significantly to flowering stage drought tolerance in rice (Kumar and Kujur, 2003). Gowri (2005) reported a decrease in the values of membrane stability in aerobic rice.

2.5.4.3. Chlorophyll Stability Index (CSI)

The CSI is a measure of integrity of membrane or heat stability of pigments under stress conditions (Murty and Majumdar, 1962). Drought tolerant rice varieties had higher chlorophyll stability with a lower index (Nadarajan and Kumaravelu, 1993).

Madhan Mohan *et al.* (2000) stated that the CSI was an indication of the stress tolerance capacity of plants and higher CSI helped the plants to withstand stress through better availability of chlorophyll leading to increased photosynthetic rate, more dry matter production and higher productivity. Similar findings were observed by Michael Gomez and Rangasamy (2002) and Yogameenakshi (2002) in hybrids, land races and varieties of rice. Contradictory results were also reported that the CSI was not correlated to drought tolerance in rice by Thangaraj and Sivasubramanian (1990).

Martignone *et al.* (1987) showed significant role of N in the stability of the chlorophyll molecules.

2.5.4.4. Leaf Water Potential (LWP)

Varieties that adjusted to the LWP were adjudged as the dehydration tolerant ones. O'Toole and Moya (1978) observed that maintenance of higher LWP in a cultivar was due to better root system. Upland rice cultivars maintained higher LWP during drought (O'Toole and Cruz, 1980). They also observed a linear relationship of leaf diffusive resistance and leaf rolling with LWP. Ekanayake *et al.* (1990) noticed higher LWP in drought resistant rice lines. The LWP of upland rice varieties decreased with the increase in soil moisture stress (Krishnayya and Murty, 1991; Lilley and Fukai, 1994) because of large demand for transpiration water (Boonjung and Fukai, 1996).

Decline in LWP was most rapid in susceptible varieties especially when stress was imposed during reproductive stage (Lilley and Fukai, 1994).

Working with 28 rice varieties, Dingkuhn *et al.* (1989) reported a critical LWP between -0.8 to -1.2 MPa for stomatal closure. Drought resistant varieties showed higher LWP in their tissues than susceptible types even under moisture deficit conditions (Nadarajan and Kumaravelu, 1993). The LWP was closely related to leaf RWC but was confounded by osmotic adjustment (Lafitte, 2002).

2.5.4.5. Proline content

Proline accumulation in dehydrated plant tissues was first noted by Kemble and Mac-Pherson (1954). Proline, an amino acid, accumulated in plants including rice when subjected to water stress (Sheela and Alexander, 1996; Zhang *et al.*, 1997).

Itai and Paleg (1982) suggested several possible functional roles of proline such as cytoplasmic osmoregulation, prevention of enzyme inactivation and stabilization of biopolymer stability. Dingkuhn *et al.* (1991) determined free proline in seven diverse rice genotypes and reported that proline content was higher in lowland adapted cultivars both under control and stressed plants. Proline accumulation under stress had been linked with its role as an osmolyte (Voetberg and Sharp, 1991) by contributing towards the osmotic adjustment between cytoplasm and vacuole (Delauney and Verma, 1993). Yang *et al.* (1995b) reported that there was a significant increase in proline accumulation with progressed water stress in rice. Nguyen *et al.* (1997) further observed that the rice genotypes exhibiting higher proline accumulation had a marked effect on the ability to maintain water stress, consequently delayed tissue death and leaf senescence in rice under water shortage. During stress conditions, at least a part of free proline accumulated due to protein breakdown consequent to increased protease activity (Agarwal *et al.*, 1999). Proline levels increased in stressed rice plants more in shoots than in roots (Pandey *et al.*, 2004).

Increased proline accumulation was often observed with N supply in green bean plants (Sanchez *et al.*, 2002).

2.5.4.6. Gas exchange parameters

Stomata are openings through which gases diffuse into and out of leaves during photosynthesis and transpiration respectively. They are the major conduct for the transfer of many trace gas species between the terrestrial biosphere and atmosphere. Consequently, stomata are the major sites in the biological control of the climate system and the chemistry of atmosphere (Buckley, 2005).

The leaf characteristics viz., photosynthetic rate, transpiration, stomatal resistance and leaf temperature expressed the significance of various physiological processes along with their impact on biomass production and grain yield (Dey and Rao, 1989). In rice, stomatal conductance showed direct relationship with photosynthesis and grain yield

(Dingkuhn *et al.*, 1989; Murty *et al.*, 1991). Water stress decreased photosynthesis at both single leaf and plant community level (Yang *et al.*, 1995a).

Leaf diffusive resistance (LDR) was linearly related to leaf water potential (O'Toole and Cruz, 1980; Dingkuhn *et al.*, 1989). Higher LDR was observed in upland than in semi dwarf varieties. Dingkuhn *et al.* (1991) reported that stomatal closure was more sensitive in upland variety during stress. Leaf water deficit restricted gas exchange through leaf rolling and also reduced the stomatal conductance. There were significant differences in gas diffusion resistance among rice cultivars which in turn decided the diffusion of CO₂ from atmosphere to the active site of carboxylation (Chen *et al.*, 1990). Wang *et al.* (1996) observed a decrease in photosynthesis of rice cultivars as soil water potential decreased and the drought resistant cultivars showed lesser decrease in photosynthesis. Chauhan *et al.* (1996) reported that the improved upland cultivar transpired less water during moisture stress because of higher stomatal resistance. They further noted that stomatal resistance increased with increasing intensity of moisture stress. Wopereis *et al.* (1996) observed lower transpiration with the decreasing soil moisture content in rice.

2.5.5. Nutrio-physiological aspects

Fertilizer application appeared to have a major role in increasing the production efficiency of rice per unit of water used.

Sufficient nitrogen (N) supply enabled maintenance of green leaf area after heading and thereby contributed to active photosynthesis available for grain production (Yoshida, 1981; Kropff *et al.*, 1993). The N application significantly improved its uptake and hence yield as suggested by several authors (Dhurandher and Tripathi, 1999; Paikaray *et al.*, 2001). They also stated that use of higher dose of nitrogen might have helped in inducing good vegetative growth and root system, which increased the higher N uptake by plants and ultimately increased yield components and yield of rice.

Russo and Iside (1998) reported that N uptake was significantly lower under dryland condition compared with the flooded condition, independent of the rate of N application. They also stated that under dry cultivation, mechanism of N uptake in rice was dramatically changed and affected the yield. Cassman *et al.* (2002) suggested that the upland system could have equal or higher values of N recovery than flooded systems.

In aerobic systems, the dominant form of N was nitrate and relatively little ammonia volatilization could be expected after fertilizer N application (Belder *et al.*, 2005).

Changes from saturated to (partially) aerobic soil conditions affected the form, availability and loss processes of nutrients such as P and N (Willett, 1982; Muirread *et al.*, 1989).

Increased uptake of N and P was observed under submergence by Yoshida and Padre (1975). Similar results were reported by Pathak *et al.* (1980) and Islam *et al.* (1986). Tanguiling *et al.* (1987) found decline in N, P and K content in shoot and root of water stressed rice. However, Paikaray *et al.* (2001) found that inorganic N supply improved the uptake of K in rice.

It is contemplated that the aerobic condition conspicuously increased the uptake of Mn by rice plant (Gooth and Patrick, 1972). Iron uptake was more pronounced under anaerobic than under aerobic conditions (Gooth and Patrick, 1972). Uptake of Zn and Cu increased under oxidizing condition than reducing one whereas anaerobic condition stimulated the uptake of P by rice plant as compared to aerobic condition (Abou Seeda, 1993).

Similar results were obtained earlier by Patrick and Reddy (1977) stating that reduction of ferric compounds to more soluble ferrous form released P from the soil.

To summarize, very little information is available on the effect of irrigation and N fertilizer application on the uptake of nutrients by aerobic rice. Further study is needed to obtain better insight on the above aspect.

2.5.6. Yield and yield components

2.5.6.1. Panicles

Number of panicles was significantly lower in plants exposed to aerobic condition at vegetative stage than the plants under flooded situations (Nieuwenhuis *et al.*, 2002). They further showed that in clay loam soil, the number of panicles was relatively high in aerobic condition only at reproductive stage due to the production of second-generation tillers at grain filling stage.

It was observed that the N application could improve the number panicles (Paikaray *et al.*, 2001; Singh and Singh, 2005).

2.5.6.2. Spikelet sterility

Reduction in LWP at anthesis caused poor panicle exertion (O'Toole and Namuco, 1983; Cruz and O'Toole, 1984; Ekanayake *et al.*, 1989) which increased percentage of sterile spikelets because of abnormalities in pollination. Water stress affected many complex and phenologically increasing biochemical and physiological events between panicle initiation and grain filling. Studies of panicle water relations (O'Toole *et al.*, 1984; Garrity *et al.*, 1986; Ekanayake *et al.*, 1989), abnormalities of gamete formation (Namuco and O'Toole, 1986) and panicle exertion (O'Toole and Namuco, 1983; Cruz and O'Toole, 1984) provided insight into the causes of sterility induced by water stress and the resultant decrease in grain yield.

2.5.6.3. Filled grain percentage

Filled grain percentage was often related to the current assimilation around anthesis period, which was particularly susceptible to water stress (Boonjung, 1993). Garrity and O' Toole (1994) established a strong correlation between spikelet fertility and grain yield. They further opined that the retention of spikelet fertility would be important in maintaining higher grain yield under terminal drought situation.

It is suggested that N application increased the number of filled gains per panicle in rice (Krishnakumar, 1986; Paikaray *et al.*, 2001).

2.5.6.4. Panicle Harvest Index (PHI)

The problem with measuring spikelet fertility was that it required a lot of labour and many measurements; it was often prone to error. Therefore, many researchers made a substitute for this. One such reliable parameter was PHI. Lafitte *et al.* (2003) reported that the correlation between per cent fertility and PHI was quite high for rice which experienced water stress near flowering stage. Gowri (2005) showed a decline in PHI for aerobic rice.

2.5.6.5. 1000 Grain weight

A mild water stress at vegetative stage resulted in a linear decrease in 1000 grain weight in rice; however, its influence on grain yield was not significant (Cruz *et al.*, 1986). The reduction in grain yield in rice with water stress was mainly due to decrease in the number of filled grains per panicle and 1000 grain weight depending on severity of stress (Surek and Beser, 1999). Water stress at booting and heading to flowering stages reduced the number of productive tillers, grain number per plant and 1000 grain weight (Liu *et al.*, 1993).

When the crop was exposed to aerobic condition, number of grains per panicle and 1000 grain weight were significantly lowered and the percentage of spikelet sterility was increased when compared to continuous flooding in rice (Nieuwenhuis *et al.*, 2002).

An increase in 1000 grain weight was often observed in rice with the application of N fertilizers (Paikaray *et al.*, 2001). Nevertheless, Venkitaswamy (1986) was of the opinion that the grain weight in rice was independent of N application.

2.5.6.6. Grain Yield

Effect of water stress on yield decrease in rice is more pronounced during certain period of growth. These stages are called the moisture sensitive periods. The most sensitive periods to water deficits are flowering and panicle development (Surek and Beser, 1999).

Jana and Ghildyal (1971) reported that the soil water stress applied at any of the growth phases reduced the grain yield in rice compared to the continuous flooded irrigation. The ripening phase (terminal drought) appeared to be the more sensitive one than other phases. Soil water stress during the earlier growth phases (vegetative) affected the production of effective tillers, thus resulting in the reduction of grain yield; while water stress during the latter growth phases (reproductive) appeared to affect the reproductive physiology by interfering with pollination, fertilization and grain filling in the reduction of grain yield. Wann (1978) observed that continuous flooding was not essential for higher grain yield and practice of intermittent submergence at critical stages of crop gave yield comparable to the continuous flooding.

Fussel *et al.* (1991) reported that the reduction in grain yield was more than 40 per cent when stress was imposed during mid-flowering period. Lilley and Fukai (1994) observed a reduction in grain yield up to 70 per cent due to the occurrence of water deficit during reproductive stage. The grain yield of rice was reduced by 5-38 per cent under mild water stress while severe water stress reduced the grain yield by 25-67 per cent (Yang *et al.*, 1995a). Water shortage during flowering and grain filling stages reduced the yield drastically (Boonjung and Fukai, 1996).

Li *et al.* (1998) stated that higher rice yield could be obtained at 80 per cent of saturated moisture level in the root zone.

In dry season, the rice variety Apo, recorded a yield reduction of 13 per cent with the treatment of aerobic conditions in the reproductive stage and flooding in the vegetative and grain filling stages in comparison with the continuous flooding treatment. Nevertheless, aerobic condition in the vegetative and reproductive stages recorded about 29 per cent yield reduction as compared to the continuously flooding treatment. Flooding in reproductive stage did not result in the yield increase over the treatment of keeping the soil continuously aerobic (Nieuwenhuis *et al.*, 2002). Bouman *et al.* (2002) also recorded similar yield reduction under aerobic condition.

Thus, the grain yield was closely related to grain number than grain weight as the latter is relatively stable across environments. Grain yield is mostly limited by sink capacity which was the ability of grain to accept the photoassimilates (Fukai *et al.*, 1991). Number of spikelets was also directly related to the rate of assimilation between panicle initiation and anthesis, regardless of whether the assimilate production was altered by water stress or shading (Boonjung, 1993).

Positive influence of N supply on grain yield was observed by several workers (Dhyani and Mishra, 1994; Dhurandher and Tripathi, 1999; Belder *et al.*, 2005).

2.5.6.7. Harvest Index (HI)

The HI is a major yield determinant in rice due to its direct effect as well as indirect contribution from N-uptake ability, CGR, LAI at flowering, sink weight and sink volume through HI. Genotypes having greater tolerance to water stress recorded higher number of grains and grain weight per panicle, grain yield and HI (Saxena *et al.*, 1996).

Continuous flooded irrigation had higher HI; where as, the irrigation at eight-day interval after tiller initiation lowered the value for HI (Surek and Beser, 1999).

Paikaray *et al.* (2001) opined that the HI in rice could increase with the N supply.

2.5.7. Water productivity

Water productivity is a concept of partial productivity and denotes the amount or value of product over volume or value of water used (Tuong *et al.*, 2004) and to improve water productivity of rice, one has to radically change the photosynthetic process of the plant, such as incorporating the C₄ photosynthetic pathway.

Belder *et al.* (2005) stated that water productivity is calculated as the ratio of grain yield to total water input (rainfall and the sum of all irrigations including land preparation).

Compared with lowland rice, water inputs in aerobic rice were more than 50 per cent lower (only 470-650 mm) and water productivities were 64-88 per cent higher (Bouman *et al.*, 2002). Yang *et al.* (2005) observed that the water productivity of aerobic rice was higher or on par with that of the lowland variety under flooded conditions, reaching values of 0.6-0.8 g grain kg⁻¹ water.

Belder *et al.* (2005) observed higher water productivity in aerobic rice under N supply in comparison with the flooded rice supplied with the same level of N.

2.5.8. Role of biofertilizers

Biofertilizers are living organisms which are capable of fixing or solublising the nutrients needed by the crop plants. Biofertilizers contained a wide range of naturally chelated plant nutrients and trace elements, carbohydrates, amino acids and other growth promoting substances.

2.5.8.1. *Azospirillum*

Azospirillum was first isolated by Beijerinck (1925) from N poor sandy soil in the Netherlands and was originally named as *Spirillum lipoferum*. Becking (1962) showed that this organism was very pleomorphic in liquid N poor media. Since then the *Azospirillum* had been isolated from the roots of numerous wild and cultivated species of grasses, cereals and legumes from tropical, subtropical and temperate soils.

Nitrogen derived through biological fixation assumed importance in the low land soil, since it supported about 86 percent of the N requirement of the world rice. The association of *Azospirillum* with many cereal crops and their contribution to N economy of the crops was well documented (Baddeley and Dobereiner, 1995).

Azospirillum sp. produced phytohormones which could stimulate root growth and induce changes in root morphology resulting in enhanced nutrient assimilation. The major hormone produced by *Azospirillum* was indole-3-acetic acid (IAA), indole lactic acid, indole-3-butyric acid (IBA), indole-3-methanol, unidentified indole compounds, gibberellins, abscisic acid (ABA) and cytokinins (Crozier *et al.*, 1988).

Tien *et al.* (1979) reported the excretion of IAA, gibberellins and cytokinins by *Azospirillum brasilense* within the roots and on the surface of the roots. Piccoli *et al.* (1999) showed that *A. lipoferum* was able produce increased amount of GA₃ with increasing water potential.

Azospirillum sp. generally exhibited positive response on root characters such as increased root length, number of roots and root volume (Venkateswarlu *et al.*, 1984), density of root hairs (Hadas and Okon, 1987) and number of lateral and adventitious roots (Yahalom *et al.*, 1987) and root dry weight of roots (Fallik *et al.*, 1988).

With increase in osmotic stress, the dominant osmolyte in *A. brasilense* shifted from glutamate to proline. At high moisture stress, *A. brasilense* accumulated higher intracellular concentration of glycine betaine that was taken up via the glycine betaine transport system (Tripathi *et al.*, 1998).

Creus *et al.* (1997) showed that the turgor pressure of the *Azospirillum* inoculated seedlings was higher under osmotic stress which could result in increased water uptake as reflected by faster growth of the inoculated seedlings exposed to the stress. The inoculation further showed the effect of better water status on cell elasticity and apoplastic water (Creus *et al.*, 1998).

Combined application of *Azospirillum* and musooriephos had beneficial effect in improving the contents of micronutrients (Fe, Zn, Mn and Cu) in the leaves (Anonymous, 1994).

2.5.8.2. Phosphobacteria

The average soil is rich in phosphorus (P) as it contains about 0.05 per cent (w/w) P (Barber, 1984); but only one tenth of this is available to the plants due to its poor solubility and chemical fixation in the soil. The P solubilizing microorganisms help the plant not only in augmenting the P availability, but also by solubilizing the chemically fixed P in the soil, thereby reducing the dependence on chemical fertilizers (Gaur and Gaiind, 1999).

Molla *et al.* (1984) isolated several species of *Bacillus*, *Proteus*, *Serratia*, *Pseudomonas*, *Micrococcus* and *Streptomyces* from the rhizosphere of rye grass and wheat. Watanabe and Hayano (1993) isolated *B. licheniformis*, *B. mycoides* and *B. megaterium* from the rhizosphere of the paddy crop.

Positive effect of inoculating phosphate solubilising microorganisms on the yield and P uptake had been studied in crops like soybean, wheat and rice. Anthoni Raj *et al.* (1994) observed an augmentation in rice grain yield due to the inoculation of phosphobacteria along with 75 per cent of the recommended 50 kg P₂O₅ ha⁻¹.

Coinoculation of *Azospirillum* and *Bacillus megaterium* var *phosphaticum*, known as **Azophos**, to rice increased P uptake and grain yield by 18.4 and 22.0 per cent over recommended dose of N and P levels (75 %) respectively (Anonymous, 2004).

2.5.8.3. Effect of Pink Pigmented Facultative Methyлотroph (PPFM)

The facultative methyлотrophs exhibiting distinct pink pigmentation are referred as pink-pigmented facultative methyлотrophs and popularly called PPFMs (Lidstrom and Chistoserdova, 2002). The bacteria removed metabolic waste products like methanol from the apoplast of the host and using them as a nutritional source, degrade them into simple compounds, which were eventually returned to the plant (Holland, 1997).

Plants interact constantly with PPFMs that abundantly colonize leaf surfaces (phyllosphere) and are encountered in the seeds and rhizosphere (Corpe and Rheem, 1989). Facultative methyлотrophs can utilize various multi-carbon compounds in addition to single carbon compounds unlike obligate methyлотrophs that can utilize only single carbon compounds (Anthony, 1986).

Anu Rajan (2003) reported that the PPFM isolates produced IAA (4.61 to 7.83 $\mu\text{g ml}^{-1}$) and GA (10.9 to 106.97 $\mu\text{g ml}^{-1}$) from the culture broth.

The PPFM and non-PPFM isolates increased the seedling length, germination percentage and vigour index of hybrid rice (CORH 2) over uninoculated control (Thangamani and Sundaram, 2005).

Beneficial effects of PPFM on growth and development of crop plants had been attributed to the production of phytohormones (Holland, 1997) and vitamin (Basile *et al.*, 1985). The ability of methylotrophs to produce phytohormones and the effect of their products on pine tissue cultures originating from bud meristems had been studied in detail (Pirttila *et al.*, 2004).

While studying the potential of PPFM for cytokinin biosynthesis, Soumya (2005) revealed that the PPFM isolate produced trans-zeatin and IAA ranging from 22.04 to 117.32 ng g^{-1} and 0.14 to 4.69 $\mu\text{g ml}^{-1}$ of culture filtrate respectively. Thangamani (2005) reported that combined application of PPFM with 75 per cent NP and 100 per cent K increased the growth and physiological parameters in terms of total chlorophyll, protein and phenol and also the activity of urease enzyme in ADTRH 1 hybrid rice.

2.5.9. Economics of fertigation

Although initial investment and maintenance costs were high in the case of micro-irrigation system, the monetary return was also equally high as compared to the traditional methods of irrigation. Hugar (1996) observed that much higher benefit : cost ratio under drip irrigation; the water thus saved was assumed to be utilized to cover additional area of the same crop. Khan *et al.* (1999) showed that drip irrigation with 100 per cent water soluble fertilizers in potato recorded higher net profit (Rs. 38,742 ha^{-1}) than drip fertigation with 100 per cent normal fertilizers (Rs. 33,604 ha^{-1}). Similarly, using drip irrigation system in chilli, 100 per cent recommended NPK fertigation registered higher benefit : cost ratio of 2.17 (Tumbare and Bhoite, 2002).

Thus, the drip irrigation is technically feasible, economically viable and socially acceptable. This method had recorded an increase in yield by 23-90 per cent in various crops with the water saving of about 40-77 per cent as compared to the conventional method. Therefore, this method combined with fertigation could also be adopted for the

closer spaced crop in specific conditions like i) well irrigated areas constituting about 35 per cent of the irrigated area in the country and ii) water scarcity situations and command area with community wells.

The plastic revolution in one hand and introduction of water soluble NPK fertilizers on the other in conjunction with the Government's subsidy and incentive scheme in popularising the MIS, fertigation assumed greater role in improving agricultural economy of the country as well as the ecosystem in the years to come (Shivashankar, 1996).

2.5.10. Crop modeling and simulation analysis

The dynamic simulation model, ORYZA2000 was recently evaluated under potential and N-limited conditions in the Philippines (Bouman and Van Laar, 2006) and also for the alternate wetting and drying (AWD) situations in China (Belder *et al.*, 2007) and also under N-limited and rainfed conditions in Indonesia (Bolling *et al.*, 2007).

2.5.10.1. Climate change effects

Crop growth and yield under optimal conditions are largely determined by weather during the growing season. Climate change via increasing atmospheric CO₂ concentration can affect global agricultural production through changes in photosynthesis (Cure and Acock, 1986) and transpiration rates (Sionit *et al.*, 1980).

Carbon dioxide concentration in the atmosphere had increased considerably since pre-industrial times with current mean annual increments of about 1.5 ppm (Keeling *et al.*, 1984). According to the current model predictions, the increase in CO₂ and other greenhouse gases was likely to induce surface air temperature rises over the next 50 years and the concurrent changes in the precipitation patterns. While an increase in CO₂ was usually associated with an increase in photosynthesis for most of the crops (Cure, 1985), an increase in mean daily temperature might lower the rice yield potential in many areas. The combined effects of elevated CO₂ and increased temperatures were unknown for the most part and were currently under investigation.

In such cases, models are the best tools to synthesize current knowledge and hypothesize to estimate directional trends for potential changes in rice yield following climate change.

Several publications had described how rice yield might be affected by climate change. Yoshino *et al.* (1988) predicted that lowland rice yields increased in Japan by about 9 per cent following a doubling of CO₂ and subsequent climatic changes. Jansen (1990) simulated potential yield, water-use efficiency and nitrogen-limited yield of rice for combination of three temperature and three CO₂ scenarios for the years 2020 and 2100 using the weather data sets from seven sites in Asia. He concluded that the effect would be a reduction in yield in the high temperature scenario and an increase in low temperature scenarios. Similar results were obtained by Penning de Vries (1993).

Simulation studies conducted by Mohandass *et al.* (1995) indicated that the annual national rice production of India was likely to increase as CO₂ levels and temperature increase in future climates. They further showed that the large decreases in second season rice yields might be able to be offset to some extent by proper selection for temperature tolerant varieties. Ranganathan and Mohandass (1997) suggested that altered crop phenology, early vigour, increased source size and its activity were the efficient physiological traits for raising the yield plateau in the alleviation of temperature induced detrimental effects of future climate change scenarios.

2.5.10.2. Elevated CO₂ effects

The possibility that a rise in atmospheric CO₂ might significantly increase agricultural yield sparked a wave of activity from the agricultural research community (Crosson, 1989; Goudriaan and Unsworth, 1990). Chamber experiment studies by Baker *et al.* (1990a) showed an increase in grain yield and biomass as CO₂ concentration increases together with an increase in canopy net photosynthesis and water use efficiency. Baker *et al.* (1990b) found that elevated CO₂ accelerated rice development and shortened total growth duration.

2.5.10.3. Increased temperature effects

Critically low and / or high temperatures define the environment where the life cycle of the rice plant could be completed. Within the critical low and high temperature

range, temperature influences the rate of development of leaves and panicles and the rate of ripening thereby affecting the length of the growing season of a rice variety and determining the suitability of that variety to the environment (Yoshida, 1976).

Increased temperature speeded up plant development but decreased the length of grain filling period (Stansel and Fries, 1980). Seshu *et al.* (1989) observed that in principle, global warming might contribute to a northward expansion of rice growing areas and lengthening of rice growing seasons which were now constrained by low temperatures. Baker *et al.* (1990c) found that increased temperature reduced maturation time in rice, resulting in seed sterility and decrease in grain yield.

2.5.10.4. Water stress effects

Feng *et al.* (2007) observed that ORYZA2000 was sufficiently accurate in the simulation of crop growth and soil water dynamics under both flooded lowland and aerobic soil conditions. Using ORYZA2000, Bouman *et al.* (2007) explored options to reduce water inputs and depletion flows for maintaining higher yields in rice.

With this background, the present investigation was carried out in order to study the impact of drip fertigation for enhancing the grain as well as water productivity in aerobic rice. Besides, attempts have also been made to simulate the effects of drip fertigation grown under aerobic rice situation for varied climate change scenarios using ORYZA2000 model, since the information on the aspects of drip fertigation effects of aerobic rice cultivation under future climate change scenarios are very scanty in literature.

CHAPTER III

MATERIALS AND METHODS

The major aim of the present study was to elucidate information on drip fertigation in aerobic rice. To achieve this, a field trial (**Fig. 1**) was conducted at Tamil Nadu Agricultural University, Coimbatore during dry season (DS) of 2007 using PMK (R) 3 rice variety. A brief account of the materials used and methodologies followed in the experiments conducted are given below.

3.1 MATERIALS

3.1.1. Location

Field experiments were conducted in the Field No. D 1 of Wetland, Central Farm of Tamil Nadu Agricultural University, Coimbatore during DS (2007). The farm is located in the North-western tract of Tamil Nadu at 11° N latitude, 77° E longitude and at an altitude of 426.72 m above Mean Sea Level.

3.1.2 Climate and weather

The minimum required agro-meteorological variables recommended for fundamental research in rice by World Meteorological Organization and the International Rice Research Institute (IRRI) were considered in the present study.

Coimbatore is situated in Semi Arid Tropics. The normal weather condition of Coimbatore based on the 63 years weather data indicated that a mean annual rainfall of 657 mm is received in 47 rainy days. The mean maximum and minimum temperature are 31.5 and 21.4 °C, respectively. The relative humidity ranges from 91.0 per cent (0722 hrs) to 68.0 per cent (1422 hrs). The mean solar radiation is measured at 429.0 cal cm⁻² min⁻¹.

3.1.3. Soil of experimental site

The soil of the experimental field was deep clay loam with moderate drainage. The soil is classified taxonomically as *typic haplustalf*. Composite soil samples were collected prior to the experiment and analyzed for various physico-chemical characteristics. The soil fertility status was 196, 20 and 450 kg ha⁻¹ of available nitrogen

(low), phosphorus (medium) and potassium (high) respectively. The pH of the soil was 8.0. The detailed physico-chemical characteristics of the soil are given in **Table 1** and the procedures followed for the soil and plant analysis are furnished in **Table 2**.

Table 1. Soil characteristics of the experimental field

Parameters	Value (%)
A. Mechanical analysis	
Clay	45.2
Silt	9.1
Sand	43.6
Textural class	Clay loam
B. Chemical analysis	
Field capacity (%)	43.25
Permanent wilting point (%)	32.51
Available soil moisture (%)	10.74
Bulk density (g cm^{-3})	1.25
C. Chemical analysis	
pH (1: 2 of soil : water)	8.20
Electrical conductivity (dS m^{-1})	0.59
Organic carbon (%)	0.66
Available Nitrogen (kg ha^{-1})	190
Available Phosphorus (kg ha^{-1})	30
Available Potassium (kg ha^{-1})	730

Table 2. Methods employed for soil analysis

Particulars	Method	Reference
A. Mechanical analysis	Robinson's international pipette method	Piper (1966)
B. Chemical analysis		
1. Available Nitrogen	Alkaline permanganate method	Subbiah and Asija (1956)
2. Available Phosphorus	Using 0.5 M NaHCO ₃ of pH 8.5 using colorimeter	Olsen <i>et al.</i> (1954)
3. Available Potassium	Flame photometric method using neutral normal ammonium acetate extract	Stanford and English (1949)
4. Organic Carbon	Chromic acid wet digestion method	Walkley and Black (1934)
5. pH (Soil: Water = 1: 2)	Using glass electrode in the "ELICO" pH meter	Jackson (1973)
6. Electrical conductivity (Soil: Water = 1: 2)	Using "ELICO" conductivity bridge	Jackson (1973)

3.1.4. Weather conditions prevailed during cropping period

The weather parameters reported for the standard weeks (**Appendix 1**) during the cropping period of DS (2007) were furnished in **Table 3** and in **Fig. 2**. The values for mean maximum temperature were higher (34.7 °C) during 23rd standard week of 2007. The lower mean maximum temperature of 28.0 °C was recorded during 43rd week. Mean minimum temperature ranged from 21.4 (during 40th week) to 24.0 °C (during 28th week). The maximum RH value was higher (99 %) during 34th week with the lower value (74 %) during 25th week. But, the minimum RH value ranged between 45 (during 45th week) and 70 per cent (during 43rd week). The evaporation rate was higher 7.2 mm day⁻¹ during 24th week. Higher weekly rainfall of 156.1 mm was recorded in four rainy days during 43rd week, while the lowest rainfall was evident during 36th week (0.2 mm). Bright sun

shine was recorded during 33rd week (8.3 hours) with a minimum sun shine hours of 1.9 during 31st standard week of 2007. Wind speed was harsh (15.4 m sec⁻¹) during 25th week while, it was gentle (4.3 m sec⁻¹) during 42nd week. A higher solar radiation of 422.6 cal cm⁻² day⁻¹ was recorded during 33rd week with the lower radiation level (236.1 cal cm⁻² day⁻¹) during 25th standard week of 2007.

Thus, the prevailed weather was found to be favourable for better crop growth and development in both the seasons.

3.2. Methods

3.2.1. Experimental details

The field experiment was conducted during DS 2007 using variety PMK (R) 3 rice variety. The experimental details are furnished below.

Particulars	DS (2007)
Design	Randomized Block Design
Number of treatments	10
Number of replications	3
Variety	PMK (R) 3
Duration	120 days

3.2.2. Field preparation

The experimental plots were dry-ploughed and harrowed. Raised flat beds were formed and laid out with double channels around all the plots to prevent subsoil lateral water flow.

3.2.3. Seed treatment of biofertilizer

Before sowing, the wet seeds were treated with the *Azophosmet* biofertilizer at the rate of 200 g 10 kg⁻¹ of seeds and sown in the field for all the treatments except the conventional practice (T₁).

3.2.4. Sowing and spacing

Sprouted and biofertilizer treated seeds were dry-sown by hand dibbling at 3-cm depth in rows 20 cm apart, at seeding rates of 30 kg ha⁻¹.

Particulars	DS (2007)
Date of sowing	18.06.2007
Spacing	20 x 10 cm ²
Net plot size	4 m x 3 m

3.2.5. Treatments

Following treatments were employed in the study:

T₁: Surface irrigation given at 3 cm depth with IW / CPE ratio of 1.0 + 100 % RDF
(Soil application @ 150:50:50 NPK / ha)

T₂: Drip fertigation at 100 % OPE + 75 % RDF + Azophosmet

T₃: Drip fertigation at 100 % OPE + 100 % RDF + Azophosmet

T₄: Drip fertigation at 100 % OPE + 125 % RDF + Azophosmet

T₅: Drip fertigation at 125 % OPE + 75 % RDF + Azophosmet

T₆: Drip fertigation at 125 % OPE + 100 % RDF + Azophosmet

T₇: Drip fertigation at 125 % OPE + 125 % RDF + Azophosmet

T₈: Drip fertigation at 150 % OPE + 75 % RDF + Azophosmet

T₉: Drip fertigation at 150 % OPE + 100 % RDF + Azophosmet

T₁₀: Drip fertigation at 150 % OPE + 125 % RDF + Azophosmet

(OPE: Open Pan Evaporation; RDF: Recommended Doses of Fertilizers)

3.2.6. Installation of drip irrigation system

Water from the bore well was pumped through 7.5 HP motor and conveyed to the field using PVC pipe (63 mm OD) after filtering through the screen filter. By-pass arrangement was provided and used for maintaining a pressure head of 1.2 ksc in the system for irrigation. From sub main, inline laterals were laid at a spacing of 1.0 m with 8 lph emitters spaced at 60 cm such that one lateral could cover five rows of 20 cm each.

Each emitter covered 30 plants in a plot. A control tap was fixed at the entry point of each lateral to regulate fertigation for individual plot (**Plate 1a and b**). Each plot had 15 rows and each row had 40 plants thus there were 600 plants per plot.

3.2.7. Irrigation scheduling

Under surface irrigation treatment (T_1), irrigation was scheduled at 1.0 IW / CPE ratio to 3.0 cm depth throughout the crop growth. First irrigation was given immediately after sowing, life saving irrigation on 3 days after sowing (DAS) and subsequent irrigation was based on the pan evaporation values from USWB Open Pan Evaporimeter (OPE) installed at Agromet Observatory in Tamil Nadu Agricultural University. Irrigation scheduling was done at 30.0 mm CPE during all the stages of crop growth. The calculated quantity of water was applied to each plot through 63 mm PVC pipes.

In the case of drip fertigation plots (T_2 to T_{10}), initial soaking irrigation was given immediately after sowing and life irrigation on 3 DAS. Subsequent irrigation was scheduled daily through the drip system based on OPE values and the plot size using the following formula:

$$V \text{ (lpd)} = E_p \times K_p \times K_c \times W_p$$

where,

- V - Volume of water required (litres /day)
- E_p - Pan evaporation (mm/day)
- K_p - Pan co-efficient (0.8)
- K_c - Crop co-efficient
- W_p - Wetted area fraction (1.0)

The K_c values for rice at different growth stages were adopted from Doorenbos and Kassam (1979) as furnished below:

Crop stage	Duration	K_c value
Initial	0 - 30 DAS	1.10
Development	31 - 60 DAS	1.10
Mid season	61 -90 DAS	1.10
Late season	91 - 120 DAS	0.95

Time of operation of drip system to deliver the required volume of water per plot for different treatments was computed based on the formula:

$$\text{Time of operation (sec.)} = \frac{\text{Volume of water required}}{\text{Emitter discharge (8 lph) x No. of emitters}}$$

In all the ten chosen treatments, the irrigation was stopped seven days before the expected time of harvest.

3.2.8. Effective rainfall

Effective rainfall was taken into account while scheduling irrigation under drip and surface methods. The effective rainfall was calculated using water balance sheet method.

3.2.9. Fertigation

The fertigation schedule indicating the nutrient requirement at different phenological stages and quantity of nutrients to be applied for 75, 100 and 125 per cent recommended dose of NPK were given in **Table 4, 5 and 6** respectively.

All the three fertilizers viz., nitrogen, phosphorus and potassium were supplied through fertigation in the form of water soluble fertilizers as per the treatments once in a week as per the details furnished in the respective tables. Nitrogen was supplied in the form of ammonium sulphate, phosphorus as monoammonium phosphate and potassium in the form of potassium nitrate.

The fertilizer solution was prepared by dissolving the required quantity of fertilizer with water and injected into the irrigation system through fertilizer mixing tank (**Plate 2**). The fertigation was given once in a week.

In the case of conventional method (T_1), entire dose of P was applied basally before sowing. In the case of N, the recommended dose was given in four equal splits at basal, tillering, panicle initiation and first flowering; while, K was given in two equal splits at basal and panicle initiation stages. Recommended doses of FeSO_4 (50 kg ha^{-1}) and ZnSO_4 (25 kg ha^{-1}) were applied as the basal dressings before sowing in all the ten treatments.

3.2.9.1. Biofertiligation

The authenticated cultures of *Azospirillum brasilense* sp 7, *Bacillus megatherium* var phosphaticum PB1 and *Methylobacterium* sp CO 47 were obtained from the Department of Agricultural Microbiology, Tamil Nadu Agricultural University, Coimbatore.

Application of composite cultures of *Azospirillum brasilense*, *Bacillus megatherium* and *Methylobacterium* sp @ 250 ml (10^{12} cells ml⁻¹) diluted in 100 litres of water ha⁻¹ was carried out as biofertiligation. Biofertilizer solution was prepared in the fertilizer mixing tank from which it was allowed through the irrigation system during tillering, panicle initiation and flowering stages. In each time, biofertilizer application through drip system was done two days after fertigation.

3.2.10. Observations recorded

3.2.10.1. Morphological characters

Sampling of plants:

Plant samples were drawn at active tillering (AT), panicle initiation (PI), flowering (FF), grain filling (GF) / harvest (HT) for recording various morphological, physiological and biochemical characters. The following morphological and physiological parameters were recorded for the study.

The plant samples were collected based on the method suggested by Thiagarajan *et al.* (1995) and following observations were recorded during the above mentioned four stages of growth.

3.2.10.1.1. Plant height

The plant height of each plant was measured from the base of the shoot to the longest leaf and the average was worked out for the five plants in each replication and treatment and the values expressed in cm.

3.2.10.1.2. Total root length

The roots were removed carefully from the soil without damage and for measuring the total root length of each plant. Randomly selected ten roots were weighed and their

length measured and totaled and the total root length was calculated by using the weight of the total roots at the same moisture level as follows:

$$\text{Total root length (m)} = \frac{\text{Length of sample roots (cm)} \times \text{Weight of total roots (g)}}{\text{Weight of sample roots (g)}}$$

3.2.10.1.3. Root volume

The roots scooped along with soil and whole plant were washed in running water carefully and detached from the nodal bases. Any excess moisture adhering on the surface of the roots was removed wiping with blotting paper. Then, the volume of the roots were measured by volume displacement method and expressed as root volume (cc) hill⁻¹.

3.2.10.1.4. Root Length Density (RLD) and Root Mass Density (RMD)

The Root Length as well as Mass Density (RLD and RMD) was determined at different growth stages. For this, the method and the technique as developed by Pantuwan *et al.* (1997) were employed for the present study. Two adjacent hills were randomly selected before taking measurements. A root auger of 5 cm inner diameter and 50 cm length fabricated with galvanized iron tube (**Plate 3**) was placed immediately next to a hill with less than 1 cm between the closer tiller and the tube. The soil sample to a depth of 45 cm was collected and placed on a 1 mm mesh screen. Then, the roots were washed free of soil using tap water. Roots present in the core sample auger were measured for their total length and its dry weight. Then, the RLD and RMD were calculated by dividing the length/ weight of roots present per unit volume of soil up to a depth of 45 cm and the values expressed as cm cm⁻³ and mg cm⁻³ of the soil for RLD and RMD respectively.

3.2.10.1.5. Root Length Depth Index (RLDI) and Root Mass Depth Index (RMDI)

Based on the values of root length and its weight, Root Length Depth Index (RLDI) and Root Mass Depth Index (RMDI) were calculated as following by adopting the procedure of Kondo *et al.* (1998).

$$\text{RLDI (cm)} = \frac{(\text{RL}_1 \times \text{D}_1) + (\text{RL}_2 \times \text{D}_2) + (\text{RL}_3 \times \text{D}_3)}{(\text{RL}_1 + \text{RL}_2 + \text{RL}_3)}$$

$$\text{RMDI (cm)} = \frac{(\text{RM}_1 \times \text{D}_1) + (\text{RM}_2 \times \text{D}_2) + (\text{RM}_3 \times \text{D}_3)}{(\text{RM}_1 + \text{RM}_2 + \text{RM}_3)}$$

Where

RL_1, RL_2 and RL_3 = Root length in 0-10, 10-20 and 20-30 cm soil layer (cm cm^{-1})

RM_1, RM_2 and RM_3 = Root mass in 0-10, 10-20 and 20-30 cm soil layer (g cm^{-1})

D_1, D_2 and D_3 = Depth of soil layer in 0-10, 10-20 and 20-30 (cm)

3.2.10.1.6. Tiller density

Number of tillers in selected plants in each treatment was counted. Then, the average number of tillers was worked out and based on that tiller density per m^2 was derived.

3.2.10.1.7. Leaf number hill⁻¹

Four hills from each replication and treatment were removed and the leaf was counted as a single unit. The number of hill per hill was presented by calculating the mean of four hills.

3.2.10.1.8. Total Dry Matter Accumulation (TDMA)

For estimating TDMA, the entire plant was pulled out with the root system intact at different stages and separated into the leaf, culm, root and panicle portions. They were weighed separately after drying the plants at $80 \pm 2^\circ\text{C}$ for 48 hours and expressed in g m^{-2} . The total dry matter accumulation was arrived at by summing up the dry weights of leaf, culm, root and panicles and the values expressed as g m^{-2} .

3.2.10.1.9. Root / Shoot (R/S) ratio

Using shoot (leaf + culm + panicle) and root dry weight, the ratio was arrived at as follows:

$$\text{Root / Shoot ratio} = \frac{\text{Root dry weight}}{\text{Shoot dry weight}}$$

3.2.10.2. Growth attributes

3.2.10.2.1. Leaf Area Index (LAI)

Leaf area for the whole sampling unit was measured by using Leaf Area Meter (Model 3100 of LI-COR Inc., Lincoln, Nebraska, USA) and the LAI was calculated by employing the following formula of Williams (1946).

$$\text{LAI} = \frac{\text{Leaf area per plant}}{\text{Ground area occupied per plant}}$$

3.2.10.2.2. Leaf Area Duration (LAD)

Leaf Area Duration was determined by using the formula of Power *et al.* (1967) as given below and the values expressed in days.

$$\text{LAD} = \frac{L_1 + L_2}{2} \times (t_2 - t_1)$$

Where,

L_1 = LAI at first stage (t_1)

L_2 = LAI at second stage (t_2)

$(t_2 - t_1)$ = Time interval in days

3.2.10.2.3. Individual Leaf Size ($\text{cm}^2 \text{ leaf}^{-1}$)

The individual leaf size (ILS) was calculated by using the following formula and expressed in $\text{cm}^2 \text{ leaf}^{-1}$.

$$\text{ILS} = \frac{\text{Total leaf area (cm}^2\text{) hill}^{-1}}{\text{Total leaf number hill}^{-1}}$$

3.2.10.2.4. Individual Leaf Weight (mg leaf^{-1})

The individual leaf size (ILS) was obtained by utilizing the following formula and expressed in mg leaf^{-1} .

$$\text{ILS} = \frac{\text{Total leaf dry weight (mg) hill}^{-1}}{\text{Total leaf number hill}^{-1}}$$

3.2.10.2.5. Specific Leaf Weight (SLW)

Specific Leaf Weight was calculated by using the formula of Pearce *et al.* (1968) and expressed in mg cm^{-2} .

$$\text{SLW} = \frac{\text{Leaf dry weight per plant}}{\text{Leaf area per plant}}$$

3.2.10.2.6. Crop Growth Rate (CGR)

The Crop Growth Rate was estimated by using the formula of Watson (1956) and the values expressed in $\text{g m}^{-2} \text{ day}^{-1}$.

$$\text{CGR} = \frac{W_2 - W_1}{P (t_2 - t_1)}$$

Where,

W_1 and W_2 - Whole plant dry weight at time t_1 and t_2 respectively

T_2 and t_1 - Time in days

P - Ground area occupied by plant (m^2)

3.2.10.2.7. Net Assimilation Rate (NAR)

The method as modified by Williams (1946) was employed for calculating the NAR on leaf dry weight basis using the following formula and expressed in $\text{mg cm}^2 \text{ day}^{-1}$.

$$\text{NAR} = \frac{\text{Log}_e L_2 - \text{Log}_e L_1}{L_2 - L_1} \times \frac{W_2 - W_1}{t_2 - t_1}$$

Where,

W_1 and W_2 = Dry weights of whole plant at t_1 and t_2 respectively.

L_1 and L_2 = Leaf area at time t_1 and t_2 respectively

t_1 and t_2 = Time intervals in days

3.2.10.2.8. Leaf Area Ratio

The leaf area ratio (LAR) was arrived at by employing the formula given by Radford (1967) and the values expressed in $\text{cm}^2 \text{ g}^{-1}$.

$$\text{LAR} = \frac{\text{Total leaf area (cm}^2\text{) hill}^{-1}}{\text{Total plant dry weight (g) hill}^{-1}}$$

3.2.10.3. Light parameters

3.2.10.3.1. Light Interception Percentage (LIP)

The integrating Quantum / Radiometer / Photometer with the Line Quantum Sensor (Model LI-185 B of LI-COR Inc., Lincoln, Nebraska, USA) were used to measure the light intensity. The light interception was calculated using the following formula as suggested by Yoshida *et al.* (1971) and expressed as percentage.

$$\text{LIP} = \frac{\text{Light intensity at top canopy} - \text{Light intensity at bottom canopy}}{\text{Light intensity at top canopy}}$$

3.2.10.3.2. Light extinction co-efficient ('k')

The 'k' value was worked out by using the formula adopted by Monsi and Saeki (1953) as below:

$$I = I_0 \exp^{-kL}$$

Where

$$K = 1 / L \log_e (I/I_0)$$

$$L = \text{Light flux density to a horizontal surface below L units of LAI}$$

$$I_0 = \text{Light flux density above the canopy}$$

$$e = \text{The base to the natural logarithms}$$

$$\text{'k'} = \text{Extinction co-efficient}$$

3.2.10.4. Physiological and biochemical parameters

3.2.10.4.1. Contents of chlorophyll

Contents of chlorophyll 'a', 'b' and total were estimated in a fully expanded young leaf at specified time intervals and expressed in mg g⁻¹ fresh weight (Yoshida *et al.*, 1971).

$$(12.7 \times \text{O.D. at 663}) - (2.69 \times \text{O.D. at 645})$$

$$\text{Chlorophyll 'a'} = \frac{\quad}{W} \times V \text{ mg g}^{-1}$$

$$\text{Chlorophyll 'b'} = \frac{(22.9 \times \text{O.D. at 645}) - (4.68 \times \text{O.D. at 663})}{W} \times V \text{ mg g}^{-1}$$

$$\text{Total Chlorophyll} = \frac{(20.2 \times \text{O.D. at 645}) + (8.02 \times \text{O.D. at 663})}{W} \times V \text{ mg g}^{-1}$$

Where,

W = Weight of the leaf sample

V = Volume of supernatant solution made

O.D = Optical Density

3.2.10.4.2. Chlorophyll a / b ratio (Chl a / b ratio)

The chlorophyll a / b ratio was calculated by dividing the contents of chlorophyll 'a' by that of chlorophyll 'b'.

3.2.10.4.3. Chlorophyll meter readings (SPAD values)

Chlorophyll meter from Minolta (Model SPAD 502 of Minolta Co., Japan) was used to measure SPAD values (Anonymous, 1989). The most recently matured leaf was measured on the each side of the midrib at the point three - fourths of the way from base to leaf tip in plants for each replication and the mean value was worked out.

3.2.10.4.4. Photosystem II (PS II) efficiency (Fv / Fm ratio)

Photochemical efficiencies of the plant were measured by fluorescence reading using Chlorophyll Fluorescence Meter or Plant Efficiency Analyzer (Krause and Weis, 1984).

3.2.10.4.5. Soluble protein content

Soluble protein was estimated from the leaf samples following the method of Lowry *et al.* (1951) and the content expressed as mg g⁻¹ fresh weight.

3.2.10.4.6. Soluble nitrogen

The content of ethanol soluble nitrogen was estimated by microkjeldhal method as suggested by Yoshida *et al.* (1971) and expressed as mg g⁻¹ on fresh weight basis.

3.2.10.4.7. Reducing sugar

Reducing sugar content was estimated from the ethanol extract following the method described by Somogyi (1952) and the content expressed as mg g⁻¹ fresh weight.

3.2.10.4.8. Total available carbohydrate

The contents of total available carbohydrates of the plant samples were estimated for flowering and harvest stages by following the method of Somogyi (1952) and expressed in mg g⁻¹ on dry weight basis.

3.2.10.4.9. Total free aminoacids

Total free aminoacid content was estimated from the plant samples as per the procedure given by Misra *et al.* (1975) and the content expressed as mg g⁻¹ fresh weight.

3.2.10.4.10. Cytokinin content

3.2.10.4.10.1. Estimation of trans-zeatin by UV-spectrophotometric method

The content of endogenous trans-equivalent cytokinin was estimated using the UV-spectrophotometer as per the procedure suggested by Unnayar *et al.* (1996) and the content was expressed as µg g⁻¹ on trans-zeatin equivalent basis.

3.2.10.4.10.2. Estimation of trans-zeatin by HPLC method

Quantification of trans-zeatin equivalent cytokinins in the methanol fraction was also done by High Performance Liquid Chromatograph (HPLC) analysis.

Extraction of cytokinins

The plant sample was extracted with thrice with equal volumes of diethyl ether to remove auxins. The pH of the aqueous phase was adjusted to 7.0 with 1N ammonium hydroxide and extracted thrice with equal volumes of n-butanol. The organic fractions were pooled and evaporated. The residue was dissolved in 3 ml of HPLC grade methanol and used for HPLC analysis.

Estimation of trans-zeatin by HPLC

Content of trans-zeatin equivalent cytokinin was analysed by HPLC by adopting the method of Summons *et al.* (1980). A volume of 5 μl of sample was injected into HPLC. Analysis was performed using 5 μm particle size reverse phase (C_{18}) column (4.6 x 250 mm) with a solvent gradient of 30 per cent methanol in water at a flow rate of 1.0 ml min^{-1} . Quantification of cytokinins compounds in the sample was done by comparison of retention time with peak height of trans-zeatin (Sigma grade). The cytokinins compounds were quantified by integrating the areas under the peaks using UV detector at 254 nm.

3.2.10.4.11. Peroxidase activity

Peroxidase activity ($\Delta 430 \text{ nm g}^{-1} \text{ h}^{-1}$) was determined according to the procedure given by Perur (1962).

3.2.10.4.12. Superoxide Dismutase (SOD) activity

The activity of Superoxide dismutase enzyme was determined by using Nitro Blue Tetrazolium (NBT) method of Beau-Champ and Fridovich (1971) and the values expressed as enzyme units mg^{-1} unit of enzyme min^{-1} .

3.2.10.4.13. Indole acetic acid (IAA) oxidase activity

The IAA oxidase activity was estimated by the method proposed by Parthasarathy *et al.* (1970) and the enzyme activity was expressed as μg of unoxidised auxin $\text{g}^{-1} \text{ hr}^{-1}$.

3.2.10.4.14. Nitrate reductase (NRase) activity

Nitrate reductase activity of the young leaves was determined by adopting the method of Nicholas *et al.* (1976) and the enzyme activity was expressed as μg of $\text{NO}_2 \text{ g}^{-1} \text{ hr}^{-1}$.

3.2.10.4.15. Oxidizing power of root

The oxidizing power of roots can be evidenced by measuring the oxidation of the α – naphthylamine (NA) by the roots. In case where the nutrient absorption by roots is inhibited, the oxidizing power of the roots is usually very low. The α - NA oxidation is related to the rate of respiration (Ota, 1970). Usage of α - NA for the determination of the oxidizing activity of the roots is described below:

One gram fresh root samples were immediately transferred into 150 ml conical flasks containing 50 ml of 20 ppm α - NA. The flasks were incubated along with control (50 ml of α - NA only) for two hours at room temperature with continuous shaking in a mechanical shaker. After incubation, the aliquots were filtered and two ml of aliquot was transferred into graduated test tube to develop the colour using one ml of sodium nitrite (100 ppm) and one ml of sulphanilic acid. The α - NA control flask was also used to determine the quantity of α - NA oxidized by the roots. The activity is expressed as $\mu\text{g of g}^{-1} \text{ hr}^{-1}$.

3.2.10.4.16. Cation exchange capacity (CEC) of roots

The cation exchange capacity of oven dried and a milled root was by adopting the method of Crooke (1964) and expressed in meq 100 g^{-1} of dry roots.

3.2.10.5. Molecular studies

3.2.10.5.1. Protein Fraction Studies

Electrophoresis (SDS-PAGE)

The SDS-PAGE analysis was done to identify the qualitative and quantitative differences of proteins **under sterile and fertile conditions** as per the method of Laemmli (1970) with the modifications given by Sadasivam and Manickam (1996).

A known quantity of leaf sample was homogenized in phosphate buffer (pH 7.0) in a pre-chilled pestle and mortar and the homogenate was centrifuged at 10,000 rpm for 10 min and the supernatant was used for analysis.

Procedure

Thoroughly cleaned glass plates and spacers were assembled properly and were damped in an upright position on a gel casting unit with two per cent agar on bottom to seal the chamber leak proof between glass plates. 10-15 per cent gels were tried to get the better resolution.

The gel solution was poured into the chamber between glass plates carefully leaving four cm from the top and a layer of distilled water was added on top of the gel and allowed to polymerise for 30-60 min.

After removing water from the gel, stacking gel was added; comb was placed and kept for polymerizing (30-60 min). After polymerization, the comb was taken out and the gel plate was removed from the casting unit to the electrophoresis apparatus. Concentration of the protein sample was adjusted to 50-200 µg into a volume of 25-50 µl, by mixing with sample loading buffer and boiled for 2-3 minutes for ensuring complete interaction between proteins and SDS. The sample was cooled and carefully injected to each well with a micro syringe. Electrode buffer was filled in the chambers, the electrode were connected and turned on the DC power briefly and power supply was set to a constant current of 15 mA at 60 volts initially till the dye front crossed the stacking gel. Then, the current was increased to 30 mA at 120 volts until the bromophenol blue reaches bottom of the gel (about 3 h). The gel was removed from the plates and immersed in staining solution overnight. After proper staining, the gel was transferred to destainer with gentle shaking and changing the destainer frequently till appropriate visibility of the bands on gel. The gel was photographed.

3.2.10.5.2. Isozyme analysis

A quantity of 500 mg of leaf sample was homogenized in one ml phosphate buffer (pH 7.0) in a pre-chilled pestle and mortar. The homogenate was centrifuged in a refrigerated centrifuge at 18,000 rpm for 15 min, and the supernatant was used for analysis. Electrophoretic separation of isozyme was done with seven per cent polyacrylamide gel without using SDS. Casting of the gel was done as described earlier, without using SDS anywhere. Loading of the samples was done in refrigerator and chilled electrode buffer without SDS was used. The power supply was set to a constant 15 mA current and the running of the gel was done inside refrigerator.

Peroxidase (PO) staining

The gel was incubated in a solution, containing benzidine 2.08 g, acetic acid 18 ml, H₂O₂ (3 %) 100 ml and water 80 ml. when the bright blue coloured bands appeared on the gel, the reaction was arrested by immersing the gel into a large volume of 0.67 per cent NaOH or 7 per cent acetic acid solution for 10 minutes. The gel was photographed immediately as the colour was highly unstable.

3.2.10.6. Parameters of plant water relations

3.2.10.6.1. Relative Water Content (RWC)

Leaf samples from the middle of 5-6 cm of the youngest fully expanded leaves were taken for recording relative water content. Relative water content was estimated by Weatherly (1950) method and expressed in percentage as given below:

$$\text{RWC (\%)} = \frac{(\text{Fresh Weight} - \text{Dry Weight})}{(\text{Turgid Weight} - \text{Dry Weight})} \times 100$$

3.2.10.6.2. Membrane Stability Index (MSI)

Cell membrane integrity was measured in terms of percentage of ion leakage by following the method of Deshmukh *et al.* (1991).

3.2.10.6.3. Chlorophyll Stability Index (CSI)

The chlorophyll stability index (CSI) was estimated by using the method of Murty and Majumdar (1962) and expressed in percentage.

3.2.10.6.4. Leaf water potential (ψ_l)

Leaf water potential was measured by using Pressure Chamber (Soil Moisture Equipment Corp., CA 93105, U.S.A.) between 11.00 A.M. to 1.00 P.M. every alternate day during the stress period and expressed as MPa (Scholander *et al.*, 1965).

3.2.10.6.5. Proline content

Proline content of the leaves was estimated by the method described by Bates *et al.* (1973) and expressed in $\mu\text{moles g}^{-1}$ fresh weight.

3.2.10.6.6. Leaf Diffusive Resistance

Diffusive resistance was measured in fully expanded leaf using the Steady State Porometer (Model LI-1600 of LI-COR, Lincoln, Nebraska, USA) as detailed earlier. The value was expressed in s cm^{-1} .

3.2.10.6.7. Transpiration rate

The transpiration rate was measured at selected physiological stages in a fully expanded young leaf with the help of the Steady State Porometer (Model LI-1600 of LI-COR, Lincoln, Nebraska, USA). The aperture area and atmospheric pressure were initially entered into the porometer. After the cuvette had been acclimated to ambient condition, the null adjust valve was used to bring the flow rate within the dynamic range of the internal automatic flow controller. The sample was clamped in to place on the sensor head. Immediately, the humidity setting switch (HUM SET) was pressed to store the relative humidity of the cuvette into the memory as the null point humidity (typically ambient). Readings were then taken and expressed in $\mu\text{g H}_2\text{O cm}^{-2} \text{ sec}^{-1}$.

3.2.10.6.8. Leaf temperature

The leaf temperature was measured in fully expanded leaf using Steady State Porometer (Model LI-1600 of LI-COR, Lincoln, Nebraska, USA) as detailed earlier. The leaf temperature was expressed in $^{\circ}\text{C}$.

3.2.10.6.9. Canopy temperature

The temperature of the canopy was measured using hand held Infrared Thermometer with laser marker (Model Waco) and the values were expressed in $^{\circ}\text{C}$.

3.2.10.7. Nutrio-physiological analyses

3.2.10.7.1. Nitrogen uptake

The total nitrogen content of different plant parts (such as leaf, culm, root and panicle) were estimated by Microkjeldhal methods as proposed by Yoshida *et al.* (1971) and total N uptake at different stages were worked out by summing up the uptake in different parts of the plant after multiplying the total dry matter of the plant parts with the corresponding N content and expressed as kg ha^{-1} .

3.2.10.7.2. Phosphorus uptake

The dried plant samples of different parts collected at different phenophases were determined for total P content (percentage) colorimetrically from triple acid extract (Jackson, 1973) and P uptake was worked out and expressed kg ha^{-1} as furnished in 3.2.6.7.1.

3.2.10.7.3. Potassium uptake

The potassium contents of the plant samples in different part of the plant drawn at various phenophases were analysed by flame photometry using triple acid extract (Jackson, 1973) and expressed as percentage on dry weight basis. The total K uptake was then calculated and expressed as kg ha^{-1} as above in 3.2.6.7.1.

3.2.10.7.4. Calcium uptake

The calcium contents indifferent parts of the plant samples drawn at various phenophases were analysed by versanate titration method using triple acid extract (Jackson, 1973) and expressed as percentage on dry weight basis. The uptake was then calculated and expressed as kg ha^{-1} as enumerated in 3.2.6.7.1.

3.2.10.7.5. Magnesium uptake

The magnesium contents of the different parts of the plant samples drawn at various phenophases were analysed by versanate titration method using triple acid extract (Jackson, 1973) and expressed as percentage on dry weight basis. The uptake was then calculated and expressed as kg ha^{-1} as furnished in 3.2.6.7.1.

3.2.10.7.6. Uptake of micronutrients

The contents of iron (Fe), manganese (Mn), zinc (Zn) and copper (Cu) in different parts of the plant samples drawn at various phenophases were analysed using the acid extract drawn from the microwave digester. The contents were the analysed (Jackson, 1973) using the Atomic Absorption Spectrophotometer (AAS Model Thermo S Series, UK). Total uptake of the micronutrients was then calculated and expressed as g ha^{-1} as indicated in 3.2.6.7.1.

3.2.10.7.7. Rate of nutrient uptake

The rate of uptake for the chosen nutrients between two consecutive growth stages was computed by dividing the crop incremental nutrient uptake by the duration of the period between the concerned growth stages and expressed as $\text{kg ha}^{-1}\text{d}^{-1}$ for the macronutrients and $\text{g ha}^{-1}\text{d}^{-1}$ in the case of micronutrients.

$$\text{Rate of nutrient uptake} = \frac{\text{Nutrient uptake at } T_2 - \text{Nutrient uptake at } T_1}{T_2 - T_1}$$

Where,

T_1 and T_2 are crop duration in days respectively.

3.2.10.7.8. Use efficiencies of nutrients

3.2.10.7.8.1. Nutrient Use Efficiency

The nutrient use efficiency for the chosen elements was calculated as per the formula furnished below (Iqbal *et al.*, 2003):

$$\text{Nutrient Use Efficiency} = \frac{\text{NPf} - \text{NPc}}{\text{N}} \times 100$$

Where,

NPf and NPc are total nutrient uptake from fertigated and check (control: T₁) plots respectively and N is the applied nutrient in kg ha⁻¹.

3.2.10.7.8.2. Agronomic Use Efficiency

This was calculated using the following formula as suggested by Iqbal *et al.* (2003):

$$\text{AE} = \frac{\text{GYf} - \text{GYc}}{\text{N}} \times 100$$

Where,

GYf and GYc are grain yield from fertigated and check (control: T₁) plots respectively and N is the applied nutrient in kg ha⁻¹.

3.2.10.8. Microbial count

The population dynamics of *Azospirillum*, *Phosphobacteria* and *Methylobacterium sp.* in rhizosphere soil samples were made at flowering stage using N-free malic acid medium (Day and Dobereiner, 1976), Sperber's hydroxyl apatite medium (Katznelson and Bose, 1959) and ammonium mineral salt medium (Neyra and Van Berkum, 1977) for the above three organisms respectively by serial dilution and pour plating method.

3.2.10.9. Yield and yield components

For assessing the relationship between yield and its components, the following parameters were recorded at the time of harvest. The details of the method for estimating each character (Yoshida *et al.*, 1971) are indicated below.

3.2.10.9.1. Number of panicles

In each treatment and replication, five plants were selected and labeled and the number of tillers producing panicles was recorded.

3.2.10.9.2. Length of panicle

In the selected plant samples, the length of each panicle was measured. The average length was calculated and the values were expressed in cm.

3.2.10.9.3. Number of spikelets

The panicles harvested from the sample plants were threshed, cleaned and the total number of spikelets was counted manually. The number of grains per panicle was worked out and the number expressed per m² basis.

3.2.10.9.4. Number of filled grains

After harvest, five plants from each treatment and replication were selected and the number of filled grains per panicle was counted and the number expressed per m² basis.

3.2.10.9.5. Filled grain percentage

The ratio of filled grains to the total number of spikelets in the primary panicles in each hill was expressed as per cent.

3.2.10.9.6. Mean panicle weight

Ten randomly selected panicles from the main tillers in each treatment and replication were dried and their weight taken. The values were given in g panicle⁻¹.

3.2.10.9.7. Panicle Harvest Index (PHI)

Panicle harvest index was calculated by using the following formula as suggested by Lafitte *et al.* (2003) and expressed as percentage.

$$\text{PHI} = \frac{\text{Grain weight}}{\text{Weight of the panicle}} \times 100$$

3.2.10.9.8. 1000 grain weight

The grains were dried in oven at 80 ± 12°C for 24 h and 1000 grain weight for each treatment (in five replications) was recorded. The average was arrived and expressed in g.

3.2.10.9.9. Grain and straw yield

The yield of grain per plot of each treatment and replication was recorded from the net plot and expressed as g plot⁻¹. After thrashing the grains, weight of the straw was taken and expressed as g plot⁻¹.

Grain and straw yield per hectare

Grain yield per hectare was calculated from the mean plot yield and expressed in kg ha⁻¹.

3.2.10.9.10. Harvest Index (HI)

3.2.10.9.10.1. Grain Harvest Index (GHI)

Grain Harvest Index was calculated from the dry weight of grain and total dry weight hill⁻¹ at harvest by using the formula of Yoshida *et al.* (1971) as given below and expressed in percentage.

$$\text{GHI} = \frac{\text{Economic yield}}{\text{Biological yield}} \times 100$$

3.2.10.9.10.2. Nutrient Harvest Index (NHI)

As suggested by Lin *et al.* (2006), the Nutrient Harvest Index for the chosen macro, secondary and micro nutrients was calculated by using the following formula and the values expressed in percentage:

$$\text{NHI} = \frac{\text{Grain nutrient content}}{\text{Total nutrient content at harvest}} \times 100$$

3.2.10.10. Water productivity

Water productivity was calculated as the weight of grains produced per unit of water input (irrigation and rainfall) as per the following formula of Yang *et al.* (2005) and expressed as g grain kg⁻¹ water.

$$\text{Water productivity} = \frac{\text{Grain yield}}{\text{Irrigation} + \text{Rainfall}}$$

3.2.10.11. Economics of cultivation

Cost of cultivation for the present experiment was calculated using the recurring expenditures incurred for the inputs. Benefit : Cost ratio was calculated as:

$$\text{Benefit : Cost ratio} = \frac{\text{Gross return (Rs.)}}{\text{Cost of cultivation (Rs.)}}$$

3.2.10.12. Panicle growth modeling

At the time of flowering, about one hundred panicles in the selected treatments in three replications were tagged for two varieties (Jaiswal *et al.*, 1982). The panicles were sampled periodically and their dry weights recorded using an electronic balance (Model 300 of Shimadzu, Japan).

Panicle data from the treatments and varieties were tested for different panicle growth models as proposed by Thornley (1976). They include: exponential (negative), Gompertz, logistic, cubic, polynomial, quadratic and Richard's and a hybrid of Richard's-Quadratic model. Among them, the hybrid model of Richard's - Quadratic was found to be best fit. The Richard's - Quadratic (hybrid) equation given by Mohandass *et al.* (1988a) was as follows:

$$W_t = W_f [1 + e^{\theta(t)}]^{-1/n}$$

Where

W_t and W_f were panicle dry weight at time 't' and at maturity respectively, and $\theta(t)$ is the quadratic polynomial in 't'. The value of 'n' in this model was found to be 0.1.

From this hybrid model, the duration of effective grain filling period (GFP) and its filling rate (GFR) were calculated as suggested by Jones *et al.* (1979).

3.2.10.13. Crop simulation modelling

3.2.10.13.1. Model description

For the present study, an eco-physiological model, ORYZA2000 is used that simulates the growth, development and water balance of rice in situations of potential production and water limitations with time steps of 1 day (Bouman *et al.*, 2001). It is assumed that the crop is well protected against diseases, pests and weeds. A detailed

description of the model is given by (Bouman *et al.*, 2001). Detailed listings of ORYZA2000 model and the abbreviations used are furnished in **Appendix 2 and 3** respectively. In the ORYZA2000 model, leaf area index, leaf nitrogen content, partitioning of dry matter, quantity of water given and rate of fertilizer applied during the crop period were taken as the forcing functions.

3.2.10.13.2. Model parameterization

The model ORYZA2000 was parameterized following the procedure of Bouman and Van Laar (2006). The crop and water applied data for T₁ and T₆ treatments for DS (2007) were used for parameterization of the model development rates were calculated using the recorded dates of sowing, transplanting, panicle initiation, flowering and maturity. The values for the daily percolation rate of non-puddled lowland soil (for use in PADDY module) were the same as in the data profile of ORYZA2000 model (Bouman *et al.*, 2001).

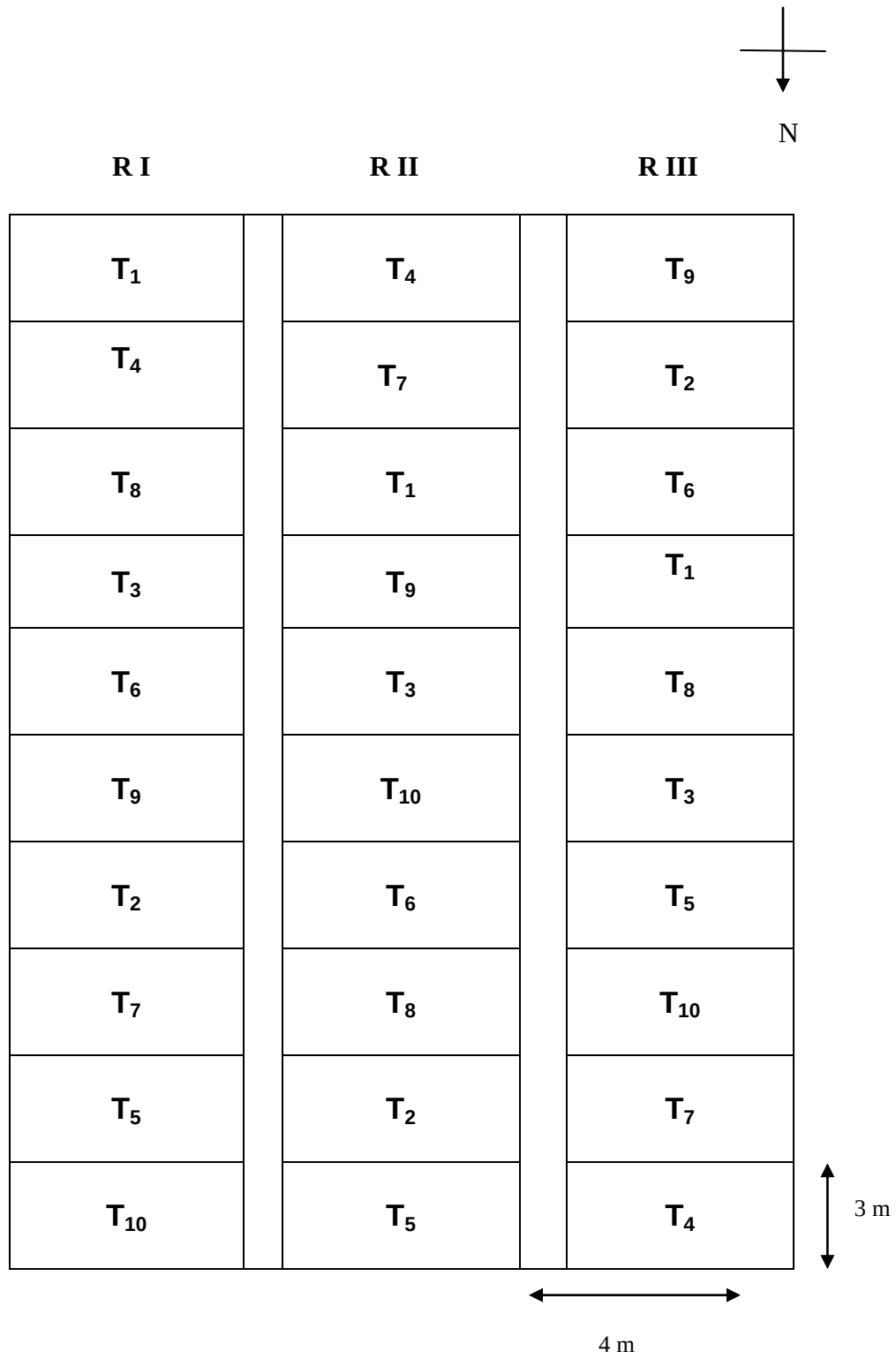
3.2.10.13.3. Model evaluation

The performance of ORYZA2000 was evaluated for the chosen treatments using the corresponding required weather data. The model was also used to extrapolate to the future climate change scenario of elevated atmospheric CO₂ (540 and 720 vppm) level and temperature (up to + 4.0°C) increase. The results of simulated grain yield were presented and discussed.

3.2.10.14. Data processing and Statistical analysis

The data collected were subjected to statistical analysis in split plot design following the method of Gomez and Gomez (1984). Correlation coefficient ('r') and path analysis of chosen parameters were also worked out wherever applicable by adopting the procedure of Heady and Dillon (1961) using INDOSTAT, Hyderabad package.

Fig. 1. Field lay out of the experiment



CHAPTER IV

EXPERIMENTAL RESULTS

Field experiments were carried out with the aim to elucidate the morpho-physiological, biochemical, molecular and nutrio-physiological bases for yield variation as noticed with the drip fertigation treatments in aerobic rice grown during dry season (DS) of 2007 using PMK (R) 3 rice cultivar in the Wetlands of TamilNadu Agricultural University, Coimbatore, Tamil Nadu (**Plates 4, 5 and 6**). The data collected in terms of morphological, physiological, biochemical, molecular, nutrio-physiological and yield and yield attributes were subjected to statistical analysis and the results are presented in this chapter.

In order to bring out the mean performance of irrigation regimes and fertilizer levels, the mean values of treatments viz., T₂, T₃ and T₄ were averaged and designated as I₁, means of T₅, T₆ and T₇ treatments as I₂ and that of T₈, T₉ and T₁₀ as I₃. Similarly, for the fertilizer treatments, the mean values of T₂, T₅ and T₈ were designated as F₁, average values of T₃, T₆ and T₉ as F₂ and that of T₄, T₇ and T₁₀ as F₃ and discussed in the following pages for each parameter.

4.1. Morphological Characters

4.1.1. Plant height (cm)

The mean values of plant height (**Table 7**) recorded during active tillering (AT), panicle initiation (PI), 50 % flowering (FF) and at harvest (HT) stages were 38.4, 48.4, 88.1 and 103.3 cm respectively. The differences due to treatments were found to be significant at all stages of growth. The mean plant height was found to be taller in the treatment of conventional irrigation and fertilizer application (T₁: 83.4) which was followed by the treatment with 150 % PE + 125 % RDF + BF through fertigation (T₁₀: 78.4). Nevertheless, increased plant height was registered with T₁ (125.9) at HT stage, which was significantly superior to the rest of the treatments tried.

The mean performance of irrigation regimes indicated that the value showed linear trend from 100 % (I₁: 60.6) to 150 % PE (I₃: 74.1). Increased level of fertilizers

also resulted in an increase in the values of plant height from 75 % (F_1 : 64.6) to 125 % RDF + BF (F_3 : 71.6). While, the conventional irrigation and fertilizer application treatment recorded a higher mean plant height of 83.4 cm.

4.1.2. Total root length (m hill⁻¹)

The mean total root length (**Table 8**) for the growth stages showed an increasing trend from AT (13.0) to FF (48.8) with a decline thereafter at HT stage (41.9). Statistical significance was attained for the parameter at all growth stages observed. An increased total root length of 55.8 m hill⁻¹ was recorded with T_4 (irrigation at 100 % PE + 125 % RDF + BF), which was closely followed by the treatment 100 % PE + 100 % RDF fertigation (T_3 : 51.9) at FF stage.

On an average, the irrigation regimes greatly influenced the total root length with higher values of 34.6 and 34.4 m hill⁻¹ observed with the treatment of 100 % (I_1) and 125 % (I_2) PE levels respectively. For the fertilizer levels, the values showed an increasing trend from 75 % (F_1 : 29.9), 100 % (F_2 : 33.3) and 125 % RDF + BF (F_3 : 35.3). The conventional irrigation and fertilizer application method registered the mean value of 33.4 m hill⁻¹.

4.1.3. Root volume (cc hill⁻¹)

Values for the root volume showed a linear trend from AT (18.9) to FF (66.5) with a decline at HT (50.9) stage (**Table 9**). Mean root volume was found to be higher in drip fertigation at 125 % PE + 125 % RDF + BF (T_7 : 56.6), which was closely followed by T_4 treatment (56.0). Nevertheless, the root volume was found to be more with the fertigation level of 125 % PE + 125 % RDF + BF (T_7 : 78.3), which was also comparable with the treatment of drip irrigation scheduled at 100 % PE + 125 % RDF + BF (T_4 : 75.6) at FF stage. Similar trend was observed at PI stage also.

For the average performance of both irrigation regimes and fertilizer levels, it was indicated that the root volume was found to increase from wetter moisture (I_3 : 38.8) to drier moisture regime (I_1 : 53.8). Whereas, the levels showed a linear increase from 75 % (F_1 : 43.1) to 125 % RDF + BF level (F_3 : 51.8). The conventional practice of irrigation and fertilizer application showed a value of 46.2 cc hill⁻¹ only.

4.1.4. Root Length Density (RLD) (cm cm^{-3})

The values of RLD (**Table 10**), observed for a soil depth of 0-30 cm, were increasing from AT (0.731) to FF (1.681) with a decline at HT stage (1.387). During FF stage, an increased value was registered when fertigation was scheduled at 100 % PE + 75 % RDF + BF (T_2 : 2.482). Similar trend was observed with higher values noticed for T_2 at AT (1.056), PI (1.723) and also at HT stage (2.045).

Mean values of RLD showed a declining trend from I_1 (1.643) to I_3 (1.010); similarly, downward trend was evident for the fertilizer levels from 1.429 (F_1 : 75 % RDF + BF) to 1.143 cm cm^{-3} (F_3 : 25 % RDF + BF). Nevertheless, the conventional method of irrigation and fertilizer application registered a mean value of 1.118 cm cm^{-3} for RLD parameter.

4.1.5. Root Mass Density (RMD) (mg cm^{-3})

With regard to RMD, observed for a soil depth of 0-30 cm, the treatment differences attained statistical significance for all the four stages studied (**Table 11**). The mean values for the stages were 0.531, 0.977, 1.131 and 0.953 mg cm^{-3} during AT, PI, FF and at HT stages respectively. For the mean performance of treatments across the stages, higher values of 1.242, 1.125 and 1.065 mg cm^{-3} were evident with T_6 , T_7 and T_5 respectively. Nevertheless, significantly superior value of 1.597 was registered by drip fertigation at 125 % PE + 100 % RDF + BF (T_6) at FF stage.

With regard to the mean performance of irrigation regimes, the value of RMD was found to higher for the moderate moisture level (I_2 : 1.144) than the lower moisture regime (I_1 : 0.850). For the fertilizer levels, 100 % RDF + BF proved its supremacy (F_2 : 0.969) than lower (F_1 : 0.780) or higher (F_3 : 0.935) fertilizer level. Recommended practice of irrigation and fertilizer application showed a mean performance of 0.931 cm cm^{-3} for the RMD parameter.

4.1.6. Tiller density (No. m^{-2})

The mean values of tiller density (**Table 12**) ranged from 111 (AT) to 496 (FF) with a decline at HT (340) stage. The mean values for treatments were higher for the treatment receiving fertigation at 150 % PE + 125 % RDF + BF (T_{10} : 348), which was

closely followed by the conventional irrigation practice and fertilizer application (T_1 : 341). The differences due to treatments were found to be significant at all growth stages studied. However, the treatment T_{10} (578) possessed significantly higher tiller production, which was also comparable with T_7 (568) at FF stage. Significantly least tillers were produced with the fertigation scheduled at 100 % PE + 75 % RDF (T_2 : 375) at FF stage.

Mean values for the tiller production was greatly influenced by the irrigation regimes with higher values registered for I_3 (335) which was followed by I_2 (317) and I_1 (242). In the case of fertilizer levels, the mean values showed increasing trend from F_1 (277) to F_3 (315) levels. The conventional irrigation and fertilizer method recorded mean tillers of 341 number m^{-2} .

4.1.7. Leaf number (No. hill⁻¹)

The time trend of production of leaf hill⁻¹ was given in **Table 13**. The values increased from 38.4 (AT) to FF stage (103.3). Mean performance of treatments indicated that the leaf production was higher in the conventional practice (T_1 : 125.9), while the least production of leaves was evident with T_2 (82.5) at FF stage.

Overall mean performance of the irrigation and fertilizer treatments across the stages inferred that an increased leaf production was evident with higher leaf production noticed in higher moisture regime (I_3 : 74.1) than the drier one (I_1 : 60.6). Regarding the fertilizer levels, the values were found to increase from 75 % (F_1 : 64.6) to 125 % (F_3 : 71.6) RDF + BF. The conventional method of irrigation and fertilizer application showed a mean leaf production of 83.4 number hill⁻¹.

4.1.8. Total Dry Matter Accumulation (TDMA) (g m⁻²)

The differences due to treatments were significant for the TDMA at all stages of crop growth studied (**Table 14**). The mean values of TDMA for different phenophases showed a gradual increase from AT (97.30) to HT stage (1114.58). Mean performance of the treatments was found to be superior with higher value of 774.01 g m⁻² when fertigation was scheduled at 150 % PE + 125 % RDF + BF (T_{10}). Nevertheless, significantly higher value of 1335.89 g m⁻² was registered by T_{10} but was on par with T_9 (1282.54) at HT stage.

Average performance of the irrigation regimes and fertilizer levels indicated that the values of TDMA increased with increase in the level of moisture supply from I₁ (562.70) to I₃ (724.31); for the fertilizer treatments, the values showed the linear increase of 595.71, 661.10 and 695.95 g m⁻² with 75, 100 and 125 % RDF + BF respectively. The conventional method registered a mean TDMA of 712.7 g m⁻².

4.1.9. Root / Shoot (R/S) ratio

The drip fertigation treatment attained statistical significance for R/S ratio at all the four phenophases studied (**Table 15**). The mean values were 0.275, 0.114, 0.129 and 0.083 at AT, PI, FF and HT stages respectively. Regarding the mean values for the treatments, the R/S ratio was higher with the drip fertigation given at 100 % PE + 75 % RDF + BF (T₂: 0.188) treatment, followed by T₇ (0.18) and T₄ (0.184). Statistically superior value of 0.394 was evident with the conventional method of irrigation and fertilizer application (T₁) at AT stage.

Mean performance of the treatments indicated that the R/S ratio was found to decline from I₁ (0.183) to I₃ (0.110) but increased from F₁ (0.129) to F₃ (0.168). The conventional method of irrigation and fertilizer (T₁) application registered a mean value of 0.173.

4. 2. Growth Parameters

4.2.1. Leaf Area Index (LAI)

Mean values of LAI for the stages were 1.37, 3.35, 4.25 and 3.99 during AT, PI, FL and GF stages respectively (**Table 16**). Mean performance of the treatments indicated that the conventional method of irrigation and fertilizer application (T₁: 4.02) and treatment in which fertigation was scheduled at 150 % PE + 125 % RDF +BF (T₁₀: 3.91) were found to be superior to the rest of the treatments studied. Nevertheless, increased and comparable values of LAI of 5.15 and 5.05 were evident with T₁ and T₁₀ respectively at FF stage.

Pertaining to the overall mean performance of the chosen treatments, the values of LAI increased with increase in the moisture levels with higher values observed for I₃ (3.53) followed by I₂ (3.29) and I₁ (2.64). Similar trend was evident for the fertilizer

levels also with higher value noticed in F_3 (3.44) with a gradual decline in F_2 (3.13) and F_1 (2.89). However, the conventional method of irrigation and fertilizer application proved its supremacy with higher mean LAI of 4.02.

4.2.2. Leaf Area Duration (LAD) (days)

The mean values of LAD for different growth stages were 70.85, 114.05 and 123.63 days during AT-PI, PI-FF and FF-GF stages respectively (**Table 17**). The treatments attained statistical significance for LAD parameter at all stages of crop growth studied. Significantly higher LAD of 152.40 days was recorded by T_1 during FF-GF phase. This was on par with the value of 148.05 days in T_{10} during the same phenophase. Similar trend was observed during AT-PI as well as PI-FF phases also.

Regarding the mean performance of the chosen treatments, the values of LAD showed an increasing trend for the irrigation regimes with the values of 85.52, 104.33 and 111.10 days for I_1 , I_2 and I_3 respectively. Similar trend was seen for the fertilizer levels also with higher values observed in F_3 (109.12) than F_2 (99.65) and F_1 (92.18) RDF levels. The mean LAD for the conventional practice was 125.55 days.

4.2.3. Individual Leaf Size (ILS) ($\text{cm}^2 \text{ leaf}^{-1}$)

The time trend of ILS was 11.2, 11.5, 8.8 and 9.8 $\text{cm}^2 \text{ leaf}^{-1}$ for AT, PI, FF and HT stages respectively (**Table 18**). However, significantly higher value of 16.0 $\text{cm}^2 \text{ leaf}^{-1}$ was evident with the drip fertigation schedule of 150 % PE + 125 % RDF + BF (T_{10}) at PI stage.

Over all mean performance of the irrigation treatments indicated that the ILS was found to increase with increase in moisture supply, with higher values noticed in I_3 (11.2). Similar trend was observed for the fertilizer levels and the values were enhanced with 125 % RDF (F_3 : 10.6) level than 75 % (F_1 : 9.8) or 100 % (F_2 : 10.2) RDF + BF. The conventional method recorded a mean ILS of 11.1 $\text{cm}^2 \text{ leaf}^{-1}$.

4.2.4. Individual Leaf Weight (ILW) (mg leaf^{-1})

The values of ILW (**Table 19**) increased from AT (26.8) to PI stage (80.6) and declined at FF (75.8) as well as at HT stage (72.1). Significantly higher value of

124.1 mg leaf⁻¹ was noticed with the drip fertigation scheduling made at 125 % PE + 125 % RDF+ BF (T₇) at PI stage.

Mean performance of irrigation regimes indicated that the ILW values increased from I₁ (63.1) to I₂ (70.7) with a sharp decline with I₃ (58.3). In the case of fertilizer levels, the ILW showed an increasing trend from 75 % (F₁: 59.8) to 125 % RDF + BF (F₂: 67.4). However, the conventional method registered a moderate mean value of 62.0 mg leaf⁻¹.

4.2.5. Specific Leaf Weight (SLW) (mg cm⁻²)

The mean values SLW (**Table 20**) for different phenophases were 2.44, 6.97, 8.57 and 7.38 mg cm⁻² at AT, PI, FF and HT stages respectively. However, the treatments, attaining statistical significance at all stages studied, indicated that fertigation scheduled at 150 % PE + 100 % RDF + BF (T₉) registered increased values of 9.74 and 9.00 mg cm⁻² during FF and HT stages respectively.

With regard to the overall mean performance of the chosen treatments across the stages, increased SLW value was recorded with higher moisture supply situations (I₃: 6.78). For the fertilizer levels, the values were more with 100 % (F₂: 6.49) and 75 % (F₁: 6.37) than 125 % (F₃: 6.28) RDF + BF. While the conventional method of irrigation and fertilizer application was endowed with the mean SLW of 5.98 mg cm⁻² only.

4.2.6. Crop Growth Rate (CGR) (g m⁻² day⁻¹)

The mean values of CGR (**Table 21**) were found to increase from SL-AT phase (1.27) to PI-FF phase (11.69) with a decline at FF-GF phase (8.73). The conventional irrigation practice and fertilizer application (T₁) registered higher values of CGR during SL-AT (1.69), AT-PI (6.49), PI-FF (14.40) and at FF-GF (11.10) phases. Least values of CGR were evident with T₂ treatment at all the phenophases studied.

From the data on mean performance of the irrigation regimes and fertilizer levels, it could be inferred that the values were found to increase steadily from drier (I₁: 4.74) to wetter moisture regime (I₃: 7.72). Similar trend was noticed for the fertilizer levels also with the values being 5.89, 6.58 and 7.17 g m⁻² day⁻¹ in 75, 100 and 125 % RDF + BF respectively. The mean value was higher with 8.42 g m⁻² day⁻¹ for the conventional method of irrigation and fertilizer application.

4.2.7. Net Assimilation Rate (NAR) (mg cm⁻² day⁻¹)

Statistical significance was achieved for the variations due to treatments for the NAR values at all phenophases studied (**Table 22**). An increased mean value of $1.624 \text{ mg cm}^{-2} \text{ d}^{-1}$ was registered during PI-FF phase. Regarding the mean performance of the treatments, T₁₀ ranked first (1.814) followed by T₉ (1.775) and T₁ (1.726). The treatment T₂ recorded the least values of 0.956, 0.752, 0.851 and $0.408 \text{ mg cm}^{-2} \text{ day}^{-1}$ during SL-AT, AT-PI, PI-FF and FF-GF phases respectively. Nevertheless, significantly superior value of $2.204 \text{ mg cm}^{-2} \text{ day}^{-1}$ was evident with the drip fertigation treatment scheduled at 150 % PE + 100 % RDF + BF (T₉), which was comparable with the schedule of 150 % PE + 125 % RDF (T₁₀: 2.135) during PI-FF phase.

Overall mean performance of the treatments indicated that the values were found to be increasing from drier (I₁: 0.829) to wetter (I₃: 1.751) moisture regimes. For the fertilizer levels, higher value of $1.450 \text{ mg cm}^{-2} \text{ day}^{-1}$ was registered for higher RDF level of 125 % (F₃) than 75% (F₁: 1.204) or 100 % (F₂: 1.314) RDF + BF. The mean value for the conventional practice was $1.726 \text{ mg cm}^{-2} \text{ day}^{-1}$.

4.2.8. Leaf Area Ratio (LAR) ($\text{cm}^2 \text{ g}^{-1}$)

The values of LAR (**Table 23**) showed a declining trend from AT (2.80) to HT stage (0.69). Regarding the mean performance of treatments, drip fertigation given at 125 % PE + 125 % RDF + BF (T₇) and conventional method (T₁) were superior (1.61) than the rest of the treatments. Nevertheless, significantly higher LAR value of $3.35 \text{ cm}^2 \text{ g}^{-1}$ was registered by T₇, which was comparable with T₆ (3.32) at AT stage.

Overall mean values for varied moisture regimes indicated a sharp increase in LAR value from drier (I₁: 1.35) to moderate (I₂: 1.54) moisture regimes. In regard to the fertilizer levels, the value was higher with 100 % RDF (F₂: 1.49) than 75 (F₁: 1.38) or 125 % RDF + BF (F₃: 1.48). The conventional irrigation and fertilizer levels showed an increased LAR value of $1.61 \text{ cm}^2 \text{ g}^{-1}$.

4.3. Light parameters

4.3.1. Light Interception Percentage (LIP)

The mean values of LIP were 65.5, 74.0, 88.4 and 72.9 at AT, PI, FF and GF stages respectively (**Table 24**). Regarding the mean performance of treatments, drip fertigation scheduled at 150 % PE + 125 % RDF + BF (T₁₀: 83.6) was superior to the rest

of the chosen treatments. However, a higher value of 96.0 per cent was evident with the drip fertigation scheduled at 125 % PE + 125 % RDF + BF (T₇), but was also on par with T₁ (92.4), T₁₀ (92.3), T₆ (92.2) and T₉ (91.2) at FF stage.

With regard to the mean performance of irrigation regimes, the LIP values showed a linear increase from drier (I₁: 63.9) to moderate (I₂: 78.0) and then to wetter (I₃: 81.7) moisture regimes. For the fertilizer levels, the linear increasing trend was observed from 75 % (F₁: 71.2) to 125 % RDF + BF (F₃: 77.2). Higher mean value of 81.4 per cent was registered by the conventional practice.

4.3.2. Light extinction co-efficient ('k')

The 'k' value observed during different growth stages (**Table 25**) indicated that the values decreased from PI (1.261) to FF (0.242) stage. At PI stage, drip fertigation schedule given at 125 % PE + 75 % RDF + BF registered the lowest value (T₅: 1.006) which was on par with T₆ (1.029). For FF stage, T₆ was found to be favoured with lower value (0.211) but was comparable with T₅ (0.218) and T₇ (0.220).

Regarding the overall mean performance of the water regimes tested, 125 % PE (I₂: 0.651) was favoured with lower 'k' value. Similar trend was evident for the fertilizer treatments showing the least value with 75 % (F₁: 0.705) RDF + BF. The conventional practice registered the mean 'k' value of 0.772.

4.4. Physiological and Biochemical Parameters

4.4.1. Chlorophyll 'a' content (mg g⁻¹)

There was an increasing trend of chlorophyll 'a' content (**Table 26**) from AT (1.110) to FF (1.756) stage with a decline at GF stage (1.241). Mean performance of treatments was found to be superior with the drip fertigation scheduled at 150 % PE + 125 % RDF + BF (T₁₀: 1.682) to the rest of the treatments. Nevertheless, an increased content of 2.108 mg g⁻¹ was evident with T₁₀, which was also comparable with T₁ (2.098), T₉ (2.089) and T₈ (2.024) and at FF stage. Similar trend was observed at PI stage also.

For the overall mean performance, the content showed a gradual increase from I₁ (0.945) to I₃ (1.599). In the case of fertilizer levels, the content of chlorophyll 'a' increased with increase in the fertilizer levels with the values being 1.231, 1.357 and

1.462 mg g⁻¹ for 75, 100 and 125 % RDF + BF respectively. Higher mean value of 1.648 mg g⁻¹ was evident with the conventional practice.

4.4.2. Chlorophyll 'b' content (mg g⁻¹)

Regarding the content of chlorophyll 'b' (**Table 27**), the mean values for different stages were 0.429, 0.568, 0.734 and 0.552 mg g⁻¹ at AT, PI, FF and GF stages respectively. Higher content of 0.879 mg g⁻¹ was observed with the treatment schedule of 100 % PE + 125 % RDF + BF (T₃), which was comparable with T₂ (0.848) at FF stage.

Mean performance of irrigation regimes showed that the values decreased with increase in moisture supply with drier regime (I₁: 0.607) showing higher content than the wetter (I₃: 0.551) moisture regime. In the case of fertilizer levels, higher content was observed with 100 and 125 % (F₂ and F₃: 0.580) than 75 % RDF + BF (F₁: 0.556). The mean value for the conventional practice was slight higher (0.561).

4.4.3. Total chlorophyll (mg g⁻¹)

The total chlorophyll content (**Table 28**) increased from AT (1.540) to FF (2.436) with a decline at GF stage (1.751). Mean performance of treatments were found to be superior with drip fertigation scheduled at 125% PE + 125 % RDF + BF (T₇: 2.236) to the rest of the treatments. A higher content of 2.799 mg g⁻¹ was evident with T₁, which was also on par with T₇ (2.722) at FF stage.

Regarding the mean performance of irrigation regimes, the values showed an increasing trend from I₁ (1.552) to I₂ (2.058) with a slight decline at I₃ (2.053). For the fertilizer levels, the values steadily increased from 75 % (F₁: 1.763) to 125 % (F₃: 1.990) RDF + BF. The conventional practice of irrigation and fertilizer application showed an increased mean value of 2.208 mg g⁻¹.

4.4.4. Chlorophyll a / b ratio

The ratio (**Table 29**) showed a declining trend from AT (2.577) to GF (2.290) stage. Performance of T₁₀ was superior with higher values of 3.000 and 2.867 at FF and GF stages respectively. Least ratio of 2.056, 1.501 and 1.191 was seen with T₂ during AT, PI and FF stages respectively.

Mean performance for different treatments showed that the values were found to increase from I₁ (1.616) to I₃ (2.896). While, higher RDF + BF showed an increased ratio (F₃: 2.528). The mean value for the conventional treatment was 2.935.

4.4.5. SPAD Chlorophyll Meter readings

The mean SPAD values for the stages were 28.7, 34.3, 35.3 and 33.2 at AT, PI, FF and GF stages respectively (**Table 30**). Mean performance of treatments indicated superiority of T₁ (34.7) followed by T₁₀ (34.6) and T₇ (34.1). A higher value of 37.2 was recorded by T₁, which was comparable with T₁₀ (36.8), T₉ (36.2), T₄ (35.9) and T₇ (35.8).

With regard to mean performance, the SPAD values showed a gradual increase from I₁ (31.2) to I₃ (33.8). Similarly, there was a linear increase of SPAD values from F₁ (31.3) to F₃ (33.8). The conventional practiced registered the mean value of 34.7.

4.4.6. Fv / Fm ratio (PS II)

The ratio of Fv / Fm (**Table 31**) was found to increase from AT (0.554) to FF (0.667) with a gradual decline at GF (0.548) stage. The performance of T₁₀ was found to be superior with higher values of 0.602, 0.666, 0.725 and 0.602 during AT, PI, FF and GF stages respectively and statistically significant in the respective stages. Least values of 0.481, 0.500, 0.521 and 0.498 were evident with T₂ at AT, PI, FF and GF stages respectively.

The mean values of PS II was found to vary from 0.524 (I₁) to 0.629 (I₃) for the irrigation regimes. In the case of fertilizer levels, F₃ (0.610) registered a higher value followed by F₂ (0.589) and F₁ (0.562). The convention method recorded a mean value of 0.641.

4.4.7. Soluble protein (mg g⁻¹)

The mean content of soluble protein in leaf (**Table 32**) was 5.41, 7.22, 8.60 and 6.89 mg g⁻¹ at AT, PI, FF and GF stages respectively. Superior mean performance of treatments was noticed when irrigation was scheduled at 150 % PE + 125 % RDF + BF (T₁₀: 8.32) which was closely followed by the conventional irrigation and fertilizer application (T₁: 8.24). The content of soluble protein was favourably influenced in T₁₀ at PI (8.02), FF (10.23) and GF (8.89) stages. The values were found to be the lowest with T₂ at all stages of crop growth studied.

Overall mean performance indicated that the soluble protein content was found to increase with increase in the moisture supply with higher values noticed in I₃ (7.66). Similar trend was noticed with the fertilizer levels also and the values ranged from 6.34 (F₁: 75 % RDF + BF) to 7.39 (F₃: 125 % RDF+ BF). The conventional irrigation and fertilizer practice showed a higher mean value of 8.24.

4.4.8. Soluble nitrogen (mg g⁻¹)

The time trend for the soluble nitrogen (**Table 33**) in different stages was 1.51, 1.68, 2.63 and 1.14 mg g⁻¹ during AT, PI, FF and GF stages respectively. The differences due to the treatments were significant for all the stages tried. The drip fertigation treatment given at 125 % PE + 100 % RDF + BF (T₆) registered significantly lower values of 1.38, 1.42, 1.97 and 0.94 at AT, PI, FF and GF stages respectively.

Mean performance of irrigation regimes showed that the value was lower at moderate water supply (I₂: 1.49) than lower (I₁: 1.88) or higher (I₃: 1.79) water supplying situation. With regard to the fertilizer treatments, the soluble N showed an increased trend from 75 % (F₁: 1.65) to 125 % (F₃: 1.82) RDF + BF. The conventional method of irrigation and fertilizer recorded a mean value of 1.91 mg g⁻¹.

4.4.9. Reducing sugars (mg g⁻¹)

The values of reducing sugars (**Table 34**) showed a linear increasing trend from AT (2.07) to GF (10.96) stage. The differences due to the treatments attained statistical significance at all stages of crop growth studied. The mean performance of treatments was found to be superior with the drip fertigation scheduled at 100 % PE + 75 % RDF + BF (T₂: 8.08). Nevertheless, higher contents of 3.15, 4.05, 10.05 and 15.05 mg g⁻¹ were evident with T₂ at AT, PI, FF and GF stages respectively.

Overall mean performance of irrigation treatment indicated that the content was found to be lower with I₂ (4.95) than I₁ (7.40) or I₃ (5.65). With reference to the fertilizer levels, the values decreased from 75 % (F₁: 6.61) to 125 % (F₃: 5.33) RDF + BF. The conventional practice of irrigation and fertilizer possessed a lower mean value of 4.45 mg g⁻¹.

4.4.10. Total Available Carbohydrates (TAC) (mg g^{-1})

Significant differences were observed for the contents of TAC at all growth stages studied (**Table 35**). The mean values for the growth stages were 85.32, 112.07, 242.56 and 149.95 mg g^{-1} at AT, PI, FF and GF stages respectively. Significantly higher values of 95.56, 138.69, 309.23 and 178.14 mg g^{-1} were recorded with the drip fertigation schedule of 125 % PE + 100 % RDF + BF (T_6) at AT, PI, FF and GF stages respectively.

Regarding the irrigation regimes, the mean TAC content showed an increasing trend from I_1 (101.73) to I_2 (168.34) with a decline in I_3 (164.31). For the fertilizer levels, the mean values showed an increasing trend from 75 % (F_1 : 136.02) to 125 % (F_3 : 149.74) RDF + BF. The conventional irrigation and fertilizer practice registered a higher mean value of 171.59 mg g^{-1} .

4.4.11. Total Free Aminoacids (TFAs) (mg g^{-1})

Mean contents of TFAs were 2.02, 2.52, 2.71 and 1.59 mg g^{-1} at AT, PI, FF and GF stages respectively (**Table 36**). The chosen treatments attained statistical significance at all growth stages studied. A higher content of 3.18 mg g^{-1} was registered by the schedule of drip fertigation at 125 % PE + 75 % RDF + BF (T_5), which was also on par with T_3 (3.08) and T_2 (3.10) at FF stage.

Mean performance of irrigation treatments for TFAs showed that the contents were found to decrease from drier (I_1 : 2.42) to wetter (I_3 : 1.90) moisture regimes. With regard to the fertilizer levels, the values decreased from 75 (F_1 : 2.36) to 100 (F_2 : 2.23) and 125 % (F_3 : 2.15) RDF + BF. For the conventional irrigation and fertilizer practice, the mean value was moderate with 1.88 mg g^{-1} .

4.4.12. Cytokinin content ($\mu\text{g g}^{-1}$)

The contents of endogenous cytokinins analysed during two growth stages (**Table 37**) indicated that the values declined from FF (37.27) to 10 days after FF (10 DAF) (27.44). The treatment differences attained statistical significance at both the stages studied. Nevertheless, a higher content of 49.50 $\mu\text{g g}^{-1}$ was noticed with the drip fertigation scheduling of 125 % PE + 100 % RDF + BF (T_6) at FF stage.

Overall performance of water treatments indicated that content was higher with 125 % (I_2 : 39.59) than 100 % (I_1 : 23.43) or 150 % (I_3 : 34.33) PE level. Similar trend was observed for the fertilizer levels with increased cytokinins content in 100 % (F_2 : 34.97) than 75 % (F_1 : 30.96) or 125 % (F_3 : 31.42) RDF + BF. In the case of conventional practice of irrigation and fertilizer application, the mean value was $31.53 \mu\text{g g}^{-1}$.

4.4.13 Peroxidase (PO) activity ($\Delta 430 \text{ nm g}^{-1}\text{hr}^{-1}$)

The mean activity of PO (**Table 38**), an important scavenging enzyme, was found to vary from 0.79 (AT) to 5.99 (FF) with a decline at GF (3.67) stage. The enzyme activity was significantly enhanced with the drip fertigation given at 100 % PE + 75 % RDF + BF (T_2 : 8.75) at FF stage. Similar trend was observed at AT, PI and GF stages also. But, lower activity of the enzyme was noticed with the conventional irrigation and fertilizer practice (T_1) especially at PI (1.81) and FF (4.55) stages.

Mean performance of irrigation treatments across stages showed that the enzyme activity was found to be lower with higher level of moisture regime (I_3 : 2.74) than drier (I_1 : 4.98) or moderate (I_2 : 3.88) regimes. In the case of fertilizer levels, the activity showed declining trend from 75 % (F_1 : 4.37) to 125 % (F_3 : 3.63) RDF + BF. For the conventional practice of irrigation and fertilizer, lower mean value (2.31) was registered.

4.4.14. Superoxide Dismutase (SOD) activity (enzyme units $\text{mg}^{-1} \text{protein hr}^{-1}$)

The differences due to treatments for the SOD activity were significant (**Table 39**) in both the stages analysed. Higher mean activity was noticed at FF (6.40) than PI (4.53) stage. The activity was much pronounced with drip fertigation scheduled at 100 % PE + 75 % RDF + BF (T_2) at both PI (7.01) and FF (8.23) stages which were significantly superior in both the stages.

With regard to the mean performance of the treatments, the SOD activity was greatly influenced by the water supply with higher activity noticed with lesser supply (I_1 : 7.07) than moderate (I_2 : 5.27) or higher (I_3 : 4.38) water regime. With reference to the fertilizer treatments, the value was enhanced with fertigation stress at 75 % (F_1 : 6.09) than 100 % (F_2 : 5.41) or 125 % (5.22) RDF + BF. The mean SOD activity was low (4.53) in the case of conventional method of irrigation and fertilizer application.

4.4.15. IAA oxidase activity ($\mu\text{g g}^{-1}$)

The time trend of unoxidized auxin content (**Table 40**) was found to increase from AT (3.33) to PI (10.50) and declined at FF (8.93) and GF (5.84) stages. The treatment of provision of drip fertigation at 150 % PE + 125 % RDF + BF (T_{10}) proved its supremacy with increased contents of 14.01, 13.28 and $8.26 \mu\text{g g}^{-1}$ of unoxidized auxins at PI, FF and GF stages respectively.

For the irrigation treatments, the content increased with increase in the moisture availability. The values were 4.46, 7.40 and $8.67 \mu\text{g g}^{-1}$ in 100, 125 and 150 % PE level of moisture respectively. In regard to the fertilizer levels, similar trend was seen with increasing trend from 75 (F_1 : 5.68) to 125 % (F_3 : 8.05) RDF + BF. The conventional practice of irrigation and fertilizer application showed a higher mean value of $9.68 \mu\text{g g}^{-1}$.

4.4.16. Nitrate Reductase (NRase) activity ($\mu\text{mole g}^{-1} \text{hr}^{-1}$)

The mean activities of NRase were 0.546, 0.621, 0.689 and $0.495 \mu\text{mole g}^{-1} \text{hr}^{-1}$ at AT, PI, FF and GF stages respectively (**Table 41**). The treatment differences attained statistical significance at all stages studied. Higher activity (0.830) was endowed with the conventional method of irrigation and fertilizer application (T_1) but was comparable with T_7 (0.826) and T_6 (0.801) at FF stage. Significantly lower activity was noticed with the provision of drip fertigation at 100 % PE + 75 % RDF + BF (T_2) at all stages of crop growth studied.

Overall mean performance of the chosen treatments indicated that the activity of NRase increased from I_1 (0.446) to I_2 (0.686) with a decline at I_3 (0.591). For the fertilizer treatments, the activity was shown to increase with increase in the fertilizer levels with higher activity observed in 125 % (F_3 : 0.618) RDF + BF. The conventional practice of irrigation and fertigation showed an increased activity of $0.713 \mu\text{mole g}^{-1} \text{hr}^{-1}$.

4.4.17. Oxidizing power of roots ($\gamma \text{ g}^{-1} \text{hr}^{-1}$)

The time course of oxidizing power of roots showed a declining trend from AT to GF stage (**Table 42**). The mean values were 128.5, 103.7, 85.9 and $74.9 \gamma \text{ g}^{-1} \text{hr}^{-1}$ at AT, PI, FF and GF stages respectively. The mean performance of treatments was superior with the fertigation scheduled at 125 % PE + 125 % RDF + BF (T_7 : 117.6). An increased

value of $156.4 \gamma \text{ g}^{-1} \text{ hr}^{-1}$ was registered with T_7 , which was on par with conventional irrigation and fertilizer practice (T_1 : 152.6) at AT stage. Least oxidizing power of 85.9, 80.0, 70.9 and $59.6 \gamma \text{ g}^{-1} \text{ hr}^{-1}$ was shown by the treatment receiving 100 % PE + 75 % RDF (T_2) at AT, PI, FF and GF stages respectively.

Regarding the overall performance of irrigation treatments, the value was higher with 125 % (I_2 : 111.3) than 100 % (I_1 : 79.8) or 150 % (I_3 : 98.0) PE level. For the fertilizer treatments, the value was found to increase with increase in the levels of fertilizer possessing higher root oxidizing power of $100.7 \gamma \text{ g}^{-1} \text{ hr}^{-1}$ noticed in 125 % RDF + BF (F_3). The conventional practice registered an increased mean value of $114.9 \gamma \text{ g}^{-1} \text{ hr}^{-1}$.

4.4.18. Cation Exchange Capacity (CEC) of roots ($\text{meq } 100 \text{ g}^{-1}$)

The values of CEC showed (**Table 43**) an increasing trend from AT (9.24) to PI (17.76) declined at FF (12.30) and GF (9.19) stages. The chosen treatments attained statistical significance at all growth stages studied. A higher CEC of $23.02 \text{ meq } 100 \text{ g}^{-1}$ was evident with the drip fertigation treatment scheduled at 125 % PE + 100 % RDF + BF (T_6) which was statistically superior to the rest of the treatments at PI stage.

Overall mean performance indicated that the CEC was greatly influenced by the irrigation regimes, with higher values noticed with moderate irrigation level (I_2 : 13.79) than lower (I_1 : 8.80) or higher (I_3 : 13.13) irrigation supply. With regard to the fertilizer levels, the CEC showed upward trend with increased value of $12.83 \text{ meq } 100 \text{ g}^{-1}$ for 125 % (F_3) RDF + BF. The conventional treatment showed an increased mean value of CEC (14.04).

4.5. Parameters on Plant Water Relations

4.5.1. Relative Water Content (RWC) (%)

The mean values of RWC were 74.57, 79.62, 87.08 and 78.63 per cent during AT, PI, FF and GF stages respectively (**Table 44**). However, higher RWC value of 92.56 per cent was recorded by the fertigation treatment receiving 125 % PE + 100 % RDF + BF (T_6) but it was on par with the treatments of T_1 , T_5 , T_7 , T_9 and T_{10} at FF stage. Similar trend was observed at PI and GF stages. At all stages of crop growth, the treatment, T_2 was found to be statistically inferior with lower values of RWC.

With regard to the overall performance of treatments, irrigation regime showed positive influence with 125 % PE (I_2 : 83.57) with a declining trend in 150 % (I_3 : 80.41) and 100 % (I_1 : 74.28) PE level. For the fertilizer treatments, higher RWC value was noticed with 100 % RDF + BF (F_2 : 81.09). A slightly higher mean RWC value of 84.94 per cent was recorded with the conventional practice of irrigation and fertilizer application.

4.5.2. Membrane Stability Index (MSI) (%)

Similar to RWC, the values of MSI were found to be increasing (**Table 45**) from AT (73.10) to FF (81.92) with a decline at GF stage (73.23). Mean performance of T_{10} (82.24), T_1 (81.19), T_9 (80.94) and T_7 (80.43) were found to be superior. Nevertheless, an increased value of 89.32 per cent was noticed in T_{10} was evident, which was also on par with T_1 (88.23), T_7 (87.26) and T_9 (86.56) at FF stage. Significantly inferior and least values of 65.30, 72.42, 70.08 and 60.02 per cent were observed in T_2 at AT, PI, FF and GF respectively.

In the case of overall performance of the chosen treatments, the MSI values showed upward trend with the moisture status of the soil possessing increased value with 150 % PE level (I_3 : 80.99). Regarding the fertilizer levels, the MSI values increased with increase in fertilizer levels with higher value of 78.48 per cent with 125 % RDF + BF (F_3). The mean value for the conventional practice was 81.19 per cent.

4.5.3. Chlorophyll Stability Index (CSI) (%)

The mean values of CSI were 79.69, 84.19, 74.80 and 64.93 per cent at AT, PI, FF and GF stages respectively (**Table 46**). The treatment receiving fertigation treatment of 150 % PE + 125 % RDF + BF (T_{10}) was adjudged as the superior one with statistically higher CSI value of 80.80 per cent, which was comparable with T_1 (80.32), T_9 (78.69) and T_7 (78.64) at FF stage.

Regarding the overall performance of treatments across the stages, the values of CSI increased with increase in water supply. Higher value was endowed with 150 % PE level (I_3 : 78.28). With reference to the fertilizer levels, higher value of 77.78 per cent was evident with 125 % RDF + BF (F_3). The conventional treatment recorded a mean CSI value of 80.05 per cent.

4.5.4. Leaf water potential (LWP) (-MPa)

The values for LWP showed a linear increasing trend (**Table 47**) from AT (-0.93) to GF stage (-1.80). The treatments attained statistical significance at all growth stages studied. A higher LWP value of -0.85, -1.25, -1.40 and -1.52 MPa were evident with the drip fertigation treatment of 150 % PE + 125 % RDF + BF (T_{10}) at AT, PI, FF and GF stages respectively.

Overall performance of the irrigation regimes indicated that the values of LWP showed an increasing trend from I_1 (-1.76) to I_3 (-1.30). Similarly, increasing the fertilizer level increased the LWP possessing higher value of -1.39 MPa with 125 % RDF + BF (F_3). Nevertheless, the LWP value was still higher (-1.28) with the conventional irrigation and fertilizer practice.

4.5.5. Proline content ($\mu\text{mole g}^{-1}$)

The content of proline (**Table 48**) for different growth stages was 2.90, 3.86, 4.32 and 2.75 $\mu\text{mole g}^{-1}$ at AT, PI, FF and GF stages respectively. The differences due to treatments were significant at all growth stages studied. Significantly superior value of 6.59 $\mu\text{mole g}^{-1}$ was evident with the treatment receiving drip fertigation at 100 % PE + 75 % RDF + BF (T_2) at FF stage. Similar trend was noticed at AT, PI and GF stages. The conventional practice of irrigation and fertilizer schedule possessed significantly the least values at AT (1.21), FF (2.50) and GF (1.20) stages.

For the overall performance, increasing the water levels decreased the proline content with the higher value noticed in the drier (I_1 : 4.73) than the wetter (I_3 : 2.44) regime. Referring to the fertilizer levels, accumulation of proline showed a declining trend from 75 % (F_1 : 4.15) to 125 % (F_3 : 3.05) RDF + BF.

4.5.6. Leaf Diffusive Resistance (LDR) (s cm^{-1})

The time trend of LDR showed that the mean values for different stages were 0.151, 0.170, 0.183 and 0.130 s cm^{-1} at AT, PI, FF and GF stages respectively (**Table 49**). The treatment differences attained statistical significance at all stages of growth studied. Significantly higher resistance (0.255) was evident with the drip fertigation treatment receiving 100 % PE + 75 % RDF + BF (T_2) level at FF stage. Similar trend was observed at AT (0.201), PI (0.222) and GF (0.163) stage also.

Overall mean performance indicated that the LDR values increased with decrease in water supply. Increased resistance was observed by 100 % (I_1 : 0.196) followed by 125 % (I_2 : 0.161) and 150 % (I_3 : 0.129) PE level of water supply. In the case of fertilizer levels, lower mean LDR was noticed with 125 % (F_3 : 0.148) followed by 100 % (F_2 : 0.163) and 75 % (F_1 : 0.176) RDF + BF. Lower mean resistance of 0.123 s cm^{-1} was recorded by the conventional practice and irrigation and fertilizer application.

4.5.7. Transpiration rate ($\mu\text{g H}_2\text{O cm}^{-2} \text{ s}^{-1}$)

The mean values of transpiration rate (**Table 50**) as influenced by the treatments were 22.03, 32.17, 48.19 and $37.28 \mu\text{g H}_2\text{O cm}^{-2} \text{ s}^{-1}$ at AT, PI, FF and GF stages respectively. Mean performance of the treatments indicated that transpiration rate was higher with drip fertigation scheduled at 150 % PE + 125 % RDF + BF (T_{10} : 46.49). However, higher rate of $62.99 \mu\text{g H}_2\text{O cm}^{-2} \text{ s}^{-1}$ was exhibited by T_{10} treatment, which was comparable with T_1 (62.33) at FF stage.

With regard to the overall performance of the chosen treatments, the rate of transpiration increased with increase in the supply of water with higher value noticed in 150 % PE (I_3 : 43.32) with a decline in 125 % (I_2 : 34.98) and 100 % (I_1 : 22.95) PE based water supply. Similar trend was observed for the fertilizer levels, with higher transpiration rate of $37.09 \mu\text{g H}_2\text{O cm}^{-2} \text{ s}^{-1}$ with 125 % RDF + BF (F_3). The transpiration rate for the conventional practice of irrigation and fertilizer was $45.46 \mu\text{g H}_2\text{O cm}^{-2} \text{ s}^{-1}$.

4.5.8. Leaf temperature ($^{\circ}\text{C}$)

The differences due to treatments were significant for leaf temperature at PI and FF stages only (**Table 51**). The temperature varied from 31.1 (AT) to 33.8 $^{\circ}\text{C}$ (GF). With regard to the mean performance of the treatments, drip fertigation given at 150 % PE + 125 % RDF + BF (T_{10}) maintained cooler leaf temperature at PI (30.9) and FF (32.2) stages.

Regarding the overall mean performance, the leaf temperature was decreasing with increase in moisture supply with higher value observed in 100 % PE (I_1 : 33.2) than 125 % (I_2 : 32.2) or 150 % (I_3 : 32.0) PE level. In the case of fertilizer levels, the leaf temperature decreased from 75 % (F_1 : 33.0) to 125 % (F_3 : 32.0) RDF + BF. The conventional treatment possessed cooler leaf temperature of 31.9 $^{\circ}\text{C}$.

4.5.9. Canopy temperature (°C)

The canopy temperature attained statistical significance at AT and PI stages only (**Table 52**). The mean values for the stages were 28.0, 29.8, 30.7 and 32.3 °C at AT, PI, FF and GF stages respectively. Lower canopy temperatures of 27.2 and 28.9 °C were evident with the drip fertigation scheduled at 150 % PE + 125 % RDF + BF (T₁₀) level AT and PI stages respectively. However, the canopy temperature was found to be warmer with T₂ at all the above mentioned stages.

For the overall mean performance, irrigation regimes showed distinct variations with cooler temperature maintained at increased water supply situation (I₃: 29.8) followed by I₂ (30.0) and I₁ (31.0). Similarly, the canopy was cooler in the treatment receiving higher RDF + BF (F₃: 29.8). Nevertheless, the conventional practice of irrigation and fertilizer possessed lower canopy temperature of 29.7 °C.

4.6. Nutrio-physiological characters

4.6.1. Total uptake of nutrients

4.6.1.1. Total nitrogen (N) uptake (kg ha⁻¹)

The differences due to the chosen treatments showed statistical significance for total N uptake at all the stages studied (**Table 53**). Significantly superior total N uptake values of 213.98 and 233.78 kg ha⁻¹ was evident with the scheduling of drip fertigation at 150 % PE + 125 % RDF + BF (T₁₀) at FF and HT stages respectively. However, significantly least uptake of 89.91 and 102.37 kg ha⁻¹ were evident with T₂ (receiving drip fertigation at 100 % PE + 75 % RDF + BF) at FF and HT stages respectively.

Over performance of treatments indicated that the total N uptake values increased with increase in water supply possessing higher value (I₃: 133.13) at 150 % PE level. For the fertilizer treatments, 125 % RDF + BF (F₃:123.58) was favoured with higher uptake for total N. The conventional treatment registered a mean value of 133.25 kg ha⁻¹.

4.6.1.2. Total phosphorus (P) uptake (kg ha⁻¹)

The time trend of total P uptake for different stages of growth was 4.72, 15.66, 22.87 and 24.68 kg ha⁻¹ at AT, PI, FF and HT stages respectively (**Table 54**). Similar to

total N uptake, higher total P uptake was registered with the scheduling of drip fertigation at 150 % PE + 125 % RDF + BF (T_{10}) level at FF (30.49) and HT (31.39) stages.

The mean performance of irrigation treatments showed that the total P uptake showed an increasing trend with the water supply registering higher value with 150 % PE level of drip irrigation (I_3 : 19.90). With regard to the fertilizer levels, an increased uptake was evident with 125 % RDF + BF (F_3 : 18.36). Mean value for the conventional method was moderate at 20.73 kg ha⁻¹.

4.6.1.3. Total potassium (K) uptake (kg ha⁻¹)

With regard to the total K uptake (**Table 55**), the mean values for the stages ranged from 17.11 (AT) to 111.77 kg ha⁻¹ (HT). Statistical significance was noticed for the chosen treatments at all stages of crop growth studied. Significantly higher uptake of 146.93 kg ha⁻¹ was registered with T_1 which was on par with T_{10} (145.61) at HT stage.

Mean values of irrigation treatments were 58.10, 78.13 and 88.32 kg ha⁻¹ for I_1 , I_2 and I_3 respectively. In relation to the fertilizer levels, the mean value was higher with 125 % RDF + BF (F_3 : 84.96). In the case of conventional method, the average value of total K uptake was slightly higher at 96.77 kg ha⁻¹.

4.6.1.4. Total calcium (Ca) uptake (kg ha⁻¹)

In the case of total Ca uptake (**Table 56**), the values steadily increased from 1.88 (AT) to 29.40 kg ha⁻¹ (HT). With regard to the treatments attaining statistical significance at all stages of growth studied, higher total Ca uptake was registered with the drip fertigation scheduled at 150 % PE + 125 % RDF + BF (T_{10}) at PI (12.32), FF (23.93) and at HT (39.41) stages. Nevertheless, least uptake values were evident with T_2 at PI (7.57), FF (11.80) and HT (17.12) stages.

Overall performance of the water treatments indicated that the total Ca uptake was enhanced with increase in water supply possessing increased value at higher (I_3 : 17.76) water supply scenario. For the fertilizer levels, the total Ca uptake slowly increased from 75 % RDF + BF (F_1 : 12.94) to 125 % RDF + BF (F_3 : 16.20). The conventional treatment was vested with the mean uptake of Ca at a moderate level of 17.58 kg ha⁻¹.

4.6.1.5. Total magnesium (Mg) uptake (kg ha^{-1})

The differences due to the chosen treatments attained statistical significance for the total Mg at all stages of phenophases studied (**Table 57**). The mean values of total mg uptake in different stages were 1.74, 9.25, 22.62 and 30.12 kg ha^{-1} at AT, PI, FF and HT stages respectively. Similar to Ca uptake, the drip fertigation treatment scheduled at 150 % PE + 125 % RDF + BF (T_{10}) was favoured with significantly higher total Mg uptake (37.94) at HT stage. Similar trend was noticed at FF stage also.

With regarding to the overall mean performance of the treatments, higher total Mg uptake was noticed with higher water supplied treatment (I_3 : 18.15). In the case of fertilizer levels, the uptake increased with increased level of fertilizer application with higher value as evidenced with 125 % RDF + BF (F_3 : 17.20). The conventional treatment possessed moderate mean total mg uptake of 17.93 kg ha^{-1} .

4.6.1.6. Total iron (Fe) uptake (g ha^{-1})

In the case of total Fe uptake (**Table 58**), the mean values were found to be 0.484, 2.465, 3.056 and 3.359 g ha^{-1} at AT, PI, FF and HT stages respectively. Significantly superior performance was noticed with the drip fertigation scheduled at 150 % PE + 125 % RDF level (T_{10}) possessing increased total Fe uptake of 3.900 and 4.342 g ha^{-1} at FF and HT stages respectively. Similarly, the treatment in which drip fertigation was scheduled at 100 % PE + 75 % RDF + BF (T_2) showed statistically inferior uptake values at AT (0.296), PI (1.558), FF (2.034) and HT (2.200) stages.

Mean performance of the irrigation regimes indicated that the total Fe uptake values showed a linear increase from 100 % (I_1 : 1.797) to 150 % PE (I_3 : 2.682). Similar trend was noticed for the fertilizer levels with higher uptake observed for 125 % (F_3 : 2.524) RDF + BF. Mean performance of conventional practice was moderate at 2.757 g ha^{-1} .

4.6.1.7. Total manganese (Mn) uptake (g ha^{-1})

Statistical significance was achieved for the total Mn uptake at all stages of crop growth studied (**Table 59**). The mean values for the stages were 0.068, 0.410, 1.064 and

1.339 g ha⁻¹ at AT, PI, FF and HT stages respectively. Significantly higher uptake of 1.507 and 1.950 g ha⁻¹ were evident at FF and HT stages respectively for the treatment receiving the drip fertigation at 150 % PE + 125 % RDF + BF (T₁₀).

For the irrigation treatments, mean performance of total Mn uptake was favoured with higher values at higher irrigation regime (I₃: 0.881) than lower (I₁: 0.478) or moderate irrigation level (I₂: 0.739). Regarding the fertilizer levels, the mean uptake values were 0.572, 0.716 and 0.810 g ha⁻¹ for 75, 100 and 125 % RDF + BF respectively. For the conventional method of irrigation and fertilizer application, the mean uptake was found to be moderate (0.906).

4.6.1.8. Total zinc (Zn) uptake (g ha⁻¹)

Total uptake of Zn showed statistical significance at all growth stages studied (**Table 60**). For the stages, the mean values were 0.020, 0.098, 0.231 and 0.247 g ha⁻¹ at AT, PI, FF and HT stages respectively. Nevertheless, statistical superiority was vested with the treatment receiving drip fertigation at 150 % PE + 125 % RDF + BF (T₁₀) at both FF (0.307) and HT (0.330) stages. Least values of 0.151 and 0.164 g ha⁻¹ were registered by the drip fertigation at 100 % PE + 75 % RDF + BF (T₂) at FF and HT stages respectively.

The mean performance of total Zn uptake for water as well as fertilizer levels indicated that higher uptake value was noticed with 150 % PE water supply (I₃: 0.172) as well as at 125 % RDF + BF (F₃: 0.164). In the case of conventional irrigation and fertilizer practice, the mean total Zn uptake was 0.173 g ha⁻¹.

4.6.1.9. Total copper (Cu) uptake (g ha⁻¹)

Regarding the total Cu uptake (**Table 61**), the mean values for the stages ranged from 0.014 (AT) to 0.115 (HT). Statistical superiority was vested with the drip fertigation at 150 % PE + 125 % RDF + BF (T₁₀) at both FF (0.139) and HT (0.151) stages. Least values of 0.009, 0.038, 0.072 and 0.078 g ha⁻¹ were registered by T₂ at AT, PI, FF and HT stages respectively.

In the case of irrigation levels, overall mean performance was found to be superior with higher water regime (I₃: 0.081) than lower (I₁: 0.060) or moderate

(I₂: 0.073) level. In the case of fertilizer treatments, mean performance was phenomenal at 125 % RDF + BF (F₃: 0.083). The conventional practice registered a moderate mean value of total Cu uptake of 0.087 g ha⁻¹.

4.6.2. Rate of uptake of nutrients

4.6.2.1. Rate of nitrogen uptake (kg ha⁻¹day⁻¹)

The mean rate of N uptake ranged from 0.37 (FF-HT) to 3.40 (AT-PI) kg ha⁻¹ day⁻¹ (**Table 62**). The differences due to treatments attained statistical significance at all phenophases studied. Scheduling drip fertigation at 100 % PE + 100 % RDF + BF (T₆: 4.64) was found to be superior but was comparable with T₇ (4.59) during AT-PI phase.

With reference to the mean performance of irrigation regimes, the values increased with increased water supply possessing higher values with I₃ (2.20). Similar trend was observed for the mean values of fertilizer levels tried with increased values noticed for 125 % (F₃: 2.00) RDF + BF. The conventional method showed a moderate mean value of 2.12 kg ha⁻¹day⁻¹.

4.6.2.2. Rate of phosphorus uptake (kg ha⁻¹day⁻¹)

The mean values for the rate of P uptake (**Table 63**) in different phenophases were 0.438, 0.240 and 0.060 kg ha⁻¹day⁻¹ during AT-PI, PI-FF and FF-HT phases respectively. Significantly higher value was noticed with the drip fertigation treatment given at 125 % PE + 125 % RDF + BF (T₇: 0.573) but again on par with T₆ (0.541) during AT-PI phase.

Mean performance of the treatments indicated that with regard to the water levels, the values showed upward trend from lower (I₁: 0.164) to higher (I₃: 0.286) water supplying situations. For fertilizer levels, the mean value was higher with 125 % RDF + BF (F₃: 0.259). The mean value for the conventional treatment was 0.297 kg ha⁻¹day⁻¹.

4.6.2.3. Rate of potassium uptake (kg ha⁻¹day⁻¹)

Statistical significance was achieved for the rate of uptake of K (**Table 64**) for the chosen treatments at all phytophases studied. The mean value was higher during AT-PI phase (2.41) which declined thereafter during PI-FF (0.82) and also during FF-HT (0.33)

phase. An increased value of $3.12 \text{ kg ha}^{-1}\text{day}^{-1}$ was registered with the drip irrigation treatment given at 125 % PE + 100 % RDF + BF (T_6) which was significantly superior but comparable with T_7 (3.07) during AT-PI phase.

With regard to the mean performance, the mean values for the irrigation regimes were 0.86, 1.23 and $1.35 \text{ kg ha}^{-1}\text{day}^{-1}$ for I_1 , I_2 and I_3 respectively. The fertilizer levels also greatly influenced the rate of uptake for K with increased value (1.28) observed with 125 % RDF + BF (F_3). For the conventional practice, the mean value was higher at $1.53 \text{ kg ha}^{-1}\text{day}^{-1}$.

4.6.2.4. Rate of calcium uptake ($\text{kg ha}^{-1}\text{day}^{-1}$)

The mean values for the total calcium uptake (**Table 65**) was higher (0.360) during FF-HT phase followed by a decline at AT-PI (0.348) and PI-FF (0.268) phases. The treatment with drip fertigation given at 150 % PE + 125 % RDF + BF (T_{10} : 0.516) registered its statistical supremacy, but was on par with T_9 (0.506) during FF-HT phase.

Regarding the mean performance of water levels, the mean values showed an upward trend from 0.214 (I_1) to 0.390 (I_3). In the case of fertilizer levels, the mean values of rate of uptake of Ca were 0.275, 0.340 and $0.343 \text{ kg ha}^{-1}\text{day}^{-1}$ for F_1 , F_2 and F_3 respectively. The mean value for the conventional treatment was moderate (0.378).

4.6.2.5. Rate of magnesium uptake ($\text{kg ha}^{-1}\text{day}^{-1}$)

With regard to the rate uptake for Mg (**Table 66**), higher mean value was registered during PI-FF (0.446) followed by AT-PI (0.301) and FF-HT (0.250) phases. Significantly higher rate of uptake was evident with the drip fertigation treatment at 150 % PE + 125 % RDF + BF (T_{10} : 0.605) during PI-FF phase. Least value was, however, recorded by T_2 (0.163) and T_3 (0.167) during FF-HT phytophase.

From the mean performance of the chosen treatments, it could be inferred that the rate of uptake of Mg was higher with increased water supply treatment (I_3 : 0.383) than moderate (I_2 : 0.342) or lower (I_1 : 0.258) water supplying environment. For the fertilizer levels tried, the rate of uptake was more for 100 % (F_2 : 0.338) and 125 % (F_3 : 0.351) levels than 75 % (F_1 : 0.295) RDF + BF. The mean value was moderate (0.367) for the conventional practice.

4.6.2.6. Rate of iron uptake ($\text{g ha}^{-1}\text{day}^{-1}$)

In the case of rate uptake of Fe, the treatments showed statistical significance at all the phenophases studied (**Table 67**). For the stages, the mean uptake values were 79.27, 23.61 and 12.16 $\text{g ha}^{-1}\text{day}^{-1}$ during AT-PI, PI-FF and FF-HT phases respectively. Regarding the treatments, higher value of 94.44 $\text{g ha}^{-1}\text{day}^{-1}$ was observed with the treatments receiving drip fertigation at 125 % PE + 125 % RDF + BF (T_7) during AT-PI phase. Significantly least value (1.31) was registered by T_4 during FF-HT phase of the crop.

Through the mean performance, it is resolved that the rate of uptake of Fe was higher with higher water supply (I_3 : 44.61). Similarly, application of 125 % RDF + BF (F_3) showed enhanced mean value (40.09). A moderate mean value of 42.24 $\text{g ha}^{-1}\text{day}^{-1}$ was evident for the conventional method of water and fertilizer application.

4.6.2.7. Rate of manganese uptake ($\text{g ha}^{-1}\text{day}^{-1}$)

The differences due to treatments showed statistical significance for the rate uptake of Mn during all the three phenophases studied (**Table 68**). The values ranged from 11.01 (FF-HT) to 26.14 (PI-FF) $\text{g ha}^{-1}\text{day}^{-1}$. The drip fertigation practice given at 150 % PE + 125 % RDF + BF (T_{10}) was endowed with significantly higher value (39.65) during PI-FF stage with lower value (5.15) recorded by T_2 treatment during FF-HT phase.

It is deduced from the mean performance of the treatments that the lower mean value was registered with lower water supply (I_1 : 10.78) than medium (I_2 : 17.23) or higher water supply (I_3 : 21.35) situation. For fertilizer levels also, an increased value of 18.56 $\text{g ha}^{-1}\text{day}^{-1}$ was observed with higher fertilizer level of 125 % RDF + BF (F_3). The mean value was moderate (21.42) for the conventional practice.

4.6.2.8. Rate of zinc uptake ($\text{g ha}^{-1}\text{day}^{-1}$)

The rate of uptake of Zn attained statistical significance at all three phenophases studied (**Table 69**). The mean values were 3.12, 5.34 and 0.69 $\text{g ha}^{-1}\text{day}^{-1}$ during AT-PI, PI-FF and FF-HT stages respectively. Significantly inferior value of 0.13 $\text{g ha}^{-1}\text{day}^{-1}$ was evident with the treatment receiving drip fertigation at 100 % PE + 125 % RDF + BF (T_4) during FF-HT phase. Nevertheless, the treatment T_{10} (*i.e.*, drip fertigation at 150 % PE + 125 % RDF) proved its statistical supremacy with higher rate of uptake of Zn (7.70) during PI-FF phase of the crop.

In the case of mean performance of the chosen treatments, irrigation regimes greatly influenced the mean values with increased rate of Zn uptake of $3.57 \text{ g ha}^{-1}\text{day}^{-1}$ noticed with higher water supply (I_3). The mean values for the fertilizer treatments ranged from 2.61 (F_1) to 3.30 (F_3) $\text{g ha}^{-1}\text{day}^{-1}$. A mean value of $3.50 \text{ g ha}^{-1}\text{day}^{-1}$ was evident with the conventional method of irrigation and fertilizer application.

4.6.2.9. Rate of copper uptake ($\text{g ha}^{-1}\text{day}^{-1}$)

The mean values of rate of uptake of Cu (**Table 70**) showed higher mean value (2.07) during PI-FF phase with a decline at AT-PI (1.70) and FF-HT (0.30) phenophases. Statistical supremacy was shown by the drip fertigation treatment scheduled at 150 % PE + 125 % RDF + BF (T_{10}) possessing significantly higher value of $2.95 \text{ g ha}^{-1}\text{day}^{-1}$ during PI-FF phenophase.

In respect of the mean performance of the treatments, the mean values showed an increasing trend from I_1 (1.11) to I_3 (1.52). This was also true for the fertilizer levels with the mean values of 1.11, 1.37 and $1.52 \text{ g ha}^{-1}\text{day}^{-1}$ for 75, 100 and 125 % RDF + BF respectively. The mean value for the conventional treatment was $1.56 \text{ g ha}^{-1}\text{day}^{-1}$.

4.6.3. Nutrient use efficiencies

4.6.3.1. Nitrogen

The values for nitrogen use efficiency (NUE: %) was higher (**Table 71**) with the drip fertigation scheduled at 125 % PE + 100 % RDF + BF (T_6 : 51.57), which was followed by T_9 (21.40).

The agronomic NUE (kg N ha^{-1}) was also favoured with higher value (5.19) at T_6 followed by T_9 (2.28) (**Table 71**).

Mean performance of the irrigation and fertilizer treatments showed that the values of nutrient as well as AE for nitrogen was favoured with moderate level of water (I_2 : 17.21 and 2.12) and fertilizer (F_2 : 28.90 and 0.31) application.

4.6.3.2. Phosphorus

Similar to nitrogen, both nutrient (9.65 %) as well as agronomic use efficiencies (15.57 kg ha^{-1}) for phosphorus was enhanced (**Table 71**) with scheduling of drip fertigation at 125 % PE + 100 % RDF + BF (T_6).

Mean performance of irrigation and fertilizer levels showed that the values of nutrient and AE for P (kg ha^{-1}) were more pronounced with moderate levels of water (I_2 : 4.40 and 6.37) and fertilizer application rate (F_2 : 7.66 and 0.93).

4.6.3.3. Potassium

In the case of potassium (**Table 71**), the nutrient use efficiency (%) was favourable at drip fertigation treatment scheduled at 125 % PE + 100 % RDF + BF (T_6 : 57.57) followed by the treatment receiving drip fertigation at 100 % PE + 100 % RDF level (T_3 : 42.82).

The agronomic use efficiency (AE) for potassium (kg ha^{-1}) was similar to that of phosphorus nutrition (**Table 71**).

With regard to the mean performance, the nutrient efficiency for K was greatly influenced by the levels of irrigation as well as fertilizer application. In that, moderate levels of both water (I_2 : 13.35) and fertilizer (F_2 : 47.36) application were endowed with higher values nutrient efficiency for K. Nevertheless, the AE for K followed the trend similar to P.

4.7. Yield characters

4.7.1. Panicles m^{-2}

The panicle number m^{-2} as influenced by the treatments (**Table 72**) showed that the drip fertigation treatment at 125 % PE + 100 % RDF + BF (T_6) registered significantly higher panicles (407), while the least panicles (258) were produced with the drip fertigation scheduled at 100 % PE + 75 % RDF + BF (T_2).

Overall performance of the treatments showed that the higher panicle number was observed with 125 % PE (I_2 : 375) and 100 % RDF + BF (F_2 : 354). The conventional practice registered 351 panicles m^{-2} .

4.7.2. Panicle length (cm)

Differences due to treatments attained statistical significance for panicle length (**Table 72**) with increased length observed with the scheduling of drip fertigation at

150 % PE + 100 % RDF + BF (T₉: 25.5) but was on par with T₆ (25.3), T₁ (25.0), T₇ (25.0), T₁₀ (24.9) and T₈ (24.5).

For the irrigation regimes, lengthier panicles were produced at 150 % PE (I₃: 25.0) and at 100 % RDF + BF (F₂: 24.6). The conventional method showed the panicle length of 25.0 cm.

4.7.3. Number of spikelets ($10^3 \times m^{-2}$)

Increased number of spikelets were produced (**Table 72**) when drip fertigation was given at 125 % PE + 125 % RDF + BF (T₇: 34.06), which was comparable with the fertigation treatment scheduled at 125 % PE + 100 % RDF + BF (T₆: 33.86).

For the irrigation regimes, the spikelet production increased with 125% PE (I₂: 32.35) than 100 % (I₁: 28.07) or 150 % (I₃: 30.51) PE level. With regard to the fertilizer levels, the spikelet production increased from 75 % (F₁: 28.58) to 125 % (F₃: 31.55) RDF + BF; while, the conventional practice produced only 30.12×10^3 spikelets m^{-2} .

4.7.4. Number of grains ($10^3 \times m^{-2}$)

Number of grains produced per unit attained statistical significance (**Table 72**). Increased grain number (29.88) was evident with the drip fertigation scheduling of 125 % PE + 100 % RDF + BF (T₆), which was significantly superior to the rest of the treatments studied. Least grain production was observed with the treatment receiving 100 % PE + 75 % (T₂: 20.71) RDF level.

Overall mean performance of the treatments indicated that the grain production was found to be increased with 125 % PE (I₂: 27.47) followed by 150 % PE (I₃: 25.83) and 100 % PE (I₁: 22.25). For the fertilizer levels, similar trend was observed with higher value (26.43) noticed with 100 % RDF + BF (F₂). The mean value was found to be moderate (26.53) for the conventional practice of irrigation and fertilizer application.

4.7.5. Filled grain percentage

The differences due to treatments were significant for filled grain percentage (**Table 72**). Higher filled grain percentage was recorded with the drip fertigation scheduling at 125 % PE + 100 % RDF + BF (T₆: 88.25), which was comparable with T₁ (88.08), T₉ (87.07), T₈ (86.36) and T₅ (85.12).

For the irrigation regimes, mean filled grain percentage was higher with 125 % PE (I₂: 84.93) than 150 % (I₃: 84.71) or 100 % PE (I₁: 79.24) level. With regard to the fertilizer levels, 75 % RDF registered the lowest percentage (F₁: 82.83) followed by 100% (F₂: 85.63) and 125 % RDF + BF (F₃: 80.41). The conventional treatment possessed an increased filled grain percentage of 88.08.

4.7.6. Mean panicle weight (g)

Mean weight of the panicle showed statistical significance due to the treatments (**Table 72**). Increased panicle weight of 2.92 g was recorded with the drip fertigation treatment at 150 % PE + 125 % RDF + BF (T₁₀) level, but was comparable with T₁ (2.85) and T₉ (2.80).

In the case of mean performance of the irrigation treatments, an increased mean panicle weight was registered with higher water supply (I₃: 2.80) than moderate (I₂: 2.24) or lower (I₁: 2.22) moisture level. Regarding the fertilizers, the weight showed an increasing trend from 75 % (F₁: 2.27) to 125 % RDF + BF (F₃: 2.52) level. The conventional irrigation and fertilizer practice possessed an increased mean panicle weight of 2.85 g.

4.7.7. Panicle Harvest Index (PHI) (%)

The PHI showed statistical significance for the differences due to treatments (**Table 72**). Higher PHI (85.12) was evident with the drip fertigation treatment at 125 % PE + 100 % RDF + BF (T₆), which was also comparable with T₉ (84.28), T₇ (84.23), T₅ (84.02), T₁ (82.71) and T₈ (82.69).

Regarding the irrigation treatments, PHI showed an increasing trend from I₁ (75.31) to I₂ (84.46) with a decline at I₃ (82.44). For the fertilizer levels, similar trend was observed with higher PHI noticed with 125 % RDF + BF (F₂: 81.92). The conventional treatment of irrigation and fertilizer treatment recorded the PHI of 82.71 per cent.

4.7.8. 1000 grain weight (g)

The differences due to treatments were significant for this parameter (**Table 72**). Higher weight of 24.78 g the drip fertigation treatment at 125 % PE + 100 % RDF + BF (T₆), which was on par with T₁, T₅, T₇, T₈, T₉ and T₁₀.

In respect of the mean performance of the treatments, the weight had increased from I₁ (22.76) to I₃ (24.40). In the case of fertilizer levels, higher weight was registered by F₂ (24.06) than F₁ (23.66) or F₃ (23.74). The 1000 grain weight of the conventional practice was 24.55 g.

4.7.9. Straw yield (kg ha⁻¹)

The straw yield (**Table 72**) was significantly superior in the treatment receiving drip fertigation at 150 % PE + 125 % RDF + BF (T₁₀: 8325) to the rest of the treatments tried.

With reference to the irrigation regimes, straw yield was found to increase from drier (I₁: 6464) to wetter regime (I₃: 7589) with a slight deviation in moderate regime (I₂: 6401). Pertaining to the fertilizer levels, the straw yield increased with increase in fertilizer level from 75 % (F₁: 6127) to 125 % RDF + BF (F₃: 7409). The conventional practice registered a mean straw yield of 6543 kg ha⁻¹.

4.7.10. Grain yield (kg ha⁻¹)

The differences due to treatments for the grain yield were significant (**Table 72**). Significantly higher grain yield of 5643 was registered with the drip fertigation schedule at 125 % PE + 100 % RDF + BF (T₆) to the rest of the treatments tried. However, this was closely followed by the drip fertigation given at 150 % PE + 100 % RDF level (T₉: 5207).

Overall mean performance of the chosen treatments inferred that the grain yield showed a linear increase from I₁ (3786) to I₂ (5201) with a decline with I₃ (5030). With reference to the fertilizer levels, higher grain yield was evident at 100 % RDF (F₂: 4912) than 75 % (F₁: 4376) or 125 % (F₃: 4729) RDF + BF. The conventional method of irrigation and fertilizer application registered a grain yield of 4865 kg ha⁻¹.

4.7.11. Grain Harvest Index (HI) (%)

With regard to the grain HI, significantly superior value of 46.79 per cent was recorded (**Table 72**) with the drip fertigation schedule of 125 % PE + 100 % RDF + BF (T₆), which was comparable with the treatment schedule of 125 % PE + 75 % RDF + BF (T₅: 46.42).

In respect of the overall performance of the treatments, the HI value was higher with moderate moisture level (I_2 : 44.92) than drier (I_1 : 36.80) or wetter (I_3 : 39.76) moisture regime. In the case of fertilizer levels, less appreciable difference was observed between 75 % (F_1 : 41.21) and 100 % (F_2 : 41.35) with a sharp decline for 125 % (F_3 : 38.92) RDF + BF. The conventional practice of irrigation and fertilizer application recorded a moderate value of 42.64 per cent.

4.7.12. Nutrient Harvest Index (NHI) (%)

It is deduced (**Table 73**) that the chosen treatments significantly influenced the values of NHI calculated on the basis of nutrient contents in both grains and whole plant. The treatment T_7 (125 % PE + 125 % RDF+ BF) was favoured with higher harvest index for N (56.65), K (11.81) and Cu (37.67). Increased values of HI for Mg (71.43), Fe (51.55) and Zn (79.33) were vested with T_6 (125 % PE + 100 % RDF + BF). For P and Ca nutrients, the NHI values were higher in T_{10} (39.92) and T_5 (58.38) respectively. In the case of Mg-HI, T_{10} proved its supremacy with higher value (59.47).

Mean performance of irrigation and fertilizer levels indicated that the higher level of water supply (I_3) favoured increased values of HI for nutrients like N (56.49), P (39.14), K (11.59), Ca (56.24), Zn (74.20) and Cu (31.31); while, moderate level (I_2) could increase the NHI values for Mg (71.13) and Fe (45.50); but, higher Mn-HI was noticed with lower water supply (I_1 : 54.00). In the case of fertilizer levels, higher rate of application (F_3 : 125 % RDF + BF) was endowed with higher HI values for N, P, K, Mg, Fe and Cu. Moderate level of RDF + BF (F_2 : 100 %) was favourable for Mn and Zn and that of Ca for lower level of fertilizer rate (F_1 : 75 % RDF). The conventional practice of irrigation and fertilizer application was found to be moderate for the HI of almost all the nutrients.

4.8 Water use (mm) and Water productivity (g grains kg⁻¹ water)

Water used in different treatments was given in **Table 74**. The results indicated that the total water applied through drip system was 466, 537 and 608 mm for 100, 125 and 150 % PE level respectively. In the case of conventional method of irrigation (T_1), a total quantity of 511 mm of water was applied.

With regard to the water productivity (**Table 74**), higher water productivity of 1.051 grains kg⁻¹ water was obtained with the drip fertigation schedule of 125 % PE + 100 % RDF + BF (T₆). The conventional method of irrigation and fertilizer application registered a moderate water productivity of 0.952 grains kg⁻¹ water applied.

Nevertheless, the irrigation regimes greatly influenced the values of water productivity with higher share for moderate level of water supply (I₂: 0.969) than lower (I₁: 0.813) or higher (I₃: 0.827) water supply. With regard to the fertilizer levels, the values tended to increase from 75 % (F₁: 0.813) to 100 % (F₂: 0.914) with a decline at 125 % RDF + BF (F₃: 0.882) level. The mean water productivity for conventional practice was moderate (0.952).

4.9. Association among morpho-physiological, biochemical characters, plant water relations, nutrio-physiological and grain yield and its components in aerobic rice under drip fertigation treatments

4.9.1. Association of morpho-physiological characters under drip fertigation

The phenotypic correlation of chosen morpho-physiological characters with the grain yield (**Table 75**) indicated that the parameters such as PS II (0.944**), oxidizing power of roots (0.911**), tiller density (0.893**), CGR (0.866**), TDMA (0.799**), NAR (0.793**), LAD (0.788**), LAI (0.765**) and SLW (0.563**) possessed significantly higher and positive correlation with the grain yield. Loose correlation was established by RMD (0.396*) with the grain yield. Highest association (0.996**) was established between LAI x LAD. But, RLD showed significant negative relationship with the yield. However, root volume did not show any correlation with the economic yield.

4.9.2. Association of biochemical characters under drip fertigation

Among the biochemical parameters observed (**Table 76**), the traits such as TAC (0.966**), cytokinin content (0.964**), total chl (0.921**), chl a (0.913**), TFA (0.892**), NRase (0.859**), IAA oxidase (0.793**), chl a/b ratio (0.773**) and soluble protein (0.709**) established highly significant positive association with the grain yield. Significant negative association was shown for the grain yield by the characters such as reducing sugar (-0.857**), chl b (-0.606**), PO (-0.818**), SOD (-0.806**) and soluble nitrogen (-0.489**). Significantly highest and positive relationship was shown between PO x reducing sugar (0.984**) and cytokinins and TAC (0.968**).

4.9.3. Association of parameters of plant water relations under drip fertigation

For association of parameters related to plant water relation with the grain yield (**Table 77**), the RWC (0.926**), MSI (0.877**), LWP (0.870**), transpiration rate (0.826**) and CSI (0.814**) were the parameters showing significant positive association with the grain yield. But, the LDR (-0.748**), proline content (-0.641**), canopy temperature (-0.486**) and leaf temperature (-0.485**) exhibited significant negative relationship with the ultimate grain yield.

4.9.4. Association of uptake of nutrients grown under drip fertigation

The grain yield exhibited significant positive relationship (**Table 78**) with the uptake of all the nutrients studied with special reference to Ca (0.900**), P (0.899**), Fe (0.863**), N (0.851**), Mg (0.848**), Mn (0.817**), Zn (0.787**), K (0.762**) and Cu (0.662**). Nevertheless, interactive uptake of Mn x Zn (0.991**) showed the highest significant positive correlation with the yield.

4.9.5. Association of nutrient harvest index under drip fertigation

The phenotypic correlation analysis of the nutrient harvest index with the grain yield (**Table 79**) indicated that the nutrients like K (0.934**), P (0.914**), N (0.880**), Zn 0.835**), Cu (0.711**), Fe (0.666**), Ca (0.645**), and Mg (0.469**) showed higher degree of positive association. However, the Mn-HI did not attain statistical significance with the grain yield.

4.9.6. Association of yield components under drip fertigation

The grain yield grown under drip fertigation practice was significantly and positively correlated (**Table 80**) with all the yield attributes such as number of panicles per unit area (0.997**), grain number per unit area (0.946**), panicle HI (0.873**), panicle length (0.914**), 1000 grain weight (0.849**) spikelet number per unit area (0.841**), TDMA (0.799**), HI (0.747**) and filled grain percentage (0.729**) and mean panicle weight (0.484**).

4.10. Path analysis

Path analysis was made for the evaluation of relative contribution of each character for both direct and indirect effects to the grain yield.

4.10.1. Direct and indirect effects of morpho-physiological characters on grain yield under drip fertigation

For the morpho-physiological characters (**Table 81**), the traits such as CGR (1.448**) and PS II (0.999**) followed by TDMA (0.805*) possessed significant positive direct effect on the grain yield. The character of NAR (-1.663**) showed significant negative direct effect. Indirect effects of the characters such as PS II, TDMA and oxidizing power of roots towards the grain yield were higher through CGR.

The trend in the genotypic correlation among yield and its attributes revealed that except the characters like root volume, root mass density and specific leaf weight, rest of the traits showed significant and positive relationship with the economic yield.

4.10.2. Direct and indirect effects of nutrient uptake on grain yield under drip fertigation

For the uptake of nutrients (**Table 82**), elements such as Fe (7.226**), K (2.311**), and Ca (1.126**) showed highest positive direct effects on the grain yield. Nevertheless, nutrients like Mn (-3.975**), Mg (-1.664**), Zn (-1.644**), Cu (-0.887**), P (-0.856**) and N (-0.804*) exhibited significant negative direct effects. Indirect positive effects of the nutrients such as K and Ca towards grain yield were high through Fe uptake.

The grain yield possessed significant genotypic correlation with all the chosen nutrient elements.

4.10.3. Direct and indirect effects of yield components on grain yield under drip fertigation

For the grain yield under drip fertigation (**Table 83**), the number of grains (1.275**) and TDMA (0.680*) exerted significant positive direct effects on the grain yield. Number of spikelets per unit area (-0.928**) showed significant negative direct effects. However, the indirect effects of TDMA, HI, panicle length and 1000 grain weight were comparatively higher towards the grain yield through number of grains per unit area.

With regard to the genotypic correlation, excepting the mean panicle weight, all the chosen yield attributes were significantly associated with the grain yield.

4.11. Economics of cultivation

Economics of aerobic rice cultivation for different treatments (**Table 84**) indicated that higher cost of cultivation (Rs. 20,800) was registered by T₄, T₇ and T₁₀ treatments. With regard to the gross and net return, increased amount of Rs. 45,144 and Rs. 27,179 were recorded with T₆ treatment respectively. Net income per unit of rupee invested (Benefit : Cost ratio) was higher with T₆ (2.41) which was closely followed by T₁ (2.39).

4.12. Crop Simulation Modelling

4.12.1. Model validation

Simulated grain yield of the chosen treatments are furnished in **Table 85** along with the observed grain yield.

Table 85. Validation of grain yield (kg ha⁻¹) simulated by ORYZA2000 model in two chosen treatments

Treatment	Field Observed Yield	Model Simulated Yield
Conventional (T ₁)	4865	↓4798 (1.38 %)
Drip fertigation (T ₆)	5643	↓5631 (0.21%)

Note: Figures in parentheses indicate % deviation from the observed yield estimates. Down arrow (↓) indicates underestimation. An estimate of less than 25 % represents good approximation of the reported yield (Srivastava *et al.*, 2004).

The results (**Table 85**) indicated that there was a fair agreement between simulated and observed grain yields for both the treatments. Therefore, further simulation runs, described in the following paragraphs, were made for future climate change scenarios, based on the results of model validation.

4.12.2. Scenario Analysis: Elevated CO₂ and Temperature

Anthropogenic influences such as rapid industrialization, urbanization, combustion of fossil fuels, mining, deforestation, etc. have released enormous quantities of carbon dioxide (CO₂), methane (CH₄) and other “green house” gases into the atmosphere. This may have serious implications that lead to global warming with the consequent rise in earth’s temperature to the tune of 1° to 4° C. As a result of global

warming, the rise in temperature can have significant impacts on agricultural production systems that are so intricately associated with the weather system causing imbalance in food supply. Hence, it is imperative to study the effects of climate change on the yield of staple food crops such as rice. The following paragraphs aim at understanding the impacts of future climates on the rice production especially in relation to the drip fertigation in aerobic rice.

Estimates were made to quantify the effect of temperature and CO₂ rise on the yield of rice grown in the DS of Coimbatore site. Different climate change scenarios (Matthews *et al.*, 1995) resulting from changes in temperature and atmospheric CO₂ concentrations were evaluated with ORYZA2000 model for their impacts on aerobic rice cultivation under drip fertigation micro irrigation system. The simulation analysis was done using the daily weather data of Coimbatore Observatory. The dates of sowing were selected as adopted in the field experiments during DS (2007).

The details of different scenarios employed in the present simulation study are as furnished below.

Scenarios used for future climate change:

1. Current CO₂ and temperature + conventional method
2. Current CO₂ and temperature + drip fertigation system
3. Current CO₂ + conventional method at +1, +2, +3 and +4 °C
4. Current CO₂ + drip fertigation system at +1, +2, +3 and +4 °C
5. x 1.5 CO₂ + conventional method at +1, +2, +3 and +4 °C
6. x 1.5 CO₂ + drip fertigation system at +1, +2, +3 and +4 °C
7. x 2 CO₂ + conventional method at +1, +2, +3 and +4 °C
8. x 2 CO₂ + drip fertigation system at +1, +2, +3 and +4 °C.

With regard to the effect of incremental levels of CO₂, the increase in grain yield with 540 and 720 vppm was 12.2 and 18.6 per cent respectively for conventional practice; similarly, the yield increase was 12.5 and 22.6 per cent respectively for the drip fertigation system in comparison with the current CO₂ level in the atmosphere (**Table 86**).

Table 86. Simulated changes in grain yield in two different irrigation systems under varied CO₂ scenarios

Treatment	CO ₂ level				
	360 vppm	540 vppm		720 vppm	
	Grain yield (kg ha ⁻¹)	Grain yield (kg ha ⁻¹)	Change (%) over 360 vppm	Grain yield (kg ha ⁻¹)	Change (%) over 360 vppm
Conventional	4692	5264	+ 12.2	5564	+ 18.6
Drip fertigation	5631	6337	+ 12.5	6905	+ 22.6

Increasing the temperature decreased the grain yield in both the systems of irrigation (**Table 87**). But, the detrimental effect of temperature was more drastic in drip fertigation than the conventional practice. For instance, the reduction in grain yield of conventional method at +3 and +4 °C of temperature increase was only -2.57 and -6.39 per cent respectively; however, for the same temperature increase, the reduction was -6.97 and -13.71 per cent respectively in the case of drip fertigation system.

Table 87. Yield changes (%) predicted for two irrigation treatments under fixed temperature increments

Irrigation system	+0°C	+1°C	+2 °C	+3°C	+4°C
Conventional	0	-1.06	-1.27	-2.57	-6.39
Drip fertigation	0	-1.94	-3.43	-6.97	-13.71

The results of the interactive effects of incremental levels of CO₂ and temperature are presented in the **Table 88**.

Table 88. Yield changes (kg ha⁻¹) predicted for two irrigation treatments in varied scenarios of CO₂ and temperature increments

CO ₂ level (vppm)	Conventional					Drip fertigation				
	+0°C	+1°C	+2 °C	+3°C	+4°C	+0°C	+1°C	+2 °C	+3°C	+4°C
360	4798	4763	4751	4680	4470	5631	5486	5450	5243	4828
540	5384	5325	5314	5248	5051	6683	6562	6453	6216	5770
720	5696	5622	5612	5544	5345	7276	7161	7016	6765	6307

There was a general increase in the grain yield with increment in CO₂ level at all levels of temperature increment. Between the irrigation systems, the drip fertigation

practice had an edge over the conventional method. It was also inferred that the temperature-induced yield reduction especially at and beyond +3 °C range could be safely moderated with the elevated level of CO₂ in both the irrigation systems.

CHAPTER V

DISCUSSION

Rice (*Oryza sativa* L.) production is one of the major users of fresh water in Asia (IRRI, 2002). There is an increasing demand for water-saving agriculture, as fresh water resources are now declining. Competition for this water is also increasing for the industrial and agriculture sector (Hayashi *et al.*, 2006; Kamoshita *et al.*, 2007). Therefore, there is a need to grow “more crop per drop”, while avoiding substantial decrease in crop productivity.

Water in irrigated rice production has been taken for granted for centuries, but the ‘looming water crisis’ may change the way by which rice is produced in the future. Water-saving irrigation technologies investigated in early 1970s, such as Saturated Soil Culture (SSC) and Alternate Wetting and Drying (AWD) are receiving renewed attention from the researchers. Nevertheless, these technologies reduce the water input mostly at the expense of significant yield loss. Therefore, it is imperative to develop a head way of growing rice that requires less water while maintaining higher yields.

Aerobic rice is emerging as an alternate system of growing the crop in non-puddled aerobic soils to save water (Bouman *et al.*, 2002) and reducing the methane emissions otherwise produced by the flooded rice fields (Tuong *et al.*, 2005). For making aerobic rice successful, newer production technologies must be developed besides making research efforts for developing newer varieties suited to the aerobic environment.

With this background, the present investigation was designed with three levels in each of irrigation (100, 125 and 150 % PE) and fertilizer levels (75, 100 and 125 % RDF *plus* biofertilization) given through drip fertigation system and compared with the conventional method of irrigation and fertilizer practice. The study was aimed to bring out the morpho-physiological, biochemical and molecular mechanisms in the aerobic-grown rice plants.

In this chapter, an attempt has been made to delineate the factors responsible for the varied yield responses due to drip fertigation treatments for enabling to develop

proper crop management strategies in the case of drip fertigation system aimed to enhance the productivity of aerobic rice. The results obtained are discussed in the following pages with the sufficient support from earlier studies.

5.1. Altered morphological attributes as influenced by drip fertigation treatments

Plant height is a direct index to assess the growth and vigour of the plant. In general, plant was found to increase in height with the age of the crop. The incremental growth in terms of plant height was higher between AT and PI stage; while, it was the least from FF to HT stage irrespective of the treatments studied. The plant height was greatly influenced by the drip fertigation treatments. Regarding the drip fertigation treatments, the values increased with increased supply of water. Taller plants were observed with 150 % PE level (111.4), which was 26.4 and 8.4 per cent increase than the 100 (88.1) and 125 % (102.8) PE levels respectively at HT stage. Nevertheless, the plants of the conventional method of irrigation were much taller (125.9) at HT stage (**Fig. 3**). Moderate plant height as observed with 125 % PE level might be due to the fact that these plants had more root growth by diverting the assimilates for its growth with comparatively lesser share of assimilates available for shoot growth (Sangsu *et al.*, 1999). Severity of the plant height at lower water supply is in corroboration with the findings of Russo (2000).

Tomar and Prasad (1996) also postulated that plant height in rice was often associated with the development of thick and deep root system. These observations were confirmed in the present investigations also especially for the drip fertigation treatments.

With regard to the fertilizer levels, plant height was found to be increasing with increase in the supply of fertilizer. This is in conformity with the findings of Sugandhi *et al.* (2003).

Thus, the beneficial effect of drip fertigation might have been vested with the more number of functional leaves and leaf area and increased number of tillers and rate of photosynthesis which ultimately led to taller plants (Shrirame *et al.*, 2000).

Knowledge about the root system of a crop is a prerequisite for understanding many problems connected with the crop production. Root characters such as length and distribution and especially root volume help in divulging the pattern of water use and

nutrient uptake by the crop. In general, the root characters such as root length, volume and its dry weight showed a gradual increase upto flowering with a decline thereafter due to root degeneration.

In the case of irrigation regimes, 100 % PE increased **total root length** (6.8 and 7.9 %), **root volume** (2.1 and 30.9 %) in comparison with the 125 and 150 % PE levels of irrigation at FF stage. Thus, most of the root characters were more pronounced in the drier moisture regime (**Fig. 4 and 5 for total root length and root volume respectively**). Such deeper root system might play an important role not only for continuous water uptake under limited water supply situations (Lilley and Fukai, 1994; Kobata *et al.*, 1996), but also for nutrient uptake under suboptimal water availability.

With regard to the N application, the root characters such as total root length and root volume tend to increase with increasing N levels in the present investigation. This is in corroboration with the findings of Dhurandher and Tripathi (1999). As proposed by Kato *et al.* (2006), it is suggested the plant characteristics such as deep root system and the ability to maintain larger amounts of N uptake are considered as advantageous prepositions for developing elite cultivars for water-saving aerobic rice agriculture.

Rai and Murty (1977) further reiterated that restricted lignin formation resulted in poor root growth under flooded irrigation situation mainly because of reduced activities of peroxidase (PO) and catalase (CAT) enzymes. This is in corroboration with the present investigation especially for the 125 and 150 % PE level of drip irrigation. With regard to the fertilizer levels, higher rate of fertilizer application favoured the root characters, which is in accordance with the findings of Dhurandher and Tripathi (1999).

It is often established that **root / shoot ratio** (R/S ratio) increased under moisture stress conditions (Yoshida, 1981). Similar indication was observed in the present study also. Vijayalakshmi and Nagarajan (1994) further observed that under water deficit conditions, the drought tolerant genotypes produced slender and longer roots to absorb more moisture from the deeper soil layers. This is in corroboration with the present investigation especially in the case of drip fertigation practice. For fertilizer levels, the values of R/S ratio increased with increase in the level of fertilizer application.

Surprisingly, the layer-wise analysis of mean Root Length Density (RLD) and Root Mass Density (RMD) observed at FF stage in different irrigation regimes (**Table 89**) indicated that the roots of 100 % and 150 % PE levels, experiencing deficit and excess water stress respectively, showed proliferation of root at the top 0-10 cm soil layer. But for the moderate (125 % PE) moisture regimes, fair degree of root distribution was noticed in all the three soil layers in terms of both RLD and RMD. Uyprasert *et al.* (2004) also observed higher RMD of rice root located at 0-15 cm depth for the rainfed lowland rice cultivars.

Table 89. Mean distribution of Root Length Density (RLD: cm cm⁻³) and Root Mass Density (mg cm⁻³) in different soil layers as influenced by irrigation and fertilizer levels at flowering stage

Treatment	Root Length Density (cm cm ⁻³)			Root Mass Density (mg cm ⁻³)		
	0-10 cm	10-20 cm	20-30 cm	0-10 cm	10-20 cm	20-30 cm
Irrigation regime						
100 % PE	3.714	1.657	1.015	1.730	0.997	0.472
125 % PE	2.157	1.511	1.139	2.414	1.354	0.617
150 % PE	1.906	1.273	0.867	1.515	0.750	0.414
Fertilizer level						
75 % RDF	3.050	1.449	1.159	1.686	0.850	0.457
100 % RDF	2.786	1.373	0.896	2.164	1.058	0.496
125 % RDF	2.660	1.195	0.719	1.618	0.838	0.446
Conventional practice	2.088	1.485	1.036	1.739	0.976	0.454

Thus, the favoured root characters as observed with the drip fertigation treatments was mainly due to the proliferation of root at top soil layer as opined by Vijayalakshmi and Nagarajan (1994). As a result, the plants of 100 and 125 % PE maintained favourable water balance through out the crop growth period due to better moisture extraction from all the three layers. This was further supplemented with the use of moderate level of fertilizers at 75 and 100 % RDF + BF levels.

With regard to the parameters of vertical root distribution such as root length depth index (RLDI) and root mass depth index (RMDI) observed at FF stage, the roots were deeper with lower and moderate water supplying situations of 100 and 125 % PE levels of drip irrigation than at 150 % PE as well as conventional irrigation practice. Similar trend was observed in the case of fertilizer levels. The values of RLDI and RMDI were greater for 75 and 100 % RDF + BF levels in comparison with 125 % RDF + BF and conventional method of fertilizer application (**Fig. 6**). Thus, the increased values of RLDI and RMDI helped the plants grown with moderate levels of water and fertilizer to extract more water and nutrients from the deeper soil layers. This is in corroboration with the findings of Kato *et al.* (2006) suggesting that deeper root length and canopy size governed water relations of rice grown in upland situations.

Occurrence of abnormal roots

Under unfavourable situations, occurrence of abnormal roots (**Plate 7**) such as “lion tail” (Ota, 1970) is often noticed. In the present investigation, excess soil N supply as well as deficit and excess water supplying conditions were often associated with the formation of such “lion tail roots” as observed at FF stage (**Fig. 7**). In the opinion of Ota (1970), the toxic substances such as hydrogen sulphide as noticed under the unfavourable soil conditions might have caused the roots that emerged from the pericycle to grow into its own cortical tissue to make them abnormal. He further observed that such abnormal roots were inefficient in the absorption of water and nutrients.

Nevertheless, the conventional irrigation and fertilizer practice was pushed to an unfavourable situation for all the chosen root characters.

Tiller density showed a general reduction with lower water supply (100 % PE) and the values being 23.3 and 25.1 per cent in comparison with 125 and 150 % PE levels respectively at FF stage (**Fig. 8**). Similar reduction in tiller production due to water stress was observed by Cruz *et al.* (1986) and Gowri (2005). However, it could also be negated with the proper rate of fertilizer application indicating that the tiller density increased with the increase in N supply. This is in accordance with the findings of Krishnakumar (1986) showing an increased tiller production with N supply, which might be due to the increased protein content due to N application leading to the production of more lateral buds thus favouring more tillers.

Summing up, drip fertigation scheduled at 125 % PE + 100 % RDF (T₆) was found to be superior for majority of the morphological attributes studied.

5.2. Modified growth components as influenced by drip fertigation treatments

Leaf area index (LAI), an important source in manufacturing photoassimilates for determining dry matter accumulation and crop yield, was reduced with decrease in water supply. Such reduction was found to be phenomenal in the 100 % PE level (-18.9 and -22.9 % in comparison with 125 and 150 % PE levels respectively) at FF stage (**Fig. 9**). The reason for such reduction in leaf area under moisture stress was due to rapid decline in leaf elongation and greater leaf death (Lilley and Fukai, 1994; Fukai and Cooper, 1995). Further, Bunce (1977) also observed a linear relationship between elongation rate and turgidity of stressed leaves. The range of LAI observed at FF stage with 125 (4.35) and 150 % (4.58) PE level was well within the optimum LAI range of 4-6 for maximizing productivity in rice as opined by Yoshida (1981).

With regard to the fertilizer levels, the values of LAI increased with increase in the fertilizer levels. Decrease in the level of LAI with lower level of fertilizers might be due to the insufficient level of nucleic acids owing to lesser N availability for the cell division. This is in accordance with the earlier findings (Zhao *et al.*, 2005). Belder *et al.* (2005) further reasoned out that the increase in LAI due to increased N supply might also be ascribed to the N-induced enhancement of leaf area. Nevertheless, the grain yield increased linearly with increasing LAI till an optimal value, above which the yield decreased (as seen with drip fertigation at 150 % PE and 125 % RDF + BF), which is consistent with the previous study (Jing *et al.*, 2007).

Thus, early attainment of an optimum LAI is often considered to be very essential for better productivity in rice (Yoshida, 1981). In the present investigation, the plants maintained optimum LAI at all growth stages with special reference to the biofertigation treatments. There was also evidence to show that the existence of optimum LAI particularly at reproductive phase had a specific role in deciding dry matter accumulation and grain yield of rice (Rajkumar, 2001).

Drastic reduction in the values of **Individual Leaf Size (ILS)** observed in the present study with lower water supplying treatments indicated that plant water status was

sub-optimal in them (Cabuslay *et al.*, 2002; Tao *et al.*, 2006). Similarly, the fertigation stress also resulted in decline in ILS values.

Additionally, the *Methylobacterium* mediated hormonal activity (Soumya, 2005; Thangamani, 2005), used in *Azophosmet* composite culture, might be attributable for the optimum leaf area and other growth parameters.

The present finding of reduction in **leaf area duration (LAD)** due to insufficient water supply (100 % PE) corroborated with the findings of Gowri (2005) in aerobic rice. Comparing the 100 % PE level, the effect was phenomenal between FF-GF phase with increased longevity of 28.7 and 35.5 per cent in the case of well watered situation of drip irrigation scheduled at 125 and 150 % PE level respectively. Towards this, the role of biofertigation was also noteworthy in enhancing the values of LAD favourably.

In the present investigation, the **specific leaf weight (SLW)** or leaf weight per unit leaf area was found to be more in the drip irrigated plants at 150 % PE level than that of the 100 or 125 % PE level. This indicated that greater amount of assimilates were partitioned to the leaf area in the former case, thus registering higher SLW values (Uprety and Sirohi, 1985). Reports are also available stating that the SLW, photosynthetic rate, grain yield and quality were significantly different under different irrigation methods (Borell *et al.*, 1997; Lin *et al.*, 2005).

Optimum level of fertilizers (100 % RDF + BF) increased the values for SLW especially at FF stage. Positive association of SLW with photosynthetic rate was also reported by Pearce *et al.* (1969). Similar fair agreement was established in the present investigation also.

Crop growth rate (CGR), a measure of dry matter accumulation per unit leaf area per unit time, was found to be fairly higher between PI-FF stages with a decline towards maturity. Under limited water supply environment (100 % PE), the reduction in CGR was evident to the tune of 37.3 per cent in comparison with 150 % PE level during PI-FF stage. This could be due to the inhibition of physiological activities under the treatment as viewed by Zhang *et al.* (1997). Comparing the fertilizer treatment of 75 % RDF + BF level, increase in the CGR values were 13.7 and 23.6 per cent with 100 and 125 % RDF + BF levels respectively during the above phenophase.

Similar trend of increased values of **net assimilation rate (NAR)**, a measure to express the rate at which the dry matter is accumulated, was also evident especially for varied drip fertigation treatments. Reduction in the values of NAR under deficit water supply is in conformity with the findings of Williams and Snapter (1955) reporting reduction in NAR under deficit moisture situation. Nevertheless, the reduction in NAR was found to be mitigated with higher levels of fertigation (100 and 125 % RDF + BF).

Maintenance of higher **total dry matter accumulation (TDMA)** indicated the increased photosynthetic efficiency of the plants. In the present investigation, reduction in TDMA was evident at harvest under stressed situation of 100 % PE level of drip irrigation, the reduction being 15.7 and 25.0 per cent in comparison with the higher water supply at 125 and 150 % PE levels respectively (**Fig. 10**). Simane *et al.* (1993) and Yang *et al.* (1995a) also observed similar findings of higher reduction in TDMA in the case of drought susceptible rice varieties mainly due to accelerated leaf senescence.

Similar trend was observed for the fertilizer levels tried. Obviously, the TDMA increased with fertilizer levels as reported by Venkitaswamy (1986) and Rajeswari (1990) in rice.

The increase in plant growth parameters due to the biofertigation with *Azophosmet* might be possible due to increased availability of nitrogen by nitrogen fixing *Azospirillum* and facultative methylotrophs (Nayak *et al.*, 1986; Sy *et al.*, 2001) besides the synergistic effect of biosynthesis of plant growth promoting substances like cytokinins, indole acetic acid and gibberellic acid, vitamins and antibiotic substances by the microbial inoculants (Mishra and Bhattacharyya, 1994).

Close observation of the data on **light interception percentage (LIP)** especially at FF stage indicated that the stressed plants of 100 % PE level had lesser ground coverage as compared to the non-stressed plants of 125 and 150 % PE levels thus leading to lesser LIP values in the deficit water supply situation. Similar results were obtained by Bouman *et al.* (2006) who observed that the amount of intercepted light decreased with increasing dryness of the soil for the aerobic rice varieties.

Similar view was expressed by Yoshida (1972) and Monteith (1981). The reduction in LIP could be negated with the biofertigation leading to higher leaf area

development coupled with higher ground area coverage. This indirectly indicated better harnessing of solar energy by the plants grown especially under drip fertigated scenario. This was further supported by the data on **light extinction co-efficient ('k')**. Thus, the higher LIP often associated with low light extinction co-efficient contributed to the increase in the biomass and grain production under drip fertigation treatments.

In summary, scheduling of drip fertigation at 125 % PE + 100 % RDF + BF (T₆) performed better for most of the growth parameters selected.

5.3. Changed physiological and biochemical aspects as influenced by drip fertigation treatments

The adaptive behaviour of rice varieties under drip fertigation scenario in aerobic environment is discussed hereunder through various physiological and biochemical aspects.

Chlorophyll pigments play vital role in crop productivity, since these pigments are highly responsible for photosynthesis in plants. The contents of **chlorophyll 'a' and total** generally declined with decrease in moisture availability. The reduction in total chlorophyll content was phenomenal with the drip irrigation scheduled at 100 % PE level and the decrease was 24.3 and 23.6 per cent in comparison with 125 and 150 % PE level at FF stage respectively (**Fig. 11**). Similar reduction in chlorophyll content of rice was observed under water stress by several workers (Deka and Baruah, 2000; Meghanatha Reddy *et al.*, 2007). As opined by Garica *et al.* (1987), the reduction in chlorophyll content under water stress might be due to enhanced activity of chlorophyllase enzyme which was sensitive to water deficit and highly deleterious to crop productivity. Close analysis of the data revealed that the decline in total chlorophyll content was due to drastic reduction in chlorophyll 'a' content at 100 % PE level. Surprisingly, the content of chlorophyll 'b' was found to be increasing especially under water deficit situations (as in 100 % PE). The increase in chlorophyll 'b' fraction was to the tune of 15.8 and 16.0 per cent for 100 % PE as compared to 125 and 150 % PE level of water availability. This was also reflected in the lowered **chlorophyll a / b ratio (chl a/b ratio)** in the water-stressed 100 % PE level especially at FF stage.

The chlorophyll 'b' is considered to be the primary light harvesting pigment for photosystem II and hence largely responsible for the oxidation of cytochrome and water

(Boardman and Anderson, 1964). Besides, it enlarges photosystem II for better harnessing of the entire machinery (Phrosene and Karlander, 1973) and thus plays a dominant role under water stress situations in higher production of assimilatory powers (such as ATP, NADPH₂ etc.) which are required for survival of plants under stress (Pieters and El Souki, 2005). Thus, the increase in chlorophyll 'b' content under water stress might gear the metabolic systems for efficient functioning for fixing more CO₂ to the extent possible.

Nevertheless, enhancement of chlorophyll content ('a', 'b' and total) was often observed with the increased level of fertilizers. This might be due to the enhanced chlorophyll synthesis with the N supply as it is the major constituent of chlorophyll (Stevens *et al.*, 2001). Towards this, biofertilization was quite encouraging with increased values of chlorophyll content more prominently in 125 and 150 % PE levels. Similar results were obtained in ADTRH 1 hybrid rice by Thangamani (2005) with increased content of chlorophyll due to the inoculation of PPFM.

The **SPAD readings** generally followed the similar trend as that of the chlorophyll pigment. Reduction in SPAD values was often observed with decreased water availability as observed by Maibangsa (1998) and Gowri (2005). Such reduction in leaf SPAD value under stress might be attributed to the inhibition of ethylene synthesis (Leslie and Romani (1988). For this parameter also, significant positive role of biofertilization with optimum level of fertilizers was evident. In the present investigation, N supply positively influenced the SPAD readings. This was supported by Mahendar Kumar *et al.* (2001) reporting that N fertilization influenced the SPAD readings.

Chlorophyll fluorescence (Fv / Fm ratio) indicates the photosynthetic efficiency of plants and it is a valuable indicator of water stress (Meghanatha Reddy *et al.*, 2007). For **PS II efficiency** (Fv / Fm ratio), the drip irrigation scheduled at 100 % PE level often caused reduction in the ratio irrespective of the biofertilization levels. Such decline in Fv / Fm ratio might be due to photoinhibition causing damage to the portions of PS II (Cao and Govindjee, 1990) combined with increase in energy dissipation in the chlorophyll pigment antennae system (Adams and Adams, 1996), the process often observed in the plants under water stress environment. Meghanatha Reddy *et al.* (2007) further reiterated

that decreased values of F_v / F_m could also be due to the partial breakdown of the photosynthetic apparatus under water stress. Biofertilization treatments proved their supremacy in enhancing the values of F_v / F_m especially at FF stage (**Fig. 12**).

RUBISCO, a prime carboxylating enzyme for carbon fixation in photosynthesis (Noggle and Fritz, 1986), consists of more than 50 per cent of **soluble protein** in the leaves. The capacity of protein synthesis decreases considerably in response to water stress. Martignone *et al.* (1987) elucidated that soluble protein content was the first nitrogenous compound lost during water deficit conditions. Similar situation was observed when drip irrigation was scheduled at 100 % PE level. The reduction in the level of soluble protein content due to reduced water availability was 12.7 and 19.5 per cent at FF stage. Deka and Baruah (2000) and Meghanatha Reddy *et al.* (2007) also observed similar sensitivity of rice cultivars for reduction in soluble protein content under water stress. This reduction in soluble protein content was attributable to the down regulation of PS II activity under water stress resulting in an imbalance between the generation and utilization of electron apparently, which caused changes in the quantum yield. These changes in the photochemistry of chloroplasts of the water stressed leaves could generate active oxygen species (AOS), which were potentially dangerous to the plants under water deficit situations (Peltzer *et al.*, 2002). These AOS also initiated degradation of RUBISCO (Ishida *et al.*, 1998; Meghanatha Reddy *et al.*, 2007). Possible other reason for reduced content of soluble protein under water stress might be due to decreased synthesis of RUBISCO *per se* by a rapid decrease in the abundance of smaller units of RUBISCO (Vu *et al.*, 1999) and due to the reduced activity supplemented by the accumulation of tight-binding inhibitors within the catalytic sites of the enzyme under water deficit conditions (Parry *et al.*, 1993).

In the present study, it is evident that the increased N supply increased the soluble protein content. This is in accordance with the findings of Martignone *et al.* (1987), which might be ascribed to enhanced chlorophyll synthesis under higher N supply forming a major part of soluble protein.

Biofertilization with *Azophosmet* enhanced the content of soluble protein at all the stages of growth. Madhaiyan *et al.* (2005) further reiterated that the inoculation of

Methylobacterium sp. (PPFM) increased the photosynthetic activity in sugarcane by enhancing the number of stomata and contents of chlorophyll and malic acid.

Contents of **soluble nitrogen** were enhanced under low water supplied treatments. Such higher fraction of soluble nitrogen under the given water stress situation might impair normal fertilization and grain setting (Sahu and Murty, 1976) resulting in increased spikelet sterility under the stressed environment. Nevertheless, optimum fertigation treatment comparatively reduced the content of soluble nitrogen.

Carbohydrates are the photosynthetic products in the green plants and the ability of plants to accumulate carbohydrates with its partitioning into economically useful parts often determine the yielding ability of the crop. In the present investigation, an increased accumulation of **reducing sugars** was noticed with the drip irrigation scheduled at 100 % PE level. Especially during GF stage, the per cent increase in the accumulation of reducing sugars for 100 % PE was 49.5 and 34.4 in comparison with 125 and 150 % PE level of drip irrigation respectively. Similar results were obtained by Wang *et al.* (1996) and Jha and Singh (1997). It was further reported that more accumulation of reducing sugars in the less favourable environment, as in 100 % PE level, might be an indication that translocation of assimilates was disrupted to a greater extent in the lesser moisture supplying situation. This was also supported by the reports of Weng *et al.* (1982) and Arrandea (1989). In accordance with these findings, lesser contents of reducing sugars, as observed with the drip irrigation given at 125 % PE level, could have helped these plants for enhancing the assimilate transport to the 'sinks' thus improving the yield potential in such optimum moisture supply situation. Regarding the biofertigation treatments, both 100 and 125 % RDF + BF levels were found to be beneficial than 75 % RDF + BF level in reducing the content of reducing sugar.

Influence of drip fertigation treatment was more marked for the content of **total available carbohydrate** especially at FF stage (**Fig. 13**). Similar findings were observed by Yamada *et al.* (1957). Comparatively higher degree of spikelet sterility as observed in the present study for the drip irrigation given at 100 % PE level was found to be mostly a post-fertilization problem leading to the higher proportions of ill-developed grains (Venkateswarlu, 1977). Grain filling after fertilization was largely dependent upon the

carbohydrates present during ripening period (Murayama *et al.*, 1955). Murty and Murty (1982) further observed that impairment in the translocation of accumulated carbohydrates from 'source' to the 'sink' resulted in the degeneration of spikelets (Murata, 1969). Similar situation existed in the low water supplying environment at 100 % PE level, where the accumulation of carbohydrates and their translocation to the panicles were impaired resulting in the enhancement of higher degree of spikelet sterility (Sikder and Das Gupta, 1976).

Nevertheless, the effects of limited water availability on the carbohydrate chemistry could be favourably negated with the biofertilization practice especially at 100 and 125 % RDF level.

In the present investigation, the **ratio of soluble N / total N (Fig. 14)** observed during maturity stage was also higher with lower water supply situation. Such higher concentration of soluble N to total N would impair normal fertilization and grain setting (Khan, 1973). This is in corroboration with the present findings especially for the drip irrigation scheduled at 100 % PE level. Nevertheless, the higher ratio could be narrowed down due to the biofertilization treatment, which resulted in higher degree of spikelet fertility in these treatments even under the low water supplying environment.

Similarly, **ratio of total available carbohydrates to total N (TAC / N)** was also greatly influenced by the water treatments. The decreased ratio of TAC / N under limited water supply situation could be negated with the drip fertilization practice which favoured higher degree of filled grain percentage in them. Thus, biofertilization helped to increase the ratio for the low moisture scenario in order to step up the spikelet fertility as evidenced with the values of the ratio during maturity stage (**Fig. 15**).

Content of total free aminoacids reflects a healthy N metabolism in plants. However, in the present study, low water supplying situations and fertilization stress resulted in the accumulation of free amino acids mainly due to impaired protein synthesis coupled with protein degradation under the unfavourable stressed scenarios. This is in accordance with the findings of Girusse *et al.* (1996) and Jha and Singh (1997).

The hormonal regulation in grain setting has been reported by several workers (Michael and Seiler-Kelbrisch, 1972; Mounla and Michael, 1973). In order to understand

the possible regulation of **cytokinins** in altering the yield formation under drip fertigation practice was studied in the present investigation. The content of trans-zeatin equivalent cytokinin estimated by UV-spectrophotometric method for T₆ treatment at FF stage was crossed checked with that of the HPLC analysis. Based on the analysis of test of significance, the contents of both the analyses were found to fairly agree with each other within the acceptable standard error range (T₆: 50.01 ± 0.55 with HPLC as against 49.50 µg g⁻¹ with spectrophotometry). The HPLC chromatogram for the standard run with pure trans-zeatin is given in **Appendix 4**.

The panicles of well-watered treatments registered higher concentration of **endogenous cytokinin** (trans-zeatin equivalent) both at FF and 10 DAF. However, the contents showed increasing trend with increase in water supply with the per cent increase in the content being 66.0 and 53.0 in 125 and 150 % PE levels respectively as compared to 100 % PE. Towards this, Murty and Murty (1981) reported an interference in the assimilate flow into the sink due to a decrease in cytokinin levels in the panicles under lowlight stress. This is in corroboration with the present findings of reduced content of cytokinins under 100 % PE level of drip irrigation especially at FF stage (**Fig. 16**) resulting in higher degree of spikelet sterility in the mentioned treatment. Such reduction in the content of cytokinin under reduced water availability might be due to reduced cytokinin import from the roots rather than enhanced turnover in the leaves (Wareing *et al.*, 1977).

Nevertheless, water-stressed induced spikelet sterility could be safely narrowed down with the biofertigation treatment. This could be attributed to the fact that *Azophosmet* containing PPFMs had the ability to synthesize cytokinins (zeatin, *trans*-zeatin and *trans*-zeatin riboside) as reported by Ivanova *et al.* (2000) and Koeing *et al.* (2002) which might have been involved in better transport of assimilates from source to the sink even under lesser water availability as well as fertilizer stressed situations.

Apparent Contribution Rate (ACR)

Under stress-free conditions, a major portion of rice grain carbohydrate comes from ‘current photosynthesis’ during ripening period (Yoshida and Ahn, 1968). Nevertheless, mobilization of accumulated carbohydrate and N (at flowering) appears to support the growth of rice grain during ripening when photosynthesis is restricted due to

external stress situations (Yoshida, 1972). Apparent Contribution Rate (ACR), i.e., the contribution of accumulated carbohydrate and N at FF stage to the panicle reserve at HT stage is worked out (Yoshida and Ahn, 1968) with reference to the selected treatments and discussed below (**Table 90**):

Table 90. Apparent Contribution Rate (ACR) for carbohydrate and nitrogen (%) due to drip fertigation treatments in PMK (R) 3 aerobic rice

Treatment	ACR - Carbohydrate	ACR - Nitrogen
Irrigation regime		
100 % PE	33.7	50.1
125 % PE	28.9	43.2
150 % PE	20.6	39.8
Fertilizer level		
75 % RDF + Biofertigation	20.7	33.6
100 % RDF + Biofertigation	33.8	48.9
125 % RDF + Biofertigation	28.7	50.6
Conventional practice	18.1	28.2

The above data indicated that the ACR values for carbohydrate and N decreased with increase in the water availability. Nevertheless, the biofertigation at higher levels (125 and 150 % RDF + BF) showed higher rates, thus indicating the role of accumulated compounds in grain filling. This was in corroboration with the findings of Janardhan *et al.* (1980) and Mohandass (1989) for the lowlight stressed environment. It is thus indicated that the biofertilized treatments utilized more of accumulated photosynthetic reserves for grain filling, while the conventional practice of irrigation and fertilizer application depended more on current photosynthetic contribution to grain yield. Thus, the superiority of the drip-biofertilized plants for grain yield resulted from higher ACR values for both carbohydrate and nitrogen.

It is often reported that the AOS generation under water stress might also be responsible for most of the damages caused to the cellular components (Allen, 1995; Willekens *et al.*, 1995).

As revealed in the present investigation, the AOS scavenging enzymes such as **PO and SOD** were over expressed with 100 % PE water level irrespective of the fertilizer levels tried. This is in supportive of the findings of Manivannan *et al.* (2007) reporting that the drought induced damage could be negated with the increased activities of SOD, PO and CAT enzymes. These metalloenzymes constituted an important defense mechanism for the cells against superoxide free radicals generated under the stress conditions and thus increased SOD activity was known to confer oxidative stress tolerance (Slooten *et al.*, 1995). Reddy *et al.* (2004) further reiterated that the combined action of CAT and SOD converted the toxic O_2^- and H_2O_2 to water and molecular oxygen, averting the cellular damage under unfavourable water as well as fertilizer supplying conditions.

The AOS scavenging enzyme is thus important in imparting tolerance against oxidative stress (Noctor and Foyer, 1998). It might therefore be presumed that enhancement of the antioxidative system favoured water stress resistance (Noctor *et al.*, 2000).

Towards this, favourable role of biofertiligation at optimum RDF level increasing the activities of PO and SOD under limited water supply for averting the damage from AOS accumulation in the cells was also realized in the present investigation especially at FF stage (**Fig. 17 for SOD**). Thus, from the present results and afore said discussion, it is clear that the plants supplemented with the aforementioned biofertiligation practice are favourably upregulated by the components of the antioxidative system under drought stress.

In the water stressed plants, the capacity for auxin induced cell wall loosening is reduced. Coupled with loss of turgidity, this would severely limit the ability of the plant to continue its growth normally (Gonzalez-Bernaldez *et al.*, 1968). This is evident in the present study especially under drip irrigation at 100 % PE and 75 % RDF + BF level wherein the plant height and auxin content were considered together.

That is, the increased **activity of IAA oxidase** (resulting in reduced oxidized IAA content) was accompanied with reduced plant height under reduced water and fertilizer supplying situations, which might be due to the accelerated auxin degradation by IAA oxidase enzyme. Conversely, reduced activity of the IAA oxidase was often associated with the increased content of unoxidised auxins. Nevertheless, the activity of IAA oxidase was less pronounced in 125 and 150 % PE as well as 100 and 125 % RDF + BF levels of fertigation. Significant role played by the biofertigation treatments in moderating the activity of IAA oxidase activity could also help the low-watered plants in maintaining comparatively higher unoxidized IAA content with less reduction in plant height. This is in confirmation with the findings of Jain *et al.* (1996) establishing inverse relationship between IAA oxidase activity and endogenous auxin content. Darbyshire (1971) further reported that water stress would lead to premature senescence as indicated by increased activity of IAA oxidase. Such process would likely to decrease the photosynthetic activity. This might hold good for the plants grown with drip fertigation at 100 PE + 75 % RDF + BF level.

Nitrate reductase (NRase), a key enzyme in nitrogen metabolism in plants, is highly sensitive to environmental fluctuations. In the present investigation, the reduction in the activity of NRase enzyme was more prominent in the drip fertigation at 100 % PE as well as 75 % RDF + BF level. Results of Anaytullah *et al.* (2007) indicated that the drought tolerant rice genotypes possessed minimum percentage of reduction for NRase activity under water stress situations. Similar scenario was observed for the drip fertigated plants at 125 % PE as well as at 100 and 125 % RDF + BF levels showing minimal alteration in NRase activity.

Jha and Singh (1997) opined that the stability of NRase enzyme under moisture stress was found to be associated with drought tolerance in rice. In accordance with this, the activity of NRase enzyme was moderated and stabilized with the biofertigation practice more prominently under medium water availability situations, thus conferring drought tolerance in them for alleviation of ill-effects of water deficit conditions. The increased enzyme activity with N supply could be because of its substrate inducible nature.

Oxidizing power of roots, a key factor for root activity, was greatly influenced by the irrigation regimes and fertilizer levels. The values were found to be decreasing from tillering to maturity. However, the value was higher with moderate supply of water than lower and higher water regimes. The oxidizing power at 125 % PE level was 23.9 and 8.7 per cent more in comparison with 100 and 150 % PE levels of drip irrigation respectively with special reference to FF stage (**Fig. 18**). Increased root oxidizing power with the aid of biofertiligation was quite evident. Towards this, use of biofertiligation at 100 and 125 % RDF + BF levels proved more beneficial.

The **cation exchange capacity (CEC)** of roots was found to be negatively influenced by the water supplying levels and was more affected with the low water supplied plants. Nevertheless, it could be offset with the use of biofertiligation (**Fig. 19**). Increased root volume coupled with better oxidizing power of the roots as noticed with the biofertiligation treatments might probably be influencing the increased values of CEC of roots under the water as well as fertilizer stressed environment.

On the whole, performance of drip fertigation scheduled at the combined level of 125 % PE + 100 % RDF +BF (T₆) was superior for most of the physiological and biochemical characters studied in the present investigation.

5.4. Altered plant water relations as influenced by drip fertigation treatments

A critical gate way for averting water stress effects is to maintain favourable internal water balance for realizing sustainable crop productivity under limited water supplying environment.

Water deficit, a consequence of the imbalance between water uptake and transpiration, affected crop growth and the degree or intensity of water stress (Mohandass *et al.*, 1989). In order to fully understand the physiological and biochemical functions of the plants, it is imperative to study the variations in plant water status and concomitant physiological and biochemical processes of the plants. Therefore, attempts have been made to elucidate the information on plant water relations under different water regimes and biofertiligation scenarios as hereunder.

Relative water content (RWC) of leaves is often considered as a measure of plant water status, reflecting metabolic activity in the tissues. This was further supported by the

association between RWC and crop production under water stress situation (Blum, 1998). Reduction in RWC under water stress is a general phenomenon (Anaytullah *et al.*, 2007).

In the present investigation, the plants grown with the drip irrigation at 125 and 150 % PE maintained higher values of RWC than that of the 100 % PE plants. In support of this, Meghanatha Reddy *et al.* (2007) also established a significant positive relationship of maximum RWC on grain yield in rice.

The reduction in RWC as noticed with the stressed plants of 100 % PE as well as with 75 % RDF + BF system was found to be associated with the decrease in NRase activity as shown by Gowri (2005) for the aerobic rice. Besides, Lawlor (1995) further observed marked changes in plant metabolic process with the cessation of photosynthesis and much increased respiration in rice under reduced values of RWC.

The biofertiligated treatments maintained comparatively higher RWC in the leaf cells irrespective of the water regimes tested. Thus, maintenance of higher plant water status (in terms of higher values of RWC) played a vital role in stabilizing various plant processes and yield (Blum, 2002; Lafitte, 2002; Kumar and Kujur, 2003). Besides, increased values of RWC with higher N supply might also be due to the role of excess nitrogen in improving the succulence of the plants.

The **leaf water potential (LWP)** is a dependable indicator of plant water status especially under limited water supplying environment. In that, the water stressed plants of 125 and 150 % PE levels generally possessed higher LWP (less negative values) at all growth stages studied. Conversely, lower values of LWP in the stressed plants of 100 % PE might be due to the existence of a higher resistance to water uptake probably caused by the stress related root injury (Kramer, 1950). Among the water regimes, the drip irrigation scheduled at 125 % PE level was more favourably placed mainly because of the better root proliferation (in terms of total root length, root volume and root length and mass densities) for continuous moisture extraction even from the deeper soil profiles which helped for stabilizing the grain yield. This aspect of the present investigation also enjoyed the support of Fukai *et al.* (1999) emphasizing the ability of rice plants to maintain higher LWP to stabilize rice yield even in rainfed areas.

The biofertiligation treatments also favoured for increased LWP as seen in **Fig. 20** particularly at FF stage. The probable means by which this could occur comprised of:

i) changes in the rate of water loss from the plant and ii) changes in the balance of forces affecting the water within the plant cells as suggested by Singh *et al.* (1973) in barley.

Leakage of solutes from tissues could be used as a dynamic measure of assessing damage to the membranes as caused by the limited water availability situations (Leopold *et al.*, 1981). Close perusal of the data on **membrane stability index (MSI)** indicated that the values increased with increase in the water supply. Similar trend was observed for the fertilizer levels also (**Fig. 21**). Specifically, biofertilization given at 100 and 125 % RDF + BF levels was found to be highly beneficial in averting the membrane damage even under both water and fertilizer stressed conditions. Maintenance of membrane integrity and function as a measure of drought tolerance was indicated by several workers (Premchandra *et al.*, 1990; Deshmukh *et al.*, 1991; Anaytullah *et al.*, 2007). Thus, the increased values of MSI vested drought tolerance ability to the stressed plants of drip fertigation scheduled at low (100 %) and medium (125 %) PE levels as observed in the present study. Also, the higher values of MSI with increased N supply could be due to the fact that N is the structural component of proteins necessary for the membrane integrity.

Chlorophyll stability index (CSI) is a reliable parameter for assessing capacity of drought tolerance in plants (Sanandachari, 1978). Water stress generally reduced the values of CSI with distinct variation among the irrigation regimes and fertilizer levels. Moderate water supply (125 % PE) and higher fertilizer strategies (100 and 125 % RDF + BF) were more favourably placed for the CSI values. This is in conformity with the findings of Nadarajan and Kumaravelu (1993) and Michael Gomez and Rangasamy (2002) reporting that the drought tolerant varieties of rice had higher CSI values under water stress scenario. Thus, the increased values of CSI had endowed better drought tolerance capacity to the plants grown under the above specified special scenarios. A higher CSI also meant better availability of chlorophyll (Meghanatha Reddy *et al.*, 2007) leading to increased photosynthetic rate (soluble protein content), more TDMA and higher productivity as suggested by Madhan Mohan *et al.* (2000). Conversely, the decrease in the values of CSI as noticed for the stressed plants of drip fertigation at 100 % PE + 75 % RDF + BF level would be pertained to the enhanced activity of the chlorophyllase enzyme as opined by

Gowri (2005) for aerobic rice. In addition, increased values of CSI with N supply could also be ascribed to the structural role of N in the synthesis of chlorophyll pigment.

One of the important consequences of water stress is the accumulation of **proline** in rice. Proline acts as a compatible solute and a protective agent for cytoplasmic enzymes and structures. In the present investigation, proline content increased by 1.26 and 1.88 folds in 100 % PE in comparison with 125 and 150 % PE levels of drip irrigation respectively at FF stage. This could occur in different pathways such as, stimulation of synthesis from glutamic acid perhaps due to loss of feed back inhibition of the synthesis of the intermediate Δ^1 – pyrroline – 5 – carboxylate; inhibition of proline oxidation; impaired incorporation of free proline into protein and reduced export of proline via phloem. Nevertheless, reasonable hypotheses based on the possible roles of proline accumulation under water stress had been well documented as the store house for N and energy and NH_3 - detoxification product and cytosolic osmoregulation.

The role of biofertiligation was also significant in increasing the content of proline by 9.7 and 33.9 per cent more in 75 % RDF level than 100 and 125 % RDF + BF levels respectively with special reference to FF stage. Biofertiligation with *Azophosmet* could increase the hydrolysis of macro-molecules into the simpler ones like mono and disaccharides and amino acids especially proline etc. and consequently higher osmolyte concentration resulting in favourable osmoregulation process (Aruna Tyagi *et al.*, 1999) under water and nutrient stressed conditions as observed in the present investigation. Further, the differential response of proline accumulation in different levels of biofertiligation might be due to rapid hydrolysis of storage protein or synthesis of amino acids like proline for adaptation to the given stressed conditions (Shankhdhar *et al.*, 2000).

Leaf diffusive resistance (LDR) got increased under limited water supply due to the imposition of water stress irrespective of the stages studied. The increase in LDR was more pronounced in 100 % PE level of drip irrigation and the increase was 1.27 and 1.60 times more than 125 and 150 % PE levels respectively. Nevertheless, the plants supplemented with biofertiligation were able to curtail the water loss by offering more and moderate diffusive resistance at stomatal level with 75 and 125 % RDF + BF levels respectively.

Transpiration, the major process involving water loss from the plants, was higher under limited water supply situations. In the present study, the drip irrigation at 100 % PE level resulted in severe reduction in transpiration rate. Further, close analysis of the data showed that the reduction of the transpiration rate in the drier moisture regime (100 % PE) was 38.3 and 48.9 per cent as against that of the moderate (125 % PE) and wetter (150 % PE) moisture regimes respectively at FF stage (**Fig. 22**). Such reduction in the transpiration was associated with increased LDR (Mishra and Pradhan, 1972).

Due to the biofertilization practice, the reduction in the transpiratory loss of water from the nutrient-stressed plants (at 75 % RDF + BF) was generally minimal than that of the high fertilizer levels (100 and 125 % RDF + BF) tried. Lanceras *et al.* (2004) opined that the radiation load on the leaf canopy affected the leaf temperature and transpiration especially under the stressed situations. This in turn had closer relation to the water uptake and nutrient assimilation necessary for grain production.

Observations on **leaf and canopy temperature** indicated that the values were influenced by the irrigation regimes as observed in the present study. The plants given with drip irrigation at 150 % PE level maintained cooler temperatures than that of the plants at 100 or 125 % PE level. Biofertilization was found to be superior with significant lowering of both leaf and canopy temperatures and maintained cooler canopies more efficiently at higher level of 125 % RDF + BF, which might be due to the maintenance of favourable LWP.

Thus, the present investigation indicated that adequate supply of water led to higher values of LWP and the stomatal conductance and cooler leaves. Nevertheless, biofertilization practice exhibited more avoidance mechanism of drought stress in maintaining favourable LWP (by way of osmoregulation), cooler temperature and enhanced physiological processes such as hydration of colloids and viscosity of protoplasm leading to elevation in leaf water potential as observed by Ali (1985).

To conclude, supplementation with biofertilization not only did have the impact on the efficiency of water use for crop production as shown by several authors (Thangamani, 2005; Jeya Bharathi, 2006) but also hold promise to decrease the probabilities of high water demand especially during critical phases of water requirement.

Summing up, the plants of the drip fertigation treatment given at 125 % PE + 100 % RDF + BF level (T₆) maintained favourable internal plant water status.

5.5. Modified molecular mechanism as influenced by drip fertigation treatments

The molecular aspects of the study enumerated in the following pages were carried out for the chosen treatments at FF stage.

5.5.1. Leaf soluble protein profile

The total leaf protein was extracted and separated by SDS-PAGE method. The detailed electrophoretic protein-banding pattern of the rice plants with the chosen drip fertigation treatments has been presented in **Plate 8**. The banding pattern was phenomenal with additional number in the case of drip fertigated plants of varied water and fertilizer levels. In these treatments, several new protein bands were observed in comparison with the conventional practice. For instance, two protein bands with higher intensity were observed in all the treatments at the molecular weights of 25.0 and 97.4 kDa. With special reference to the treatments of T₂ and T₆, one more additional protein band with higher intensity (at more than 97.4 kDa) was noticed.

The extra protein bands as observed with drip fertigation treatments were found to be specific to drought tolerance ability. These were expressed only during water stress scenario, suggesting that these proteins were the induced gene product. As such, they might belong to Late Embryogenesis Abundant (LEA) group of proteins (Roberts *et al.*, 1993). These proteins might have played decisive role in repairing the cellular damage occurred during water as well as fertilizer stress situations as suggested by Dure *et al.* (1989) and Dure (1993). Xu *et al.* (1996) also reported that expression of LEA proteins conferred drought tolerance in rice.

On the other hand, number and intensity of protein bands were comparatively lesser in the case of conventional method of water and fertilizer application.

5.5.2. Peroxidase (PO) isoform profile

The isozyme profile for the AOS scavenging enzyme of peroxidase (PO) was studied through NATIVE-PAGE method.

Native gel electrophoretic separation of enzyme extracts from the rice plants with the chosen treatments showed different peroxidase (PO) isoform patterns (**Plate 9**). The treatments of T₂, T₅ and T₆ showed four isoforms (PO 1, PO 2, PO 3 and PO 4). Besides, T₆ exhibited one more additional isoform of PO 5. But, T₁ (conventional method) and T₁₀ possessed only two isoforms with higher intensity (PO 1 and PO 2). This might be due to the high moisture situations in the latter treatments.

In the present investigation, different isoforms of PO were regulated differentially in response to the stress as observed by Morita *et al.* (1999). In the given environment, above mentioned three treatments expressed three additional isoforms, which could have helped the plants in eliminating the processes of oxidative damage, lipid peroxidation and denaturation of protein under the limited or moderate input conditions (Bowler *et al.*, 1992).

5.6. Modified nutritio-physiological aspects as influenced by drip fertigation treatments

Water is one of the most important environmental factors that regulate plant growth and development. Among the diverse consequences of drought effect on plant development, restricted nutrient and water acquisition are commonly recognized (Agnew and Warren, 1996).

It is generally elucidated that the moisture stress retarded the nutrient uptake by impairing the following three major processes whereby the ions could come into contact with the roots (Marais and Wiersma, 1975). The processes were: i) diffusion of ions along a concentration gradient set up by the depleting action of plant roots, ii) passive conveyance of ions to the root / soil interface occasioned by plant - water uptake and iii) root extension into the untapped zones. A decline in soil moisture supply was often associated with a reduction in the cross sectional area of capillary films thus causing a decrease in the rate of diffusion of water to the root (Barber, 1962). The extent of moisture stress in inhibiting the uptake of nutrients could be evaluated by assessing the nutrient status of plant.

Under limited water supplied scenario, the total uptake of all the chosen nutrients was significantly reduced at all stages of crop growth. The reduction in transpiration would also hamper the uptake of nutrients under the given stressed environment (Tanguiling *et al.*, 1987). Besides, shortage of water indirectly led to N-deficiency in the plants (Schjoerring, 1995).

Higher **uptake of N** under saturated unflooded conditions was documented by Miyasaka (1970). The results of the present study confirmed with the above findings in terms of higher N uptake observed under the drip irrigation especially with 125 and 150 % PE levels during AT and PI stages. This might be substantiated to the better root penetration and proliferation (in terms of RLD and RMD) equally in all the three soil layers coupled with shortening of transportary distance in terms of moderately dwarfed plants in the drip fertigation system. Besides, such stimulated roots into the deeper soil layers maintained their activities and promoted N uptake at later stages (Horie *et al.*, 2005). The biofertilization favoured the **uptake of total N** especially under moderate and higher RDF + BF levels at harvest (**Fig. 23**).

It is further inferred that the grain yield increased linearly from the initial N uptake and decreased at higher N uptake. This is consistent with the previous study (Jing *et al.*, 2007). This might be because rice yield was mainly driven by the required amount of N uptake (Witt *et al.*, 1999) and leveled off or even decreased when N was not a limiting factor for rice growth (van Keulen, 1982).

Olsen *et al.* (1962) established a positive and linear relationship between moisture content and P uptake. Dikshit and Padihar (1988) recorded a greater P uptake under alternate submergence and saturation till maximum tillering. The result of the P uptake in the present investigation is in corroboration with the above. Drip fertigation practice enhanced the **uptake of total P** and its mobility in the plant parts as observed at harvest stage (**Fig. 24**).

Potassium availability was reported to be enhanced under aerated conditions. Therefore, higher uptake of total K as noticed under the drip fertigation conditions at harvest stage is explainable (**Fig. 25**). Similar increased uptake of Ca and Mg was also seen with the drip fertigated treatments before FF stage. This was supported by the findings of Srinivas *et al.* (1989) recording higher uptake of N, P, K, Ca and Mg in drip irrigation system than under furrow irrigation.

Higher uptake of Fe and Mn by rice is expected under water logged conditions while reverse trend in uptake of Zn and Cu was observed (Thiyagarajan and Selvaraju, 2001). In the present investigation, higher uptake of Fe and Mn was noticed during vegetative

stage especially with the high moisture supplying scenarios of both conventional and drip fertigation treatments. Nevertheless, the higher uptake of Zn and Cu was prominently evident under moderate water supplied treatments in the drip fertigation practice at all stages excepting harvest.

On the contrary, lower uptake of nutrients observed under lower water and fertilizer application rates were attributed to decreased rate of transpiration with the decreasing soil moisture content (Wopereis *et al.*, 1996).

Higher nutrient use efficiency was observed with moderate level of water and fertilizer levels. Similarly, the Agronomic Efficiency (AE) was also higher for drip fertigation practice at moderate level of water and fertilizer application.

The results of the present investigation clearly demonstrated that the biofertigation is a more efficient method of nutrient management in aerobic rice than the conventional way of fertilizer application. Similar results were also reported by Alam *et al.* (1999) and Iqbal *et al.* (2003).

The values for nutrient HI were generally favoured with the drip fertigation treatments than the conventional method of irrigation and fertilization application. From a human nutritional point of view, higher contents of Zn and Fe in the rice grain are of paramount importance (Gao *et al.*, 2006). The values for Zn- and Fe-harvest index were greatly influenced by water as well as fertilizer levels (**Fig. 26**) registering increased values with special reference to the fertigation treatment scheduled at 125 % PE + 100 % RDF + BF (T₆). Nevertheless, Rengel *et al.* (1999) indicated that the soil application of Zn could not fully meet the objective of increasing the Zn level in the edible portions of wheat. Therefore, drip fertigation should be considered as an alternate strategy to increase the concentrations of Zn and Fe in the rice grain thereby improving the values of Zn and Fe-Harvest Index.

Thus, on the whole, the nutritio-physiological aspects of plants grown with drip fertigation at the combination of 125 % PE + 100 % RDF +BF level (T₆) was found to be congenial for better crop growth and yield under micro irrigation technique.

5.7. Ultimate effects on yield and yield components as influenced by drip fertigation treatments

Knowledge on the association of yield components with yield and among themselves will be vital in formulating effective technology development for adoption by the farmers with ease.

Grain yield is the final manifestation of several complex morpho-physiological processes in the plants, which is often influenced by various metabolic processes. Number of panicles per unit land area, the dominant yield component influencing grain yield, linearly decreased with the number of tillers per square meter (Cruz *et al.*, 1986). In the present study, the reduction in the **number of panicles** was found to be greater (**Fig. 27**) in the case of lower to moderate moisture availability situation (26.5 % lesser in 100 % than 125 % PE level). Similar reduction of productive tillers due to water stress was observed by Ichwantori *et al.* (1999). Nevertheless, lesser tiller number with higher panicle weight was considered as the important character for augmenting the yield (Bhattacharya and Ghosh, 2004; Gowri, 2005). Nevertheless, this hypothesis was slightly deviated in the present investigation that moderate number of panicles with increased panicle weight did not translate into yield especially in higher moisture regime. Higher per cent reduction in **mean panicle weight** was evident in low and moderate water supply conditions (26.1 and 25.0 per cent in 100 and 125 % PE in comparison with 150 % PE level respectively).

Increase in the number of productive tillers and mean panicle weight with the use of biofertilization was clearly evident especially at 100 % RDF + BF level. This could be due to the favourable plant water relations (Mohandass *et al.*, 1988b) as observed in the present study.

Number of spikelets, an important yield component decided during PI and for determining the grain number during anthesis, was found to be reduced with decreased water supply (Rajkumar, 2001). In the present study, similar reduction in the production of spikelets due to water stress was observed in 100 % PE level of drip irrigation. Use of fertigation was favourable with increased number of spikelets per unit area. This was more prominent for higher category of 100 and 125 % RDF + BF levels.

Production of **grains and their filling percentage** was significantly influenced by the irrigation regimes and fertilizer levels. Nevertheless, the drip irrigation treatment given at 125 % PE level was better placed than drier or wetter moisture regimes. Similar results were observed by Lanceras *et al.* (2004) indicating that the drought stress occurring during the reproductive stage (as observed with 100 % PE level) increased the per cent spikelet sterility (PSS) and consequently decreased the grain yield. Further evidence was also reported by Boonjung and Fukai (1996), in which the yield reduction to the tune of 40 per cent was due to the increment of PSS when drought occurred during grain filling period (Jongdee *et al.*, 2002).

Since the water stress caused abnormalities of gamete formation (Namuco and O'Toole, 1986) and panicle exertion (O'Toole and Namuco, 1983; Cruz and O'Toole, 1984), the reduction in the number of filled grains produced and its percentage as noticed in the present investigation could be reasonable with distinct variations among the fertigation treatments. Towards this, the unfavourable situation faced by the treatment of 100 % PE and at 75 % RDF + BF level might be due to the embryo abortion owing to the perturbation of consequential events such as gamete production, poor panicle growth and exertion, anthesis and fertilization under stressed scenario (Saini and Lalonde, 1996). They further highlighted that the changes in carbohydrate levels and enzyme activities associated with the inhibition of starch as well as solute accumulation in the cells of pollen, were some of the potential causes of spikelet sterility due to lower osmotic adjustment.

Use of the biofertigation could also be able to maintain better plant water relations (Garrity *et al.*, 1986; Ekanayake *et al.*, 1989) even for the stressed 100 % PE situation which could have been reasoned out for increased number of grains as well as their filling percentage (**Fig. 28**).

With regard to **panicle harvest index (PHI)**, a reliable parameter for assessing the degree of spikelet fertility, the values were greatly influenced by the water as well as fertilizer levels. Increased values of PHI were evident with 125 as well as 150 % PE levels, which might be attributable to higher filled grain percentage as observed by Lafitte *et al.* (2003) for water stressed transplanted rice and Gowri (2005) for aerobic

environment. The positive role of biofertilization practice used in the present study in registering higher values of PHI with moderate level of fertilizers (125 % RDF + BF) was also worth mentioning especially under the conditions of drip fertigation practice.

The **test weight of grains (1000 grain weight)**, an important parameter influencing grain yield of rice, showed wide variations in the drip fertigation system. Biofertilization had proved to be beneficial in enhancing the test weight due to higher rate of filling of developing grains because of increased translocation efficiency for photoassimilates.

The **harvest index (HI)**, proportion of total biomass partitioned to the developing spikelets, showed distinct variations for irrigation as well as fertilizer levels (**Fig. 29**). The value was found to be higher for moderate level of water supply (125 % PE level). The decrease in HI due to the deficit or excess water supply situation (-18.1 and -11.5 % for 100 and 150 % over 125 % PE level respectively). Nevertheless, Lanceras *et al.* (2004) indicated that the correlation between grain yield and HI increased dramatically as the drought stress increased, indicating that HI would be a primary determinant of grain yield under stress. Similar positive association between HI and grain yield was evident in the present investigation ($r = 0.747^{**}$). Therefore, genetic improvement of HI would also improve grain yield in rice (Fukai *et al.*, 1999; Babu *et al.*, 2003) for the low water and fertilizer supplying situations. Increased value of HI as noticed with the biofertilization at 125 % RDF level was in confirmation with the findings of Thangamani (2005) for hybrid rice ADTRH 1 grown with *Methylobacterium sp.* under the stress-free conditions of flooded submergence. Thus, the general effect of drip biofertilization treatment in increasing the values of HI under medium supply of water and fertilizer situations might be attributed to the fact of producing larger sink size and efficient transport of assimilates from leaves and stems ('source') into developing spikelets ('sinks') thus resulting in the increased grain yield.

The **grain yield** of rice is often influenced by sink capacity rather than source strength under stress-free environment (Fukai *et al.*, 1991). Higher grain yield of 5643 kg ha⁻¹ was registered with the drip fertigation practice at 125 % PE + 100 % RDF + BF level.

Conversely, limited water supply during reproductive and ripening phases appeared to affect the reproductive physiology by interfering with the pollination, fertilization and grain filling (Wann, 1978) and thus resulting in drastic reduction in the grain yield of the stressed plants of rice crop. Similar observation of yield reduction was noticed in both the low water as well as fertilizer supplying treatments (**Fig. 30**). The reduction in grain yield due to deficit water supply was more (27.2 % in 100 % PE as compared to 125 % PE level respectively. Earlier studies also indicated that the prevalence of water shortage during reproductive stage (terminal drought) was more detrimental for both transplanted (Maibangsa, 1998) and also for aerobic rice (Gowri, 2005). The reduction in yield under water stress was associated with reduced number of spikelets, filled grain percentage and number of panicles per unit area. Nevertheless, supplementation of biofertilization was able to narrow down the yield reduction especially under limited water supply (as in 100 % PE) situation. Referring to the fertilizer levels, the grain yield established quadratic response with higher yield at 100 % RDF + BF level.

As observed in the present investigation, favourable role of biofertilization supplemented with *Azophosmet* was also reported in several crops like soybean (Holland, 1997), blackgram, groundnut and sugarcane (Madhaiyan, 2002) and rice and cotton (Thangamani, 2005; Jeya Bharathi, 2006; Poorniammal, 2006) grown under stress-free situations. Overall effect of biofertilization with *Azophosmet* in increasing the grain yield in these crops were attributable to the availability of nutrients, through nitrogen fixation and production of plant growth promoting (PGP) substances like cytokinins, IAA and GA and also vitamins especially B₁₂ produced in the rhizosphere soils (Thangamani, 2005) for making available to the plants.

The results of the biofertilization with *Azophosmet* discussed elsewhere in the present study confirmed that there was a significant improvement in the growth and physiological parameters which ultimately reflected in enhancing the productivity in aerobic rice.

To substantiate the claim, population count of the three organisms in the composite inoculant of *Azophosmet* was made in the rhizosphere soil at FF stage and the

data (**Table 91**) indicated that the biofertiligated treatments were generally found to increase the populations of *Azospirillum*, *Phosphobacteria* and *Methylobacterium* sp. than the conventional method of irrigation and fertilizer application. In case of *Azospirillum*, increased moderate to higher moisture supply (125 and 150 % PE levels) had increased the microbial population. This could have facilitated higher rate of nitrogen fixation by the plant in the given moisture environment. Similar trend was also observed for *Phosphobacteria*, possessing higher population in the moderate and higher water regimes indicating higher rate of phosphorus solubilization in the soil. In case of PPFM, increased population as noticed under moderate to wetter moisture regimes could have favoured the production of growth promoting substances (preferentially cytokinins) for facilitating increase rate of mobilization of assimilates to the developing ‘sinks’ even under moderate level of moisture availability.

Table 91. Population of organisms in *Azophosmet* at flowering as influenced by drip fertigation treatments in PMK (R) 3 aerobic rice

Treatment		<i>Azospirillum</i> (10 ⁵ cfu ml ⁻¹)	<i>Phosphobacteria</i> (10 ⁴ cfu ml ⁻¹)	<i>Methylobacterium</i> (10 ⁴ cfu ml ⁻¹)
T ₁ :	Conventional method	9.8	5.7	13.4
T ₂ :	100 % PE + 75 % RDF + BF	7.1	4.7	14.7
T ₃ :	100 % PE + 100 % RDF + BF	8.0	5.4	14.6
T ₄ :	100 % PE + 125 % RDF + BF	8.4	5.1	14.8
T ₅ :	125 % PE + 75 % RDF + BF	9.8	6.8	17.5
T ₆ :	125 % PE + 100 % RDF + BF	11.2	6.5	16.7
T ₇ :	125 % PE + 125 % RDF + BF	14.0	7.2	14.8
T ₈ :	150 % PE + 75 % RDF + BF	11.2	7.0	15.9
T ₉ :	150 % PE + 100 % RDF + BF	12.8	7.1	16.9
T ₁₀ :	150 % PE + 125 % RDF + BF	13.0	7.2	16.7
Mean		10.5	6.3	15.6
SEd		0.25	0.15	0.36
CD at 5 %		0.53	0.31	0.76

Thus, the present investigation is the **first report** in the literature to show the positive role of biofertilization with *Azophosmet*, mixed inoculant biofertilizer, resulting in better water use and its productivity and increased grain production in aerobic rice grown with micro irrigation system.

This was further confirmed with the data on benefit : cost ratio that the biofertilization supplementation (T₆) registered higher ratio of 2.41, followed by the conventional practice (2.39).

5.7.1. Changed source-sink relationship as influenced by drip fertigation treatments

Since several parameters concerning the physical frame of the plants are almost exhaustively studied, it is likely that the manipulation of functional traits might enhance the yield plateau especially under low-yielding aerobic environment. Realizing this aspect, attempts are made to elucidate the ‘source’ (leaf) and ‘sink’ (panicle) inter-relationships to improve the functional efficiency of the rice plants intended for aerobic environment.

5.7.1.1. Sink characteristics

Sink strength consists of two major components, viz., sink size and sink activity (Wareing and Patrick, 1975). The sink activity is again sub-divided into two components and they are the grain filling duration (GFD) and grain filling rate (GFR) (Pearson and Hall, 1984). The GFD and GFR are calculated as follows:

Panicle dry weights collected at the chosen time interval were plotted as a function of time from anthesis until the final harvest. Panicle data were used to test the different panicle growth models (Thornley, 1976) as mentioned elsewhere in the study, of which the hybrid model of Richard’s-Quadratic function was found to be the best suited (Mohandass *et al.*, 1988a). From these models and functions (**Appendix 5 and 6**), observations were made of the dates on which 90 per cent of the final panicle weights were attained and the relative duration of the GFD of each treatment was calculated as the length of the time interval from zero flowering (anthesis) to the predicted date of 90 per cent of final grain yield (Jones *et al.*, 1979). The dry matter accumulated by the panicle at 90 per cent of the final panicle weight was divided by the GFD to arrive at the GFR. The data are furnished below in **Table 92**, which indicated that the sink capacity

calculated as the product of spikelets per m² and test weight (Yoshida, 1981) decreased (-19.1 %) under 100 % PE compared to 125 % PE level of drip irrigation. But, the values showed increasing trend with increase in fertilizer levels. Nevertheless, drastic decline in the sink capacity could be compensated when supplemented with the biofertiligation. The sink size, i.e., the spikelet number per unit area (Yoshida, 1981) was also reduced with deficit and excess water availability situations (-13.2 and -5.7 % in 100 and 150 % PE levels respectively as against 125 % PE) but compensated fairly well with biofertiligation practice.

Grain filling, a crucial determinant of grain yield in rice crop, is characterized by duration and rate of filling (Yang *et al.*, 2008). The GFD showed variations with the values ranging from 25.4 (100 % PE) to 27.1 (150 % PE) for water treatments. In the case of fertilizer levels, the GFD increased with increase in RDF levels.

Table 92. Components of sink strength due to drip fertigation treatments of PMK (R) 3 aerobic rice

Treatment	Sink capacity (g m ⁻²)	Sink size (No. m ⁻²)	Sink activity	
			GFD (days)	GFR (mg panicle ⁻¹ day ⁻¹)
Irrigation regime				
100 % PE	638.87	28.07	25.4	44.24
125 % PE	789.34	32.35	26.6	67.41
150 % PE	744.44	30.51	27.1	62.63
Fertilizer level				
75 % RDF + BF	682.84	28.58	25.6	48.56
100 % RDF + BF	740.81	30.79	26.4	64.22
125 % RDF + BF	749.00	31.55	27.1	61.50
Conventional practice	739.45	30.12	27.2	57.47

However, the reduction in GFR was found to be phenomenal with the lesser water availability treatment (100 % PE: -34.4 %) in comparison with the moderate water supply

(125 % PE). Influence of biofertilization was phenomenal in safely narrowing down such reduction in GFR values. This signified that between the two components of sink activity, the GFR played a vital role for panicle weight and grain yield increase especially in less water applied + biofertilization practice. This was in corroboration with the findings of Mohandass *et al.* (1988a) showing that the GFR possessed significant positive association ($r = 0.953^{**}$) but the duration exhibited poor correlation ($r = 0.278$) with the grain yield under lowlight stress environment. Studies on the contribution of GFD and GFR to grain yield in rice on a panicle basis further showed that the grain yield of different genotypes was mainly determined by GFR (Cho *et al.*, 1987; Jones *et al.*, 1979).

Summarizing the influence of drip fertigation system on sink characteristics in aerobic rice, it could be inferred that the yield variations observed under varied water as well as fertigation levels could be mainly due to the alterations in sink capacity and its activity. Again, the major component of sink activity, viz., GFR was greatly influenced by water and fertilizer levels. This indicated that further crop improvement and management strategies intended for stabilizing the yield under aerobic environment should be aimed at stabilizing the sink capacity and GFR.

5.7.1.2. Source characteristics

The source strength is the major factor influencing the sink strength (Yoshida, 1981). Source strength has got two components, viz., source size and its activity. The source activity is further split into two sub-components i.e., photosynthetic efficiency (in terms of soluble protein content, indirect measure of photosynthetic capacity) and longevity of source (LAD). It is noticed that the source size (in terms of both leaf number and ILS at FF stage) increased with increase in water availability (**Table 93**). Interestingly, the reduction in soluble protein content with lower water availability (100 % PE) was found to be 12.7 and 19.5 per cent in comparison with 125 and 150 % PE level of drip irrigation respectively. Similar trend was evident with LAD also with greater magnitude of reduction in the case of lower water availability situation.

Table 93. Components of source strength due to drip fertigation treatments in PMK (R) 3 aerobic rice

Treatment	Source size		Source activity	
	Leaf No. hill ⁻¹	ILS (cm ² leaf ⁻¹)	Soluble protein (mg g ⁻¹)	LAD (Days)
Irrigation regime				
100 % PE	77.87	9.77	7.46	99.2
125 % PE	97.23	12.17	8.55	127.7
150 % PE	115.70	12.73	9.27	134.4
Fertilizer level				
75 % RDF + BF	84.67	10.67	7.74	112.1
100 % RDF + BF	95.93	10.90	8.43	118.9
125 % RDF + BF	110.23	13.10	9.10	130.3
Conventional practice	110.30	10.50	10.15	152.4

These trends implied that under water stressed environment at 100 % PE level, fair crop productivity could be achieved when optimum leaf area was maintained with greater and sustained photosynthetic efficiency. This association appeared valid only when proper efficient varieties and good agronomic management practices (such as the biofertilization at optimum RDF level) were ensured for the stressed situations.

5.7.1.3. Source-sink limitation

An attempt has also been made to explain yield variations in the chosen drip fertigation treatments in terms of source- and / or sink-limitation. Sink-limitation was worked out as spikelet number x 1000 grain weight / Leaf Area at flowering (Rao and Murty, 1976). Approximate source-limitation (Sa) was calculated by taking into account the changes in dry weight of panicle (ΔY) and the biomass (ΔB) due to variation in treatments as: $Sa = (\Delta Y) / (\Delta B)$ (Gifford *et al.*, 1973).

The results of the **Table 94** indicated that though the sink-source ratio was higher with moderate level of water (125 % PE) and fertilizer (100 % RDF + BF) supply, the differences due to drip fertigation treatments were less appreciable.

Table 94. Variations in source-sink limitation due to drip fertigation treatments in PMK (R) 3 aerobic rice

Treatment	Sink / Source Ratio (Sink limitation)	Sa (Source limitation)
Irrigation regime		
100 % PE	0.905	0.602
125 % PE	0.907	0.847
150 % PE	0.813	0.985
Fertilizer level		
75 % RDF + BF	0.868	0.794
100 % RDF + BF	0.904	0.786
125 % RDF + BF	0.831	0.910
Conventional practice	0.718	0.982

On the contrary, the Sa values increased steadily from 100 % (0.602) to 150 % (0.985) PE level of drip irrigation. In the case of fertilizer levels, higher Sa (0.910) was observed at 125 % RDF + BF level. Thus, the values of Sa was centering around 1 especially for the medium and higher water supplying (125 and 150 % PE levels) treatments, which in the scale of 0 - 1 of Gifford *et al.* (1973) explained that all additional assimilates produced was fully used up by the developing grains, and thus the grain growth was entirely **source-limited** in these water treatments. However, no solid conclusion could be arrived at in respect of the fertilizer levels tried, meaning that detailed studies are required in future to unravel the mystery.

These findings also suggested that in this source-limited rice crop, future strategies should be aimed at developing efficient plant type and management options ensuring the capability of not only synthesizing more biomass under aerobic environment but also to partition it more towards ‘sink’, i.e., the developing grains.

To summarize, the performance of the aerobic rice grown with the drip fertigation practice scheduled at 125 % PE + 100 % RDF + BF level was found to be superior for most of the yield characters and the grain yield.

Grain productivity - Recapitulation and integration of physiological responses due to drip fertigation scenario

In any given crop, the final economic yield is the function of integrated expression of many physiological processes involved in the growth and development of the crop. Manipulation of the nature - genetic, physiological or agronomical - should ultimately lead to higher economic yield. Therefore, the variations in yield across different growing environments are the outcome of the differences in the underlying physiological process and also their patterns.

In the present study, the aerobic rice showed remarkable variations in yield under drip fertigation scenario. The experimental results described earlier clearly indicated greater degree of fluctuations due to the fertigation treatments.

An attempt has been made in the following pages to understand and distinguish the physiological / biochemical parameters which are responsible for yield variation in high responsive drip fertigation treatment (T_6) in relation to the conventional method of irrigation and fertilizer application (T_1).

The recapitulation and integration of the results is done based on the data collected and the salient findings. The valid conclusions drawn from them amply meet the objectives of the present investigation undertaken.

The data (**Table 95**) indicated considerable increase in grain yield in the high responsive drip fertigation treatment of T_6 was due to the cumulative effects of favourable traits such as ILW, total root length, RLD, RMD, TAC, PO, unoxidised IAA content (reduced IAA-OX activity), cytokinin content, grain filling rate, Fe-HI, Zn-HI and water productivity. The lower grain yield in the less expressive conventional method of irrigation and fertilizer application (T_1) was due to the cumulative effect of reduction in the above parameters.

Table 95. Performance of drip fertigation treatment over conventional method

Parameter	Percent increase / decrease in T ₆ (higher responsive) against T ₁
Grain yield	+ 16.0
Total Dry Matter Accumulation (TDMA)	+ 5.7
Harvest Index	+ 9.7
Individual Leaf Weight (ILW)	+ 38.1
Total root length	+ 17.4
Root volume	+ 8.6
Root Length Density (RLD)	+ 34.2
Root Mass Density (RMD)	+ 51.2
Total chlorophyll	- 5.5
Chlorophyll a / b ratio	- 6.9
Total available carbohydrate (TAC)	+ 10.7
Peroxidase activity (PO)	+ 12.7
IAA oxidase activity (IAA-OX)	- 26.2
Cytokinin content	+ 11.8
Grain filling rate (GFR)	+ 13.6
Total N uptake	+ 8.3
Iron-Harvest Index (Fe-HI)	+ 38.9
Zinc-Harvest Index (Zn-HI)	+ 48.0
Water productivity	+ 23.2

Thus, from the foregoing discussion, it is quite evident that the biofertigation practice seems to be the best fertilizer management approach for intensive sustainable production in aerobic rice, as it is used to increase the efficiency of fertilizers and the yield and to protect the environment by avoiding possible groundwater pollution.

5.8. Water use and water productivity

Total seasonal water input to rice fields (rainfall plus irrigation) is upto two to three times more than for other cereals (Tuong *et al.*, 2005). Around 1300-1500 mm is a

typical value for irrigated lowland rice in Asia (Hafeez *et al.*, 2007). Because of this large water input, the mean water productivity for rice at the field level is $0.4 \text{ kg grain m}^{-3}$ water which is about two times lesser than that of wheat (Tuong *et al.*, 2005). The large water input is mostly caused by surface drainage and seepage and percolation flows from the continuously ponded fields into ground water creeks and drains. Seepage and percolation flows account for about 25-50 per cent of all the water inputs in heavy soils with shallow (20-50 cm depth) groundwater tables (Dong *et al.*, 2004). Therefore, most water-saving technologies developed at the field level aim to reduce seepage and percolation flows (Bouman and Tuong, 2001; Tuong *et al.*, 2005).

In the present day context, drip irrigation offers a viable and alternate water-saving system for aerobic rice. In drip irrigation, the volume of wetted soil at a particular water application is controlled by the volume of water added, the discharge rate of dripper and the soil water content (Bresler, 1977). In drip system of irrigation, the seepage and percolation losses are found to be the barest minimum or even almost nil in some situations (i.e., the three dimensional wetting pattern is spherical rather than cubical confining only to the actual root zone) as elucidated by Senthilvel (1995). Besides, the fertilizer use efficiency is also improved significantly in fertigation than soil application. The fertigation also improved water use efficiency (Mohammed, 2004; Thind *et al.*, 2008).

Water productivity, the ratio between grain yield and total water applied, is often equated with drought resistance and the improvement of crop yield under stress. Water productivity is mostly discussed in terms of plant production rather than gas exchange.

In the present investigation, the data on water use in different treatments indicated that there was a saving for the total water applied to the tune of 8.8 per cent when drip irrigation was scheduled at 100 % PE level in comparison with the convention irrigation practice (511 mm). However, irrigation given at 125 and 150 % PE levels consumed 5.1 and 19.0 per cent more water than the conventional method respectively.

With reference to the water productivity, higher mean value of $0.969 \text{ g grain kg}^{-1}$ of water was registered with 125 % PE level of drip irrigation which was 19.2 and 17.2 per cent more than that recorded with 100 and 150 % PE levels respectively. Regarding the fertigation levels, moderate level of fertilizers (100 % RDF + BF)

possessed increased water productivity (0.914) than 75 (0.813) or 125 % (0.882) RDF + BF level. Similar findings were also reported by Tuong *et al.* (2004) and Belder *et al.* (2005). Higher values of water productivity as observed in the present study with moderate level of water as well as fertilizer supply might be due to the increased grain yield with lesser water consumption (Belder *et al.*, 2005). Kobata *et al.* (1996) opined that moderate rate of transpiration in rice was often associated with higher water productivity. Tao *et al.* (2006) attributed differences in water productivity partially to greater HI values.

To conclude, higher values of water productivity as contemplated with the drip fertigation at 125 % PE and 100 % RDF level was largely a function of efficient water use rather than a net improvement in plant production or biochemistry of assimilation as contemplated by Blum (2005).

In summary, from the discussion made above, it could be inferred that the drip fertigation improves water and grain productivity, nutrient uptake and quality of the produce in aerobic rice. Nevertheless, the major drawback of the drip fertigation system is its high cost; however, the cost can be recovered in a short span of time if proper nutrient and water management along with the proper design principals are followed. Among various components of drip fertigation system, cost of laterals is the major factor, which influence the total system cost. Any effort made to reduce the length of laterals required per unit area of the field will result in reduction in the system cost.

Thus, the present investigation enlarged the vision and concept of the performance of aerobic rice under drip fertigation system. Morpho-physiological, biochemical and nutrio-physiological attributes contributing for yield improvement under micro-irrigation technique had been identified. At the end of the study, there is a feeling that in-built mechanism operating for such yield increase under biofertigation practice had been understood atleast in some essential aspects (**Plate 10**).

5.9. Optimization of inputs in drip fertigation

5.9.1. Optimization of total water applied

When the grain yield was regressed over total water applied, a quadratic curve was obtained of the form, $y = a+bx+cx^2$ (**Fig. 31a**). The grain yield increases until the total water applied reached a certain value, beyond which it began to decline.

From the above equation, the optimum 'x' (total water) is calculated by:

$$dy/dx = b+2cx = 0$$

By solving the above equation, optimum total water applied for maximizing the grain yield in aerobic rice through micro irrigation drip system was found to be 562.5 mm.

5.9.2. Optimization of nitrogen applied

As solved for arriving at the optimum total water application, the quadrature curve was used to find out the optimized value for nitrogen application (**Fig. 31b**) which was arrived at 159.6 kg ha⁻¹.

5.9.3. Optimization of phosphorus / potassium applied

Similar to nitrogen, optimum level of phosphorus / potassium application for maximizing grain productivity under drip fertigation was calculated at 53.2 kg ha⁻¹ (**Fig. 31c**).

5.10. Time course of available soil moisture as influenced by drip fertigation

The time course of percentage of available moisture upto the soil depth of 60 cm was studied at the chosen growth stages in the drip fertigated treatments and the data furnished in **Table 96**.

Table 96. Time trend in soil moisture (%) due to drip fertigation treatments at chosen stages in PMK (R) 3 aerobic rice, DS (2007)

	Treatment	AT	PI	FF	GF	Mean
T ₁	Conventional method	41.91	39.69	35.83	35.27	38.18
T ₂	100 % PE + 75 % RDF + BF	39.06	37.44	33.23	33.03	35.69
T ₃	100 % PE + 100 % RDF + BF	38.84	37.68	33.56	33.23	35.83
T ₄	100 % PE + 125 % RDF + BF	37.84	37.78	34.14	33.81	35.89
T ₅	125 % PE + 75 % RDF + BF	41.23	38.84	36.07	34.88	37.75
T ₆	125 % PE + 100 % RDF + BF	40.88	38.90	35.57	34.72	37.52
T ₇	125 % PE + 125 % RDF + BF	40.07	39.01	34.85	34.70	37.16
T ₈	150 % PE + 75 % RDF + BF	44.50	39.73	37.87	37.17	39.82
T ₉	150 % PE + 100 % RDF + BF	43.76	39.92	36.70	35.91	39.07
T ₁₀	150 % PE + 125 % RDF + BF	41.75	40.16	35.82	34.96	38.17
	Mean	40.98	38.92	35.36	34.77	

It is inferred that the time trend of available soil moisture generally tended to decline gradually from AT to GF stages. Mean percentage of available soil moisture was greater in excess water supply at 150 % PE level as well as at conventional practice than 125 or 100 % PE level irrespective of the fertilizer levels tried.

Closer analysis of the data further revealed that the available soil moisture was the least with T₂ and T₃ especially during PI, FF and GF stages of growth. Comparatively, the pinch of water stress was more realized at FF and GF stages in the above treatments because of increased water requirement in these growth stages (Yoshida, 1981) resulting in higher rate of depletion of soil moisture in the specified stages. This is also true for the excess rate of fertilizer application especially in higher water supplying situations.

Though rice crop is traditionally cultivated under lowland ecosystem with continuous flooding, it is also possible to grow the crop successfully with the threshold level of not less than 20 per cent depletion of available moisture especially with the water saving aerobic ecosystem (G. James Martin, pers. commun.). Beyond this threshold level, significant reduction in rice grain yield was observed (Castañeda *et al.*, 2002).

However, in the present investigation, the values of available soil moisture content observed especially during critical stages of FF and GF in the drip fertigation treatments at 100 % PE level (T₂, T₃ and T₄) were well below the afore mentioned threshold level of moisture as suggested for the aerobic rice.

Therefore, it is inferred that the crops of various biofertigation treatments scheduled at 100 % PE level experienced comparatively higher degree of water stress. Hence, the yield reduction as observed in these treatments is quite reasonable.

5.11. Simulation analysis for climate change scenarios

Future climate change is likely to have a significant impact on agricultural production depending upon the magnitude of CO₂ and temperature increase. The impact of global climate change on agriculture has been studied extensively for various crops at different scales (Lemon, 1983; Acock and Allen, 1985). However, relatively fewer studies have been focused on rice (Baker and Allen, 1993; Mohandass *et al.*, 1993; Penning de Vries, 1993). An adverse climate change effect on rice production had also been reported by Matthews *et al.* (1995a).

In the present study, attempts have been made to simulate the climate change effects on aerobic rice production for both conventional and drip fertigation systems. Simulation analysis indicated that there was a general increase of mean grain yield by 12.4 and 20.8 per cent with 540 and 720 vppm CO₂ levels respectively than the current climate (**Fig. 32**). On the contrary, the increment in temperature gradually reduced the mean yield by 1.5, 2.4, 4.8 and 10.1 per cent for +1, +2, +3 and +4°C respectively (**Fig. 33**).

Between the two irrigation systems, the drip fertigation practice had an advantage for the elevated CO₂ conditions, with the additional yield of 1052 and 1645 kg ha⁻¹ at 540 and 720 ppm CO₂ levels respectively over the current 360 vppm CO₂; but the corresponding yield increase was only 586 and 898 kg ha⁻¹ under conventional method. However, the yield decline due to temperature increment was more pronounced in drip fertigation than the conventional practice (**Fig. 34a and b**).

Nevertheless, doubling of atmospheric CO₂ level was more than able to compensate for the detrimental effect of increased temperature for the drip fertigation system; while, it was not able to do so in the case of conventional method. Therefore, it seemed clear that the yields in the conventional system would be much more affected by an increase in temperature and the associated elevated CO₂ level in future climates than would those in the drip fertigation practice.

This difference reflected that the normally encountered higher temperatures during DS would affect the crop productivity so that any further increase in temperature would likely to be a level where spikelet sterility from high temperature damage could be a major factor limiting the grain yield. This is especially true for the conventional system of irrigation and fertilizer application in the present investigation. In rice, spikelet fertility was influenced adversely by extreme temperatures immediately before and after flowering (Yoshida, 1981). A reduction in spikelet fertility reduced the number of grains that could form, so that even if carbohydrate production in the grain-filling period was unaffected, yields were reduced (Matthews *et al.*, 1995c).

Similar reduction in spikelet sterility and modified crop duration due to temperature increase were also observed by several authors (Kropff *et al.*, 1994; Matthews *et al.*, 1995b; Mohandass *et al.*, 1995).

Thus, through the simulation analysis, it could be inferred that the drip fertigation system would be better placed for aerobic rice with regard to the future climate change scenarios in terms of both elevated CO₂ and temperature levels. Nevertheless, it could also be possible that the temperature-induced yield alterations in future climates as observed with the conventional method of irrigation and fertilizer application could safely be narrowed down with the aid of CO₂ fertilization and biofertigation practice.

CHAPTER VI

SUMMARY AND CONCLUSION

Investigations were carried out to study the impact of drip fertigation on metabolic events related to growth and development and ultimate yield formation in aerobic rice. The field experiment was conducted during DS (2007) using PMK (R) 3 rice variety.

The present study indicated that the yield of drip fertigation practice excelled the conventional method of irrigation and fertilizer application. Favourable root characters, higher source capacity and its strength coupled with increased partitioning efficiency ultimately favoured the yield and its components in the drip fertigation practice. Advantageous effect of drip fertigation was also evidently seen to the expected level on various morpho-physiological and biochemical aspects and also on the parameters of nutritio-physiology and plant water status. In general, the growth as influenced by tiller production, root mass density, LAI, LAD, SLW, CGR and NAR and other chosen morphological attributes were favourably altered under drip fertigation system.

Biochemical processes such as higher chlorophyll content, increased photosynthetic efficiency (in terms of higher levels of soluble protein and Fv / Fm ratio) and pronounced activities of enzymes such as nitrate reductase, IAA oxidase and enhanced content of endogenous cytokinins were considered as the metabolic adjustors with the drip fertigation practice. But, increased contents of chlorophyll 'b' and proline and pronounced activities of AOS scavenging enzymes such as PO and SOD provided a mean of protection to the plants under limited water supply situations as evidenced with the stressed plants of drip fertigation system. Drip fertigated plants were endowed with higher values of ACR for both carbohydrate and nitrogen. Nevertheless, supplementation with biofertigation favoured for improvement in all the above mentioned aspects in both the water and fertigation stressed scenarios.

Though there was a serious set back in the parameters which were often related to the plant water status such as RWC, leaf water potential, MSI, CSI, transpiration rate, leaf diffusive resistance, canopy and leaf temperature under comparatively drier moisture regime, lesser impact was noticed with the supplementation of biofertigation proving their supremacy in the maintenance of favourable plant water status for restoration of

physiological and biochemical machineries which were otherwise impaired due to water insufficiency.

The uptake of nutrients of N, P, K, Ca, Mg, Fe, Mn, Zn and Cu were significantly and more favourably influenced by the drip fertigation system than the conventional practice. The retardation in the uptake of the chosen nutrients was noticed during flowering and grain filling stages in the case of limited water supplying environment. However, the supplementation of biofertigation was able to improve the uptake of nutrients by means of effective maintenance of plant water status. Incidentally, the values of Fe- and Zn-harvest index were improved with the drip fertigation thus adding nutritive value of the grains.

The major yield attributes such as panicle number, spikelet and grain number, filled grain percentage, 1000 grain weight, grain filling rate, Total Dry Matter Accumulation (TDMA), Panicle Harvest Index (PHI) and Grain Harvest Index (HI) were sufficiently improved with the drip fertigation system. Ultimately, the increase in grain yield was more pronounced in the drip fertigation practice than the conventional method of irrigation and fertilizer application. Thus, the biofertigation made definite improvement by maximizing the expression of these attributes by way of maintaining favourable internal plant water balance at all stages of crop growth. Biofertigation with *Azophosmet* could alter the shoot-root balance and thereby causing a favourable partitioning, diversion and transportation of major photoassimilates towards the reproductive 'sink'.

Molecular studies with SDS-PAGE protein profile further revealed that drought tolerant specific putative proteins were exhibited with low and moderate levels of water and fertilizer supply. These proteins could belong to Late Embryogeny Abundant (LEA) protein family which might infuse the drought tolerance ability to the above mentioned biofertilized plants. Thus, the specific and positive role of biofertigation in providing drought tolerant ability could be explicitly seen in the present investigation.

Similarly, presence of additional isoforms of peroxidase (PO) as observed with low and moderate levels of water and fertilizer supply treatments indicated their up-regulation in response to the stress which helped the plants in eliminating oxidative damage, lipid peroxidation and denaturation of protein under the stressed conditions.

Mean yield reduction of 22.2 per cent was observed with the limited water supply situations. Nevertheless, this reduction could be enhanced to + 16.0 per cent with the supplementation of biofertilization at appropriate water supply with the higher benefit : cost ratio of 2.41.

A close scrutiny of the data on correlation studies showed that grain yield of drip fertigation system was significantly and positively correlated with the traits such as PS II (Fv / Fm ratio), oxidizing power of roots, CGR, LAI, LAD, SLW, total chlorophyll, TAC, RWC and MSI. Similarly, path analysis also indicated that physiological traits such as PS II, CGR, TDMA and uptake of K, Ca and Fe possessed significant direct effects on grain yield.

The values of water productivity were higher for the drip biofertilization system than the conventional practice.

Simulation analysis of the well calibrated and validated dynamic model of ORYZA2000 using the present data inputs of drip fertigated aerobic rice indicated that under future climates, the grain yield showed a phenomenal jump (+ 22.6) with doubled CO₂. However, the temperature induced yield reduction in the changing climate could be negated with the CO₂ fertilization and biofertilization.

Significant findings and recommendations made for future adoption:

1. For aerobic rice, the drip fertigation was found suitable and yielded more than the conventional method of irrigation and fertilizer application.
2. Scheduling of drip fertigation at 125 % PE + 100 % RDF + Biofertilization (*Azophosmet*) performed better than the conventional practice.
3. Biofertilization with *Azophosmet* was an added advantage in improving morpho-physiological, growth and biochemical attributes which ultimately helped for improvement in the yield components and yield in the micro irrigation system.
4. The cytokinin producing miraculous bio-fertilizer, *Azophosmet* was highly effective with optimum water supply situations recording mean benefit : cost ratio of 2.41.
5. Through the simulation analysis, it was inferred that the temperature-induced yield alterations in future climates could be favourably mitigated with the CO₂ fertilization along with the supplementation of drip biofertilization.

REFERENCES

- Abou Seeda, W. 1993. Effect of aerobic-anaerobic condition on nutrients uptake by rice plant in waterlogged soils. **Egypt. J. Soil Sci.**, **33**: 125-134.
- Acock, B. and L.H. Jr. Allen. 1985. Crop responses to elevated carbon dioxide concentrations. Pages 53-98. **In**: B.R. Strain and J.D. Cure (Eds.) Direct effects of increasing carbon dioxide on vegetation. United States Department of Energy DOE / ER – 0238, USA.
- Adams, D.B. and W.W. Adams. 1996. Photoprotection and other responses of plants to high light stress. **Ann. Rev. Plant Physiol. Plant Mol. Biol.**, **43**: 599-626.
- Agarwal, G.C., A.S. Sidhu and N.T. Singh. 1995. Effect of the interaction of transplanting dates, irrigation schedule and N on rice yield. **International Rice Research Newsletter (IRRN)**, **14**: 22-24.
- Agarwal, R.M., R. Pandey and S. Gupta. 1999. Certain aspects of water stress induced changes and tolerance mechanisms in plants. **J. Indian Bot. Soc.**, **70**: 225-269.
- Aggarwal, P.K. and S.K. Sinha. 1987. Response of droughted wheat to mid-season water application: Recovery in leaf area and its effect on grain yield. **Aust. J. Plant. Physiol.**, **14**: 233-237.
- Agnew, C. and A. Warren. 1996. A framework for talking drought and land degradation. **J. Arid Environ.**, **33**: 309-320.
- Alam, S.M., I. Zafar and A. Latif. 1999. Fertigation technology for improved phosphorus use efficiency in wheat. **Pak. J. Sci. Ind. Res.**, **42**: 380-383.
- Ali, M. 1985. Effect of pre-sowing seed treatment, foliar nutrition and planting pattern on productivity and water use in chickpea under rainfed conditions. **Legume Res.**, **8**: 7-11.
- Allen, R.D. 1995. Dissection of oxidative stress tolerance using transgenic plants. **Plant Physiol.**, **107**: 1049-1054.

- Amischan Gani. 2001. Improving water use efficiency for sustainable rice production systems. **In:** W. Neigdijk and P. Bindraban (Eds.) Proceedings of an International workshop on Water Saving Rice Production Systems at Nanjing University, China, April 2-4, 2001.
- Anaytullah, Bandana Bose and R.S. Yadav. 2007. PEG induced moisture stress: sensing for drought tolerance in rice. **Indian J. Plant Physiol.**, **12 (N.S.):** 88-90.
- Anbumozhi, V., E.Yamaji, T. Tabuchui. 1994. Variability of flood water depth, soil properties and crop yield in a large sized paddy field. Proceedings of the International Agricultural Engineering Conference and Exhibition, Bangkok, Thailand, pp. 667–676
- Anonymous, 1989. Manual for Chlorophyll Meter SPAD-502. Minolta Camera Co., Osaka, Japan.
- Anonymous, 1994. Proceedings of the Scientific Workers Conference in Horticulture, Tamil Nadu Agricultural University, Coimbatore, India, pp. 15-17.
- Anonymous, 2004. Annual report of the All India Co-ordinated Project on Biological Nitrogen fixation (BNF), Indian Council of Agricultural Research, New Delhi, India.
- Anthoni Raj, S., G. Gopalasamy and A. Abdul kareem. 1994. Effect of graded levels of phosphorus and phosphobacteria inoculation on rice. **Indian J. Microbiol.**, **38:** 111-112.
- Anthony, C. 1986. Bacterial oxidation of methane and methanol. **Adv. Micriobiol. Physiol.**, **27:** 113-210.
- Anu Rajan, S. 2003. Studies on the occurrence of pink pigmented facultative methylotrophs on vegetable crops. **M. Sc. (Ag.) thesis** submitted to Tamil Nadu Agricultural University, Coimbatore, 641 003. India.
- Arrandean, M.A. 1989. Breeding strategies for drought resistance. Pages 107-116. **In:** E.W.G. Baker (Ed.) Drought resistance in cereals. CAB International, U.K.

- Aruna Tyagi, Narendra Kumar and R.K. Sairam. 1999. Efficacy of RWC, membrane stability, osmotic potential, endogenous ABA and root biomass as indices for selection against water stress in rice. **Indian J. Plant Physiol.**, **4** (N.S.): 302- 306.
- Asada, K. 1992. Ascorbate peroxidase - a hydrogen peroxide scavenging enzyme in plants. **Physiol. Plant.**, **85**: 235-241.
- Aujla, M.S., H.S. Thind and G.S. Battar. 2005. Cotton yield and water use efficiency at various levels of water and N through drip irrigation under two methods of planting. **Agric. Water Manage.**, **71**: 167-179.
- Babu, R.C., D.B. Nguyen, V. Chamerek, P. Shamugasundaram, P. Chezian, P. Jeyaprakash, S.K. Ganesh, A. Palchamy, S. Sadasivam, S. Sarkarung, L.J. Wade and H.T. Nguyen. 2003. Genetic analysis of drought resistance in rice by molecular markers. Association between secondary traits and field performance. **Crop Sci.**, **43**: 1457-1469.
- Baddeley, R.M. and J. Dobereiner. 1995. Nitrogen fixation associated with grasses and cereals - recent progress and perspectives for the future. **Fert. Res.**, **42**: 241-250.
- Baker, J.T. and L.H. Jr. Allen. 1993. Effect of CO₂ and temperature on rice: A summary of five growing seasons. **J. Agr. Met.**, **48**: 575-582.
- Baker, J.T., L.H. Jr. Allen and K.J. Boote. 1990a. Growth and yield responses of rice to carbon dioxide concentration. **J. Agric. Sci.**, **115**: 313-320.
- Baker, J.T., L.H. Jr. Allen, K.J. Boote, P. Jones and J.W. Jones. 1990b. Developmental responses of rice to photoperiod and carbon dioxide concentration. **Agric. For. Meteorol.**, **50**: 201-210.
- Baker, J.T., L.H. Jr. Allen, K.J. Boote, A.J. Rowland-Bamford, R.S. Waschmann, J.W. Jones, P.H. Jones and Bowes. 1990c. Response of vegetation to carbon dioxide: Temperature effects on rice at elevated CO₂ concentration. DOE Progress Report No. 60. 71 p.
- Balasubramanian, R. and J. Krishnarajan. 2001. Post harvest soil available nutrient status of direct seeded rice (*Oryza sativa* L.) influenced by water management practices. **Fert. News**, **46**: 65-68.

- Barber, S.A. 1962. A diffusion and mass flow concept of nutrient availability. **Soil Sci.**, **93**: 39-49.
- Barber, S.A. 1984. Soil nutrient bioavailability. Wiley and Sons Inc., New York, USA, pp. 179-182.
- Barker, R., D. Dawe, T.P. Tuong, S.I. Bhuiyan and L.C. Guerra. 1999. The outlook for water resources in the year 2020: challenges for research on water management in rice production. Pages 96-109. **In**: Assessment and orientation towards the 21st century. Proceedings of the 19th session of the International Rice Commission, 7-9 September 1998, Cairo, Egypt. Food and Agriculture Organization, Rome, Italy.
- Baruah, K.K., S.S. Bhuyan, T.J. Ghosh and A.K. Pathak. 1998. Response of rice genotypes to moisture stress imposed at seedling stage. **Indian J. Plant Physiol.**, **3 (N.S.)**: 181-184.
- Bar-Yosef, B. 1982. Response of tomato to N and water applied via a trickle irrigation system. **Agron. J.**, **74**: 633-638.
- Basile, D.V., M.R. Basile, Q.Y. Li and W.A. Corpe. 1985. Vitamin B₁₂ simulated growth and development of *Jungermannia leiantha* Grolle and *Gymnocolea inflata* (Huds.) Dum. (Hepaticae). **Bryologist**, **88**: 77-81.
- Basu Raychaudhuri, N.C and D.K. Das Gupta. 1981. Morphological characters of rice associated with drought tolerance in uplands. **Oryza**, **18**: 150-152.
- Bates, L.S., R.P. Waldren and T.D. Teak. 1973. Rapid determination of free proline for water stress studies. **Plant and Soil**, **39**: 205-207.
- Beau-Champ, C. and I. Fridovich. 1971. Superoxide dismutase: Improved assays and assay applicable to acrylamide gels. **Anal. Biochem.**, **44**: 276-287.
- Becking J.H. 1962. An aerobic heterotrophic Spirillum, fixing atmosphere nitrogen. Proc. 8th International Congress for Microbiology, Montreal, Canada, Abstract, B 14, 5.
- *Beijerinck, M. W. 1925. *Azotobacter chroococcum* as indicator van den ground. **K. Ned. Akad. Wet. Vrs. Gewore Vergad. Afd. Natuvrkd.**, **30**: 431-438.

- Belder, P., B.A.M. Bouman, J.H.J. Spiertz and G. Lu. 2007. Comparing options for water savings in lowland rice using a modeling approach. **Agric. Syst.**, (in press.).
- Belder, P., B.A.M. Bouman, J.H.J. Spiertz, S. Peng and A.R. Casteñda. 2005. Crop performance, nitrogen and water use in flooded and aerobic rice. **Plant and Soil**, **273**: 167-182.
- Bhattacharya, S. and S.K. Ghosh. 2004. Association among yield and yield related traits of twenty-four diverse land races of rice. **Crop Res.**, **27**: 90-93.
- Bhuiyan, S.I., M.A. Sattar and M.A.K. Khan. 1995. Improving water use efficiency in rice irrigation through wet seeding. **Irrig. Sci.**, **16**: 1-8.
- Bill Segars. 2003. Fertigation in IMC Global (Ed.) **Efficient fertilizer use: Manual**, Fourth Edition. Accessed at <http://www.agcentrl.com /imcdemo> / 10fertilization.html.
- Biswas, B.C. and I.C. Mahapatra. 1980. Uptake of plant nutrients by direct seeded rice (Pusa 21) under well-drained and waterlogged conditions. **Indian J. Agron.**, **25**: 471-478.
- Biswas, D.R. and M.S. Dravid. 2001. Phosphorus and zinc interactions influenced by magnesium on yield and nutrient uptake by rice under varying moisture regimes. **Ann. Agric. Res. New Series**, **22**: 229-234.
- Blum, A. 1998. Plant breeding for stress environments. CRC Press, Florida, USA.
- Blum, A. 2002. Drought tolerance - Is it a complex trait? Pages 17-22. **In**: N.P. Saxena and J.O'Toole (Eds.) Field screening for drought tolerance in crop plants with emphasis of rice. ICRISAT, Patancheru, India.
- Blum, A. 2005. Drought resistance, water-use efficiency, and yield potential - are they compatible, dissonant, or mutually exclusive? **Aust. J. Agric. Res.**, **56**: 1159-1168.
- Boardman, N.K. and J. Anderson. 1964. Isolation from spinach chloroplasts of particles containing different proportions of chlorophyll 'a' and 'b' and their possible role in the light reaction of photosynthesis. **Nature**, **203**: 166-167.

- Bobade, S.V. 1999. Studies on drip irrigation and nitrogen levels on the water use and yield of brinjal (CO 2). **M.Sc. (Ag) thesis**. Tamil Nadu Agricultural University. Coimbatore 641 003, India.
- Bolling, A., B.A.M. Bouman, T.P. Tuong, M.V.R. Murty and S.Y. Jatmiko. 2007. Modelling the effect of groundwater depth on yield-increasing interventions in rainfed lowland rice in Central Java, Indonesia. **Agric. Syst.**, (In press).
- Boo,Y.C. and J. Jung. 1999. Water deficit-induced oxidative stress and antioxidant defences in rice plants. **J. Plant Physiol.**, **155**: 255-261.
- *Boonjung, H. 1993. Modelling growth and yield of upland rice under water limiting conditions. **Ph.D. thesis** submitted to University of Queensland, Queensland, Australia.
- Boonjung, H. and S. Fukai. 1996. Effect of soil water deficit at different growth stage on rice growth and yield under upland conditions. II. Phenology biomass production and yield. **Field Crops Res.**, **48**: 47-55.
- Borell, A., A. Garside and S. Fukai. 1997. Improving efficiency of water use for irrigated rice in a semi-arid tropical environment. **Field Crops Res.**, **52**: 231-248.
- Bouman, B.A.M. 2001. Water efficient management strategies in rice production. **IRRN**, **26 (2)**: 17-22.
- Bouman, B.A.M. and H.H. Van Laar. 2006. Description and evaluation of the rice growth model ORYZA2000 under nitrogen-limited conditions. **Agric. Syst.**, **87**: 249-273.
- Bouman, B.A.M. and T.P. Tuong. 2001. Field water management to save water and increase its productivity in irrigated rice. **Agric. Water Manage.**, **49**: 11-30.
- Bouman, B.A.M., L. Feng, T.P. Tuong, G. Lu, H. Wang and Y. Feng. 2007. Exploring options to grow rice using less water in northern China using a modeling approach. II. Quantifying yield, water balance components and water productivity. **Agric. Water Manage.**, **88**: 23-33.
- Bouman, B.A.M., M.J. Kropff, T.P. Tuong, M.C.S. Wopereis, H.F.M. Ten Berge and H.H. Vann Laar. 2001. ORYZA2000: Modelling lowland rice. International Rice Research Institute, Wageningen University and Research Centre, Los Baños, Philippines, Wageningen, Netherlands, 235 pp.

- Bouman, B.A.M., Y. Xiaoguang, W. Huaqui, W. Zhiming, Z. Junfang, W. Changgui and C. Bin. 2002. Aerobic rice (Han Dao): A new way growing rice in water short areas. pp. 175-181. **In:** Proceedings of the 12th International Soil Conservation Organization Conference, May 26-31, 2002 held at Beijing, China. Tsinghua University Press.
- Bouman, B.A.M., Y. Xiaoguang, W. Huaqi, W. Zhiming, Z. Junfang, C. Bin. 2006. Performance of aerobic rice varieties under irrigated conditions in North China. **Field Crops Res.**, **97**: 53-65.
- Bowes, G., W.I. Orgen and R.H. Hageman. 1972. Light saturation photosynthesis rate, RuBP carboxylase activity and specific leaf weight in soybeans grown under different light intensities. **Crop Sci.**, **12**: 77-79.
- Bowler, C., M. Van Montagy and D. Inze. 1992. Superoxide dismutase and stress tolerance. **Ann. Rev. Plant Physiol. Plant Mol. Biol.**, **43**: 83-116.
- Bresler, E. 1977. Trickle / drip irrigation: principles and application to soil-water management. **Adv. Agron.**, **29**: 343-393.
- Buckley, T.N. 2005. The control of stomata by water balance. **New Phytol.**, **168**: 275-295.
- Bunce, J.A. 1977. Leaf elongation in relation to leaf water potential in soybean. **J. Exptl. Bot.**, **28**: 156-161.
- Buttar, G.S., H.S. Thind and M.S. Aujla. 2006. Methods of planting and irrigation at various levels of nitrogen affect the seed yield and water use efficiency in transplanted oilseed rape (*Brassica napus* L.). **Agric. Water Manage.**, **85**: 253-260.
- Cabuslay. G.S., O. Ito and A.A. Alejar. 2002. Physiological evaluation of responses of rice (*Oryza sativa* L.) to water deficit. **Plant Sci.**, **163**: 815-827.
- Cao, J. and J. Govindjee. 1990. Chlorophyll 'a' fluorescence transient as an indicator of active and inactive photosystem II in thylakoid membranes. **Biochem. Biophys. Acta**, **1015**: 180-188.
- Cassman, K.G., A. Dobermann and D.T. Walters. 2002. Agroecosystems, nitrogen-use efficiency and nitrogen management. **Ambio.**, **31**: 132-140.

- Castañeda, A.R., B.A.M. Bouman, S.Peng and R.M.Visperas. 2002. The potential of aerobic rice to reduce water use in water-scarce irrigated lowlands in the tropics. Pages 165-176. **In:** B.A.M. Bouman, H. Hengdijik, H.Hardy, P.S. Bindraban, T.P. Tuong and J.K. Ladha (Eds.) Proceedings of the International Workshop on Water-wise Rice Production, 08-11 April, 2002, Los Baños, Philippines. IRRI, Los Baños, Philippines.
- Chang, T.T., G. Loresto and O. Tagumpay. 1972. Agronomic and growth characteristics of upland and lowland rice varieties. Pages 645-661. **In:** Rice Breeding, IRRI, Los Baños, Philippines.
- Chauhan, J.S., T.B. Moya, R.K. Singh and C.V. Singh. 1996. Growth and development under different soil moisture regimes in upland rice (*Oryza sativa* L.). **Indian J. Plant Physiol.**, **1** (N.S.): 270-272.
- Chen, W.F., Z.J. Xu, L.B. Zhang and S.R. Yang. 1990. Comparative studies on stomatal density and its relation to gas diffusion resistance and net photosynthetic rate in rice leaf. **Chinese J. Rice Sci.**, **4**: 163-168.
- Christopher Lourduraj, A. and A. Rajagopal. 1999. Effect of irrigation regimes and planting geometry on nutrient availability, uptake of nutrients and grain yield in rice. **Madra Agric. J.**, **86**: 347-351.
- Cho, D.S., S.K. Jong, Y.K. Park and S.Y. Son. 1987. Studies on the duration and rate of filling in rice (*Oryza sativa* L.). I. Varietal difference and effects of nitrogen. **Kor. J. Crop Sci.**, **32**: 103-111 (in Korean with English abstract).
- Chubachi, T., I. Asano and T. Oikawa. 1986. The diagnosis of nitrogen nutrition of rice plants (Sasanishiki) using chlorophyll meter. **Japanese J. Soil Sci. Plant Nutr.**, **57**: 190-193.
- Corpe, W.A. and S. Rheem. 1989. Ecology of the mehtylotrophic bacteria on living leaf surfaces. **FEMS Microbiol. Ecol.**, **62**: 243-250.
- Creus, C.M., R.J. Sueldo and C.A. Barassi. 1997. Shoot growth and water status in Azospirillum inoculated wheat seedling grown under osmotic and salt stresses. **Plant Physiol., Biochem. (Paris)**, **35**: 939-944.

- Creus, C.M., R.J. Sueldo and C.A. Barassi. 1998. Water relations in *Azospirillum* - inoculated wheat seedlings under osmotic stresses. *Can. J. Bot.*, **76**: 238-244.
- Crooke, W.M. 1964. The measurement of cation exchange of plant roots. **Plant and Soil**, **291**: 43-49.
- Crosson, P.R. 1989. Climate changes. American agriculture and natural resources: discussion. **Amer. J. Agric. Econ.**, **71**: 1283-1285.
- Crozier, A., P. Arruda, J. Jasmin, A.K.M. Anterior and G. Sandberg. 1988. Analysis of indole 3 acetic acid and other indoles in culture medium from *Azospirillum lipoferum* and *Azospirillum brasilense*. **Appl. Env. Microbiol.**, **54**: 2833-2837.
- Cruz, R.T. and J.C. O'Toole. 1984. Dryland rice response to an irrigation gradient at flowering stage. **Agron. J.**, **76**: 178-182.
- Cruz, R.T., J.C. O'Toole, M. Dingkuhn, E.B.Yambao, M. Thangaraj and S.K. De Datta. 1986. Shoot and root responses to water deficits in rainfed lowland rice. **Aust. J. Plant Physiol.**, **13**: 567-575.
- Cure, J.D. 1985. Carbon dioxide doubling responses: A crop survey. Pages 99-116. **In**: B.R. Strain and J.D. Cure (Eds.) Direct effects of increasing carbon di oxide on vegetation., U.S. Department of Energy, DOE / ER-0238.
- Cure, J.D. and B. Acock. 1986. Crop responses to carbon dioxide doubling: A literature survey. **Agric. For. Meteorol.**, **38**: 127-145.
- *Dalbro, K. and K. Dorph Peterson. 1976. Soil sampling in drip-irrigated glasshouse. **Tidsskrift for Planteavl.**, **80**: 652-655.
- Darbyshire, B. 1971. Changes in indole acetic acid oxidase activity associated with plant water potential. **Physiol. Plant.**, **25**: 80-84.
- Day, J. M. and J. Dobereiner. 1976. Physiological aspects of N₂ fixation by a *spirillum* from *Digitaria* roots. **Soil Biol. Biochem.**, **8**: 45-50.
- De Datta, S.K., 1981a. Water management practices for rice. **In**: Principles and practices of rice production, John Wiley and Sons Inc., New York, U.S.A. p. 392

- De Datta, S.K. 1981b. Principles and practices of rice production. John Wiley and Sons Inc., New York, U.S.A. 460-618 pp.
- Deka, M. and K.K. Baruah. 2000. Comparable studies of rainfed upland winter rice (*Oryza sativa* L.) cultivars for drought tolerance. **Indian J. Agric. Sci.**, **70**: 135- 139.
- Delauney, A.J. and D.P.S. Verma. 1993. Proline biosynthesis and osmoregulation in plants. **Plant J.**, **4**: 215-223.
- Deshmukh, P.S., R.K. Sairam and D.S. Shukla. 1991. Measurement of ion leakage as a screening technique for drought resistance in wheat genotypes. **Indian J. Plant Physiol.**, **35**: 89-91.
- DeSouza, P.I., D.B. Egli and W.P. Bruening. 1997. Water stress during seed filling and leaf senescence in soybean. *Agro. J.*, **89**: 807-812.
- Dey, S.K. and C.N. Rao. 1989. Effect of dehydration on photosynthesis in rice. **Oryza**, **26**: 199-200.
- Dhanda, S.S., G.S. Sethi and R.K. Behl. 2004. Indices of drought tolerance in wheat genotypes at early stages of plant growth. **J. Agron. Crop Sci.**, **190**: 6-12.
- Dhurandher, R.L. and R.S. Tripathi. 1999. Impact of sowing method and N levels on productivity of late duration rice cultivars in Vertisol. **Haryana J. Agron.**, **15**:1-5.
- Dhyani, B.P. and B. Mishra. 1994. Scheduling nitrogen application for rice in millisols. **Oryza**, **31**: 202-205.
- Dikshit, P.R. and S.K. Padihar. 1988. Effect of soil moisture regime and applied phosphorus on inorganic phosphate fractions and availability of phosphorus to rice grown on vertisol. **Oryza**, **25**: 157-163.
- Dingkuhn, M., R.J. Cruz, J.C. O'Toole, N.C. Turner and K. Dorffling. 1991. Responses of seven diverse rice cultivars to water deficits. III. Accumulation of abscissic acid and proline in relation to leaf water potential and osmotic adjustment. **Field Crops Res.**, **27**: 103-117.

- Dingkuhn, M., R.T. Cruz, J.C. O'Toole and K. Dorffling. 1989. Net photosynthesis, water use efficiency, leaf water potential and leaf rolling as affected by water deficit in tropical upland rice. **Aust. J Agric. Res.**, **40**: 1183-1192.
- Dong, B., D. Molden, R. Loeve, Y. Li, C. Chen and J. Wang. 2004. Farm level practices and water productivity in Zanghe irrigation system. **Paddy Water Environ.**, **2**: 217-226.
- Doorenbos, J. A.H. Kassam. 1979. Yield response to water. Irrigation and Drainage Paper No. 33. FAO, Rome, Italy.
- Dornhoff, G.M. and R.M. Shibles. 1976. A survey of soybean cultivars for variability in specific leaf weight. **Crop Sci.**, **16**: 377-381.
- Dure, L. 1993. A repeating 11-mer amino acid motif and plant desiccation. **Plant J.**, **3**: 363-369.
- Dure, L., M. Crouch, J. Harada, T.H.D. Ho, J. Mundy, R.S. Quatrano, T. Thomas and Z.R. Sung. 1989. Common amino acid sequence domains among the LEA proteins of higherplants. **Plant Mol. Biol.**, **12**: 475-486.
- Ekanayake, I.J., P.L. Steponkus and S.K. De Datta. 1990. Sensitivity of pollination to water deficits at anthesis in pland rice. **Crop Sci.**, **30**: 310-315.
- Ekanayake, I.J., S.K. De Datta and P.L. Steponkus. 1989. Spikelet sterility and flowering response of rice to water stress at anthesis. **Ann. Bot.**, **63**: 257-264.
- Fadzillah, N.M., V.Gill, R.P. Finch and R.H. Burdon. 1996. Chilling, oxidative stress and antioxidant responses in shoot cultures of rice. **Planta**, **199**: 552-556.
- Fallik, E., Y. Okon and M. Fischer. 1988. The effect of *Azospirillum brasilense* inoculation on metabolic enzyme activity in maize root seedlings. **Symbiosis**, **6**: 17-28.
- Fang, R.J., T.H. Li and M.Z. Zhang. 1996. Study on growing features of rice roots under water deficit irrigation conditions. **China Rural Water and Hydropower**, **8**: 11-14. (In Chinese with English. Abstract).

- Feng, L., B.A.M. Bouman, T.P. Tuong, R.J. Cabangon, Y. Li, G. Lu and Y. Feng. 2007. Exploring options to grow rice using less water in northern China using a modeling approach. I. Field experiments and model evaluation. **Agric. Water Manage., 88:** 1-13.
- Fukai, S. and M. Cooper. 1995. Development of drought resistance cultivars using physiological morphological traits in rice. **Field Crops Res., 40:** 67-86.
- Fukai, S., G. Pantuwan, B. Jongdee and M. Cooper. 1999. Screening for drought resistance in rainfed lowland rice. **Field Crops Res., 64:** 61-74.
- Fukai, S., L. Li, P.T. Vizmonte and K.S. Fischer. 1991. Control of grain yield by sink capacity and assimilate supply in various rice cultivars. **Exptl. Agric., 27:** 127-135.
- Furuki, T., 1983. Water management and requirement in paddy fields. Advanced Rice Cultivation, Irrigation and Drainage Technology in Japan, pp. 126-145.
- Fussel, L.K., F.R. Bidinger and P. Bieker. 1991. Crop physiology and breeding for drought tolerance: research and development. **Field Crops Res., 27:** 183-199.
- Ganesh, H.V. 2000. Effect of various schedules on yield and water use in transplanted paddy. **Mysore J. Agric. Sci., 34:** 222-226.
- Gao, X., C. Zou, X. Fan, F. Zhang and E. Hoffland. 2006. From flooded to aerobic conditions in rice cultivation: Consequences of zinc uptake. **Plant and Soil, 280:** 41-47.
- Garica, A.L., Torrecillas, A., A. Leon and M.C. Ruiz-Sanchez. 1987. Biochemical indicators of the water stress in maize seedlings. **Biologia Plant., 29:** 45-48.
- Garrity, D.P., E.T. Vidal and J.C. O'Toole. 1986. Manipulating panicle transpiration resistance to increase rice spikelet fertility during flowering stage water stress. **Crop Sci., 26:** 789-795.
- Garrity, D.P. and J.C. O'Toole. 1994. Screening rice for drought resistance at the reproductive stage. **Field Crops Res., 39:** 99-110.
- Gaur, A.C. and S. Gai. 1999. Phosphate solubilizing microorganisms - an overview. **Curr. Trends in Life Sci., 23:** 151-164.

- Gautam, R.C. and K.C. Sharma. 1993. Growth analysis of rice varieties under different planting schedules and densities. **Oryza**, **30**: 19-25.
- Gifford, R.M., P.M. Bremner and D.B. Jones. 1973. Assessing photosynthetic limitation to grain yield in a field crop. **Aust. J. agric. Res.**, **24**: 297-307.
- Girousse, C., R. Bournoville and J.L. Bonnemain. 1996. Water deficit-induced changes in concentrations of proline and some other amino acids in phloem sap of alfalfa. **Plant Physiol.**, **111**: 109-113.
- Gooth, S. and W.H. Jr. Patrick. 1972. Transformation of iron and manganese in a waterlogged soil as influenced by redox potential and pH. **Soil Sci. Amer. Proc.**, **36**: 738.
- Gomez, K.A. and A.A. Gomez. 1984. Statistical procedures for agricultural research. (2nd Ed.) John Wiley and Sons, New York, USA. 680 p.
- Gonzalez-Bernaldez, F., J. Lopez-Saez and G. Garica-Ferrero. 1968. Effect of osmotic pressure on root growth, cell cycle and cell elongation. **Protoplasma**, **65**: 255-262.
- Goudriaan, J. and M.H. Unsworth. 1990. Implications of increasing carbon dioxide and climate change for agricultural productivity and water resources. **In**: B.A. Kimball, N.J. Rosengerg and L.H. Allen Jr. (Eds.) Impact of carbon dioxide, trace gases and climate change on global agriculture. ASA Special Publication No. 353, American Society of Agronomy, Madison, Wisconsin, USA.
- Gowri, S. 2005. Physiological studies on aerobic rice (*Oryza sativa* L.). **M.Sc. (Ag.) thesis** submitted to Tamil Nadu Agricultural University, Coimbatore 641 003. India.
- Gratez, D.A., J.G.A. Fiskell and J.M. Myers. 1978. Chloride and bromide movement with trickle irrigation of bell peppers. **Proc. Florida State Hort. Soc.**, **91**: 319-322.
- Guerra, L.C. S.I. Bhuiyan, T.P. Tuong and R. Barker. 1998. Producing more rice with less water from irrigated systems. SWIM paper 5, IWMI/IRRI, Colombo, Sri Lanka. 24 pp.
- Hadas, R. and Y. Okon. 1987. Effect of *Azospirillum brasilense* inoculation on root morphology and respiration in tomato seedlings. **Biol. Fertl. Soil**, **5**: 241-247.

- Hafeez, M.M., B.A.M. Bouman, N. Van de Giesen and P. Vlek. 2007. Scale effects on water use and water productivity in a rice-based irrigation system (UPRIIS) in the Philippines. **Agric. Water Manage.**, **92**: 81-89.
- Hagin, J. and A. Lowengart. 1996. Fertigation for minimizing environmental pollution by fertilizers. **Fert. Res.**, **43**: 5-7.
- Hake, D.A., G.M. Bharad, S.K. Kohale and M.B. Mogdere. 1992. Effect of plant population on growth and yield of pre monsoon cotton under drip irrigation. **Indian J. Agron.**, **37**: 393-395.
- Harper, J.E. and R.L. Cooper. 1971. Nodulation response of soybeans of application rate and placement of combined nitrogen. **Crop Sci.**, **11**: 438-440.
- Hasegawa, S., M. Thangaraj and J.C.O'Toole. 1984. Root Behaviour: Field and Laboratory studies for rice and non-rice crops. International workshop on Physical Aspects of Soil Management In: Rice-Based Cropping Systems (PASMIRCS). International Rice Research Institute, Los Baños, Philippines.
- Hayashi, S., A. Kamoshita and J. Yamagishi. 2006. Effect of planting density on grain yield and water productivity of rice (*Oryza sativa* L.) grown in flooded and non-flooded fields in Japan. **Plant Prod. Sci.**, **9**: 298-311.
- Haynes, R.J. 1985. Principles of fertilizer use for trickle irrigated crops. **Fert. Res.**, **6**: 235-255.
- Heady, E.A. and T.L. Dillon. 1961. Agriculture Production Function, Iowa State University Press, U.S.A.
- Henry, T., H.T. Nguyen, R. Chandra Babu and A. Blum. 1997. Breeding for drought resistance in rice: Physiology and Molecular genetics considerations. **Crop Sci.**, **37**: 1426-1434.
- Herman, J.F. 1982. CRC Hand Book of Irrigation Technology, CRC Press, Florida, USA.
- Holland, M.A. 1997. *Methylobacterium* and plants. **Recent Res. Develop. Plant Physiol.**, **1**: 207-213.

- Horie, H. T. Shiraiwa, K. Homma, K. Katsura, S. Maeda and H. Yoshida. 2005. Can yields of lowland rice resume the increase that they showed in the 1980s? **Plant Prod. Sci.**, **8**: 257-272.
- Hugar, L.B. 1996. Technoeconomic feasibility of drip irrigation techniques. **In**: Proc. National Seminar on Modern Irrigation Technique, June 26-27,, 293-297 pp.
- Ichwantori, T., O.Y. Takamura and M. Tsuchiya. 1999. Growth response of rice (*Oryza sativa* L.) to drought. I. Varietal difference in growth rate, nitrogen uptake and tillering habit at vegetative state. **Japanese J. Crop Sci.**, **58**: 740-747.
- *Inada, K. 1985. Spectral ratio of reflectance for estimating chlorophyll content of leaf. **Japanese J. Crop Sci.**, **54**: 261-265.
- Iqbal, Z., A.Latif, S. Ali and M. Iqbal. 2003. Effect of fertigated phosphorus on P use efficiency and yield of wheat and maize. **Songklanakarin J. Sci. Technol.**, **25**: 697-702.
- IRRI (International Rice Research Institute). 1964. The Mineral Nutrition of the Rice Plant. pp. 271–281. International Rice Research Institute, Los Banos, Philippines.
- IRRI (International Rice Research Institute). 1997. Rice Almanac. Second Edition. International Rice Research Institute, Los Baños, Philippines.
- IRRI (International Rice Research Institute). 2001. Annual Report for 2000-2001. Rice Research: The way forward. pp. 71-73. International Rice Research Institute, Los Banos, Philippines.
- IRRI (International Rice Research Institute). 2002. Rice Almanac. Third Edition. International Rice Research Institute, Los Banos, Philippines.
- Iruthayaraj, M.R. and Y.B. Morachan. 1980. Note on the effect of seasons, stages, water management and nitrogen levels on the uptake of phosphorus in two swamp rice varieties. **Indian J. Agric. Res.**, **14**: 254-258.
- Ishida, H., S. Shimizu, A. Makino and T. Mae. 1998. Light-dependent fragmentation of the large sub unit of ribulose - 1, 5-bisphosphate carboxylase / oxygenase in chloroplasts isolated from wheat. **Planta**, **204**: 304-309.

- Islam, M.R., K.A. Haq and L.R. Bhuiyan. 1986. Effect of different water management practices on grain yield, weed population and recovery and applied nitrogen in rice cultivation. **Bangladesh J. Agric.** **1** : 57-64.
- Itai, C. and L.G. Paleg. 1982. Response of water stressed *Hordeum distichum* and *Cucumis sativus* to proline and betaine. **Plant Sci. Lett.**, **25**: 329-335.
- Ivanova, E.G., N.V. Doronina, A.O. Shepelyakovskaya, A.G. Lama, F.A. Broivko and Y. A. Trotsenko. 2000. Facultative and obligate aerobic methylobacteria synthesize cytokinins. **Mikrobiologiya**, **69**: 764-769.
- Jackson M. 1997. Hormones from roots as signals for the shoots of stressed plants. **Elsevier Trends Journals**, **2**: 22-28.
- Jackson, M.L. 1973. **Soil chemical analysis**. Prentice Hall of India Pvt Ltd., New Delhi, India.
- Jain, S., R.M. Agarwal and H.S. Tiwari. 1996. Seedling growth of rice (*Oryza sativa* L. var. "Kranti") under polyethylene glycol '6000' induced water stress. **Physiol. Mol. Biol. Plants.**, **2**: 71-74.
- Jaiswal, B.P., A.K. Jha, N.L. Sah and U.S. Prasad. 1982. Characteristics of fruit growth and development in litchi varieties. **Indian J. Plant Physiol.**, **25**: 411-414.
- Jana, R.K. and B.P. Ghildyal. 1971. Effect of varying soil water regimes during different growth phases on yield of rice under different atmospheric evaporative demands. **Il Riso**, **20**: 31-37.
- Janardhan, K.V., K.S. Murty and N.M. Dash. 1980. Effect of low light during ripening period of grain yield and translocation of assimilates in rice varieties. **Indian J. Plant Physiol.**, **23**: 163-168.
- Jansen, D.M. 1990. Potential rice yields in future weather conditions in different parts of Asia. **Neth. J. Agric. Sci.**, **38**: 661-680.
- Jayabalan, M., C. Chandrasekaran, E.G. Wesely, P. Mahalingam and C. Shaji. 1995. Metabolic response of rice varieties under water stress. **J. Ecotoxicology and Environmental Monitoring**, **5**: 59-66.

- Jeya Bharathi, M. 2006. Studies on the role of mixed inoculant *Azophos* on the water stress management of rice. **M.Sc. (Ag.) thesis** submitted to Tamil Nadu Agricultural University, Coimbatore 641 003. India.
- Jha, B.N. and R.A. Singh. 1997. Physiological responses of rice varieties to different levels of moisture stress. **Indian J. Plant Physiol.**, **2**: 81-84.
- Jiang, M.Y., J.M. Jing and S.T. Wang. 1991. Effect of osmotic stress on membrane lipid peroxidation and endogenous protective systems in rice seedlings. **Acta Phytophysiological Sinica**, **17**: 80-84.
- Jing, Q., T. Dai, D. Jiang, Y. Zhu and W. Cao. 2007. Spatial distribution of leaf area index and leaf N content in relation to grain yield and nitrogen uptake in rice. **Plant Prod. Sci.**, **10**: 136-145.
- Jones, D.B., M.L. Peterson and S. Geng. 1979. Association between grain filling rate and duration and yield components in rice. **Crop Sci.**, **19**: 641-644.
- Jongdee, B., S. Fukai and M. Cooper. 2002. Leaf water potential and osmotic adjustment as physiological traits to improve drought tolerance in rice. **Field Crops Res.**, **76**: 153-163.
- Joseph, M.C., D.D. Randall and C.J. Nelson. 1981. Photosynthesis and RUBP-case of polyploidy tall fescue. **Plant Physiol.**, **68**: 894-898.
- Kamoshita, A., M. Ishikawa, J. Abe and H. Imoto. 2007. Development of water saving rice-winter crop production system in a shrub in Tokyo in the view of water productivity. **Plant Prod. Sci.**, **10**: 219-231.
- Kato, Y., A. Kamoshita, J. Yamagishi and J. Abe. 2006. Growth of three rice (*Oryza sativa* L.) cultivars under upland conditions with different levels of water supply. I. Nitrogen content and dry matter production. **Plant Prod. Sci.**, **9**: 422-434.
- Katznelson, H. and B. Bose. 1959. Metabolic activities and phosphate dissolving capacity of bacterial isolates from wheat roots, rhizosphere and non-rhizosphere soil. **Can. J. Microbiol.**, **5**: 79-85.

- Keeling, C.D., Carter, A.F. and W.G. Mook. 1984. Seasonal, latitudinal and secular variations in the abundance and isotopic ratios of atmospheric CO₂. **J. Geophys. Res.**, **89**: 4615-4628.
- Kemble, A.K. and H.T. Mac-Pherson. 1954. Liberation of amino acids in perennial ryegrass during wilting. **Biochem. J.**, **8**: 46.
- Kerby, T.A., R.G. Cassman and M. Keelay. 1990. Genotypes and plant densities for narrow root cotton system. II. Leaf area and dry matter partitioning. **Crop Sci.**, **30**: 649-653.
- Khanda, C.M. and L. Dixit. 1996. Effect of zinc and nitrogen fertilization on yield and nutrient uptake of summer rice. **Indian J. Agron.**, **41**: 368-372.
- Khan, M.M., R. Shivashankar, R. Krishna Manohar, R. Sree Rama and Kasiyanna. 1999. Fertigation in horticultural crops. **In**: Proc. Advances in micro-irrigation and fertigation. 21-30 June, 1999, Dharwad, India. P. 181-197.
- Khan, R.A. 1973. Nutritional imbalance as the cause of sterility in rice. **Indian J. agric. Res.**, **7**: 51-57.
- Khind, C.S. and M.F. Kazibwe. 1983. Efficiency of different urea fertilizers in lowland rice. **IRRN**, **8 (5)**: 21-22.
- Kirloskar, S. 2003. Manage water to enrich lives. Second India-ASEAN Summit-2003, New Delhi, India.
- Kobata, T., S. Tanaka, M. Utumi, S. Hara and T. Imaki. 1994. Sterility in rice (*Oryza sativa* L.) subject to drought during the booting stage occurs not because of lack of assimilate or of water deficit in the shoot but because of dehydration of the root zone. **Japanese J. Crop Sci.**, **63**: 510-517.
- Kobata, T., T. Okuno and T. Yamamoto. 1996. Contributions of capacity for soil water extraction and water use efficiency to maintenance of dry matter production in rice subjected to drought. **Japanese J. Crop Sci.**, **65**: 652-662.
- Koeing, R.L., R.O. Morris and J.C. Polacco. 2002. t-RNA is the source of low-level trans-zeatin oriduction in *Methylobacterium* sp. **J. Bacteriol.**, **184**: 1832-1842.

- Koga, K. 1992. Introduction to paddy field engineering, Asian Institute of Technology, Bangkok, Thailand, p. 118.
- Kondo, M. P.P. Pablico, D.V. Aragones, R. Agbisit, J. Abe, S. Morita and T. Winn. 1998. Upland rice root system and nutrient effects on its development. **In:** IRRI Program Report for 1998, International Rice Research Institute, Los Baños, Philippines.
- Kramer, P.J. 1950. Effects of wilting on the subsequent intake of water by plants. **Amer. J. Bot.**, **37**: 280-284.
- Krause, G.H. and E. Weis. 1984. Chlorophyll fluorescence as a tool in plant physiology. II. Interpretation of fluorescence signals. **Photosynth. Res.**, **5**: 139-157.
- Krishnakumar, V. 1986. Agrometeorological parameters and hydronutritional management practices of rice cultivars. **Ph.D. thesis** submitted to Tamil Nadu Agricultural University, Coimbatore 641 003. India.
- Krishnakumar, V. and S. Subramonian. 1992. Nitrogen uptake, per cent recovery and response to nitrogen of rice varieties with different water management practices. **Madras Agric. J.**, **79**: 694-699.
- Krishnayya, G.R. and K.S. Murty. 1991. Influence of different levels of soil moisture stress on physiological parameters of upland rice cultivars. **Indian J. Plant Physiol.**, **34**: 387-397.
- Kropff, M.J., H.H. Van Laar and R.B. Matthews. 1994. ORYZA1: An ecophysiological model for irrigated rice production. SARP Research Production, IRRI, Los Baños, Philippines and Wageningen, 110 p.
- Kropff, M.J., K.G. Cassman, H.H. Vann Laar and S. Peng. 1993. Nitrogen and yield potential of irrigated rice. **Plant and Soil**, **155/156**: 391-394.
- Kumar, R. and Kujur, R. 2003. Role of secondary traits in improving the drought tolerance during flowering stage in rice. **Indian J. Plant Physiol.**, **8**: 236-240.
- Laemmli, U.K. 1970. Cleavage of structural proteins during the assembly of the head of the bacteriophage T4. **Nature**, **227**: 680-685.

- Lafitte, H.R., B. Courtis and M. Arrauddau. 2002. Genetic improvement of rice in aerobic systems: progress from yield to genes. **Field Crops Res.**, **75**: 171-190.
- Lafitte, R. 2002. Relationship between leaf relative water content during reproductive stage water deficit and grain formation in rice. **Field Crops Res.**, **76**: 165-174.
- Lafitte, R., A. Blum and G. Atlin. 2003. Using secondary traits to identify drought-genotypes tolerant. Pages 37-48. **In**: K.S. Ficher, R. Lafitte, S. Fukai, G. Altlin and B. Hardy (Eds.) Breeding rice for drought-prone environments. IRRI, Los Baños, Philippines.
- Lanceras, J.C., G. Pantuwan, B. Jongdee and T. Toojinda. 2004. Quantitative trait loci associated with drought tolerance at reproductive stage in rice. **Plant Physiol.**, **135**: 384-399.
- Lawlor, D.W. 1995. The effects of water deficit on photosynthesis. Pages 129-160. **In**: N. Smirnoff (Ed) Environment and Plant Metabolism: flexibility and accumulation. Bios Scientific Publishers Ltd., UK.
- Lemon, E.R. 1983. CO₂ and Plants: The response of plants to rising levels of atmospheric carbon dioxide. Westview Press, Boulder, Colorado.
- Leopold, A.C., M.E. Musgrave and K.M. Williams. 1981. Solute leakage resulting from leaf desiccation. **Plant Physiol.**, **68**: 1222-1225.
- Leslie, C.A. and R.J. Romani. 1988. Inhibition of ethylene biosynthesis by salicylic acid. **Plant Physiol.**, **88**: 833-837.
- Li, L., J. Van Staden and A.K. Jager. 1998. Effects of plant growth regulators on the anti-oxidant system in seedlings of two maize cultivars subjected to water stress. **Plant Growth Regul.**, **25**: 81-87.
- Lidstrom, M.E. and L. Chistoserdova. 2002. Plants in the pink: Cytokinin production by *Methylobacterium*. **J. Bacteriol.**, **184**: 1818.
- Lilley, J.M. and M.M. Ludlow. 1996. Expression of osmotic adjustment and dehydration tolerance in disease rice lines. **Field Crops Res.**, **48**: 185-197.

- Lilley, J.M. and S. Fukai. 1994. Effect of timing and severity of water deficit on four diverse rice cultivars. III. Phenological development, crop growth and grain yield. **Field Crops Res.**, **37**: 225-234.
- Lin, X., W. Zhou, D. Zhu, H. Chen and Y. Zhang. 2006. Nitrogen accumulation, remobilization and partitioning in rice (*Oryza sativa* L.) under an improved irrigation practice. **Field Crops Res.**, **96**: 448-454.
- Lin, X.Q., W.J. Zhou, D.F. Zhu and Y.B. Zhang. 2005. Effect of SWD irrigation on photosynthesis and grain yield of rice (*Oryza sativa* L.). **Field Crops Res.**, **94**: 67-75.
- *Liu, B.G., C.M. Li, C.F. Ren, C.F. Cai, Q.L. Yang and X.W. Chen. 1993. A study of the physiological basis for upland culture of paddy rice. **J. Southwest Agric. Univ.**, **15**: 477-482.
- Lowry, A.H., N.T. Rose Brough, L.A. Fait and R.J. Randall. 1951. Protein measurement with folin phenol reagent. **J. Biol. Chem.**, **193**: 265-271.
- *Lu, F. and H.J. Hua. 1994. A study on the main drought resistant index of land rice. **Acta Agriculturae Boreali Sinica**, **9**: 7-12.
- Lugg, D.G. and T.K. Sinclair. 1980. A survey of soybean cultivars for variability in specific leaf weight. **Crop Sci.**, **19**: 887-892.
- Madhaiyan, M. 2002. Molecular aspects, diversity and plant interaction of facultative methylotrophs occurring in tropical plants. **Ph.D., thesis** submitted to Tamil Nadu Agricultural University, Coimbatore 641 003. India.
- Madhaiyan, M., S. Poonguzhali, H.S. Lee, K. Hari, SP. Sundaram and T.M. Sa. 2005. Pink pigmented facultative methylotrophic bacteria accelerate germination, growth and yield of sugarcane clone, CO 86032 (*Saccharum officinarum* L.). **Biol. Fertil. Soils**, **41**: 350-358.
- Madhan Mohan, M., S. Lakshmi Narayanan and S.M. Ibrahim. 2000. Chlorophyll stability index (CSI): its impact on salt tolerance in rice. **Int. Rice Res. Notes**, **25**: 38-39.

- Magen, H. 1995. Fertigation - An overview of practical aspects. **Fert. News**, **40**: 12: 97-100.
- Mahendar Kumar, R., S.V. Subbaiah, K. Padmaja, S.P. Singh and V. Balasubramanian. 2001. Nitrogen management through soil and plant analysis development and leaf colour charts in different groups of rice (*Oryza sativa* L.) varieties grown on vertisols of Deccan Plateau. **Plant Soil**, **46**: 81-88.
- Maibangsa, S. 1998. Morpho-physiological, biochemical and molecular mechanisms of water stress tolerance in rice (*Oryza sativa* L.). **Ph.D. thesis** submitted to Tamil Nadu Agricultural University, Coimbatore 641 003. India.
- *Mali, C.V. and S.B. Varade. 1981. Response of rice to varying soil moisture conditions in vertisols studies on soil pH and nutrient availability. **Zeithrift fur Aucker-Und Pflanzenbau**, **150**: 129-139.
- Malik, P.C and S.L. Mehta. 1977. Effect of drought on enzymes and free proline in rice varieties. **Phytochem.**, **16**: 1355-1357.
- Mandal, B.K. and B.N. Chatterjee. 1984. Growth and yield performance of selected rice varieties during cooler months under two water regimes. **Indian J. Agron.**, **29**: 94-100.
- Manivannan, P., C. Abdul Jallel, A. Kishore Kumar, B. Sankar, R. Somasundaram, R. Sridharan and R. Pannerselvam. 2007. Changes in antioxidant metabolism under drought stress in *Vigna unguiculata* (L.) Walp. **Indian J. Plant Physiol.**, **12** (N.S.): 133-137.
- Marais, J.N. and D. Wiersma. 1975. Phosphorus uptake by soybeans as influenced by moisture stress in the fertilized zone. **Agron. J.**, **67**: 777-781.
- Martignone, R.A., J.J. Guiamot and F. Nakayama. 1987. Nitrogen partitioning and leaf senescence in soybean as related to nitrogen supply. **Field Crops Res.**, **17**: 17-20.
- Matsuzaki, A., K. Kariya, H. Machida and K. Tsunoda. 1980. Studies on the growth control and the nutritional diagnosis in rice plants. I. The nutritional diagnosis based on the leaf color and the estimation of the number of spikelets per unit area. **Japanese J. Crop Sci.**, **49**: 439-444.

- Matthews, R. B., M.J. Kropff, D. Bachelet and H.H. Vann Laar. 1995a. Modeling the impact of climate change on rice production in Asia. CAB International, Wallingford, UK. 289 p.
- Matthews, R.B., M.J. Kropff, D. Bachelet, T. Horie, M.H. Lee, H.G.S. Centeno, J.C. Shin, S. Mohandass, S. Singh and Zhu Defeng. 1995b. Modelling the impact of climate change on rice production in Asia. Pages 314-325. **In:** S. Peng, K.T. Ingram, H.U. Neue and L.H. Ziska. (Eds.) Climate change and rice. Springer-Verlag, New York, USA and IRRI, Los Baños, Philippines.
- Matthews, R.B., T. Horie, M.J. Kropff, D. Bachelet, H.G. Centeno, J.C. Shin, S. Mohandass, S. Singh, Zhu Defeng and Moon Hee Lee. 1995c. A regional evaluation of the effect of future climate change on rice production in Asia. Pages 95-139. **In:** Modeling the impact of climate change on rice production in Asia. CAB International, Wallingford, U.K and International Rice Research Institute, Los Baños, Philippines.
- Meghanatha Reddy, A., Deepti Shankhdhar and S.C. Shankhdhar. 2007. Physiological characterization of rice genotypes under periodic water stress. **Indian J. Plant Physiol.**, **12 (N.S.):** 189-193.
- Mercier, H., G.B. Kerbaudy, B. Sotta and E. Miginiac. 1997. Effects of NO_3^- , NH_4^+ and urea nutrition on endogenous levels of IAA and four cytokinins in two epiphytic bromeliads. **Plant Cell Environ.**, **20:** 387-392.
- Michael Gomez, S. and P. Rangasamy. 2002. Correlation and path analysis of yield and physiological changes in drought resistant rice. **Int. J. Mental**, **19:** 33-34.
- Michael, J.W. and H. Seiler-Kelbritsch. 1972. Cytokinin content and kernel size of barley grain as affected by environmental and genetic factors. **Crop Sci.**, **12:** 162-165.
- Mikkelsen, R.L. 1989. Phosphorus fertilization through drip irrigation. **J. Prodn. Agric.**, **2:** 279-286.
- Mishra, D. and G.C. Pradhan. 1972. Effect of transpiration reducing chemicals on growth, flowering and stomatal opening of tomato plants. **Plant Physiol.**, **50:** 271-274.

- Mishra, D.K. and P. Bhattacharyya. 1994. *In vitro* effect of some antibiotics on *Rhizobium leguminosarum*. Nodule Res. Laf., (Bidhan Chandra Krishi Vishwavidyalaya, Mohanpur 741 252, India). **Environ. Ecol.**, **12**: 476-478.
- Misra, S.P., E.T. Mertz and D.V. Glover. 1975. **Cereal Chem.**, **52**: 844.
- Mitchell, J.H., D. Siamhan, Wamala, M.A., Risimeri, J.B. Chinymakobry, E., S.D. Henderson and S. Fukai. 1998. The use of seedling leaf death score for evaluation of drought resistance in rice. **Field Crops Res.**, **55**: 129-139.
- Mittler, R. and B.A. Zilinkas. 1994. Regulation of pea cytosolic ascorbate peroxidase and other antioxidant enzymes during the progression of drought stress and following recovery from drought. **Plant J.**, **5**: 397-405.
- *Miyasaka, A. 1970. Effect of drainage on the growth of rice in ill-drained paddy soil. **Bull. Hokuriku Agric. Exp. Stn.**, **12**: 1-80.
- Mohammed, M.J. 2004. Utilization of applied nitrogen and irrigation water by drip-fertigated squash as determined by nuclear and traditional techniques. *Nutr. Cycl. Agroecocyst.*, **68**: 1-11.
- Mohandass, S. 1989. Seasonality and its physiological impact on rice (*Oryza sativa* L.) cultivars. **Ph.D. thesis** submitted to Tamil Nadu Agricultural University, Coimbatore 641 003. India.
- Mohandass, S., A.A. Kareem, T.B. Ranganathan and S. Jayaraman. 1995. Rice production in India under current and future climates. Pages 165-181. **In**: R.B. Matthews, M.J. Kropff, D. Bachelet and H.H. Vann Laar (Eds.). Modeling the impact of climate change on rice production in Asia. CAB International, Wallingford, UK.
- Mohandass, S., R. Radhakrishnan, R.M. Panchanathan and P. Kandaswamy. 1989. Diurnal pattern of plant water relations of groundnut under water stress and potassium nutrition. **J. Agron. Crop Sci.** **163**: 18-20.
- Mohandass, S., N. Natarajaratnam and C. Kailasam. 1988a. A new hybrid model for panicle growth in rice (*Oryza sativa* L.). **J. Agron. Crop Sci.**, **161**: 207-209.

- Mohandass, S., R. Radhakrishnan, RM. Panchanathan and P. Kandaswamy. 1988b. Growth and yield response of rice to moisture regimes and cycocel sprays. **Oryza**, **25**: 201-203.
- Mohandass, S., T.M. Thiyagarajan, S. Palanisamy and A. Abdul Kareem. 1993. Impact of increased temperature and CO₂ on rice productivity in Cauvery Delta Zone, India- A simulation analysis. **J. Agr. Met.**, **52**: 721-726.
- Mohankumar, B. and K.N. Singh. 1983. Studies on nitrogen, water regimes and weed control in upland direct seeded rice. I. Nitrogen depletion by weeds and crops and crop productivity. **Indian J. Agron.**, **29**: 448-452.
- Molla, M.A.Z., A.A. Chodhury, A. Islam and S. Hoque. 1984. Microbial mineralization of organic phosphate in soil. **Plant and Soil**, **78**: 393-399.
- Monsi, M. and T. Saeki. 1953. Concerning the light factor in plant communities and its significance for dry matter production. **Japan J. Bot.**, **14**: 22-52.
- Monteith, J.L. 1981. Does light limit crop production? Pages 23-39. **In**: C.B. Johnson (Ed.), Physiological process limiting crop productivity. Butterworth's, London.
- Morita, S., H. Kaminaka, T. Masumura and K. Tanaka. 1999. Induction of rice cytosolic ascorbate peroxidase mRNA by oxidative stress, the involvement of hydrogen peroxide in oxidative stress signaling. **Plant Cell Physiol.**, **40**: 417-422.
- Mounla, M.A. and G. Michael. 1973. Gibberellin-like substances in developing barley grain and their relation to dry weight increase. **Physiol., Plant.**, **29**: 274-276.
- Muirread, W.A., J.B. Blackwell, E. Humphreys and R.J.G. 1989. The growth and nitrogen economy of rice under sprinkler and flood irrigation in South-East Australia. I. Crop response and N uptake. **Irrig. Sci.**, **10**: 183-199.
- Murakami, T, 1968. Water use in the rice cultivation of dry zone in Ceylon. **Proc. Crop Sci. Soc. Japan (Spl.Issue)**, **37**: 145-166
- Murata, Y. 1969. Physiological responses to nitrogen in plants. **In**: The physiological aspects of crop yield. Amer. Soc. Agron. Crop Sci., Madison, Wisconsin, USA.

- Murayama, N., M. Yoshino, M. Oshima, S. Tsukahara and Y. Kawarazaki. 1955. Studies on the accumulation process of carbohydrates associated with growth of rice. **Bull. Natl. Instt. Agric. Sci. (Tokyo), B, 4:** 123-166.
- Murty, K.S. and S.K. Majumdar. 1962. Modifications of the technique for determination of chlorophyll stability index in relation to studies of drought resistance in rice. **Curr. Sci., 31:** 470-471.
- Murty, N., G. Shivashankar, S. Heltamani and M. Udayakumar. 1991. Association analysis among yield and some physiological traits in rice. **Oryza, 28:** 257-259.
- Murty, P.S.S. and K.S. Murty. 1981. Variations in concentrations of growth regulators in high and low sterile rice cultivars. **Indian J. Exp. Biol., 19:** 591-592.
- Murty, P.S.S. and K.S. Murty. 1982. Spikelet sterility in relation to nitrogen and carbohydrate contents in rice. **Indian J. Plant Physiol., 25:** 40-58.
- Murugaboopathi, C., M. Tomita, E. Yamaji and S. Koide. 1991. Prospect of large-sized paddy field using direct seeding supported by surface irrigation system. **Transac. of ASAE., 34:** 2040-2046.
- Nadarajan, N. and S. Kumaravelu. 1993. Screening for drought resistant rice. **Oryza, 30:** 251-253.
- Namuco, O.S. and J.C. O'Toole. 1986. Reproductive stage water stress and sterility: I. effect of stress during meiosis. **Crop Sci., 26:** 317-321.
- Namuco, O.S., K.T. Ingram and L.T. Fuentes. 1993. Root characteristics of rice genotypes with different drought responses. **Int. Rice Res. Notes, 18:** 38-39.
- Nayak, D.N., J.K. Ladha and I. Watanabe. 1986. The fate of marker *Azospirillum lipoferum* inoculated into rice and its effect on growth, yield and nitrogen fixation of plants studied by acetylene reduction and ¹⁵N isotope dilution techniques. **Biol. Fertil. Soils, 2:** 7-14.
- Nayak, R.I., S.S. Mandal, A. Zaman and N. Das. 1981. Water management in dry season rice. **IRRN, 6:** 22.

- Neyra, C.A. and P. Van Berkum. 1977. Nitrate reduction and nitrogenase activity in spirillum lipoferum. **Can. J. Microbiol.**, **23**: 306-310.
- Nguyen, H.T., R.C. Babu and A. Blum. 1997. Breeding for drought resistance in rice: physiological and molecular considerations. **Crop Sci.**, **37**: 1426-1434.
- Nicholas, J.C., J.E. Harper and R.H. Hageman. 1976. Nitrate reductase activity in soybeans. I. Effect of light and temperatures. **Plant Physiol.**, **58**: 731-735.
- Nieuwenhuis, J., B.A.M. Bouman and A. Castañeda. 2002. Crop - water responses of aerobically grown rice: preliminary results of pot culture experiments. Pages 177-185. **In**: B.A.M. Bouman, H. Hengdijk, H.Hardy, P.S. Bindraban, T.P. Tuong and J.K. Ladha (Eds.) Proceedings of the International Workshop on Water-wise Rice Production, 08-11 April, 2002, Los Baños, Philippines. IRRI, Los Baños, Philippines.
- Noctor G. and C.H. Foyer. 1998. Ascorbate and glutathione: keeping active oxygen under control. **Ann. Rev. Plant Physiol. Plant Mol. Biol.**, **49**: 249-279.
- Noctor, G., S. Veljovic-Jovanovic and C.H. Foyer. 2000. Peroxide processing in photosynthesis: antioxidant coupling and redox signaling. **Philos. Trans. R. Soc. London, Sec. B**, **355**: 1465-1475.
- Noggle, G.R. and G.J. Fritz. 1986. Introductory Plant Physiology. Prentice Hall of India Pvt. Ltd., New Delhi. India. 171 pp.
- Ota, Y. 1970. Diagnostic methods for the measurement of root activity in rice plant. **JARQ**, **5**: 1-6.
- O'Toole, J.C. and O.S. Namuco. 1983. Role of panicle exertion in water stress induced sterility. **Crop Sci.**, **23**: 1093-1097.
- O'Toole, J.C. and R.T. Cruz, 1980. Response of leaf water potential, stomatal resistance and leaf rolling to water stress. **Plant Physiol.**, **65**: 428-432.
- O'Toole, J.C. and T.B. Moya. 1978. Genotypic variation in maintenance of leaf water potential in rice. **Crop Sci.**, **18**: 873-876.

- O'Toole, J.C., T.C. Hsiao and O.S. Namuco. 1984. Panicle water relations during water stress. **Plant Sci. Letters**, **33**: 137-143.
- O'Toole, J.C. and T.T. Chang. 1979. Drought resistance and cereals- Rice: A case study. Pages 373-405. **In**: H. Mussell and R. Staples (Eds.) Stress Physiology in Crop Plants. Johnwiley and Sons, Inc. New York, USA.
- Olsen, S.R., C.V. Cole, F.S. Watanabe and L.A. Dean. 1954. Estimation of available phosphorus in soils by extraction with sodium bicarbonate. **Circular No. 939**, USDA.
- Olsen, S.R., W.D. Kemper and R.D. Jackson. 1962. Phosphate diffusion to plant roots. **Soil Sci. Soc. Amer. Proc.**, **26**: 222-227.
- Padihar, S.K. and P.R. Dikshit. 1985. Nutrient composition and yield of rice at different levels of phosphorus and moisture. **Oryza**, **22**: 17-22.
- Paikaray, R.L., B.S. Mahapatra and G.L. Sharma. 2001. Integrated nitrogen management in rice (*Oryza sativa*) - wheat (*Triticum aestivum*) cropping system. **Indian J. Agron.**, **46**: 592-600.
- Pal, U.R., R.R. Johnson and R.H. Hageman. 1976. Nitrate reductase activity in heat (drought) tolerant and intolerant maize genotypes. **Crop Sci.**, **16**: 775-779.
- Pandey, R., R.M. Agarwal, K. Jeevaratnam and G.L. Sharma. 2004. Osmotic stress-induced alterations in rice (*Oryza sativa* L.) and recovery on stress release. **Plant Growth Regul.**, **42** : 79-87.
- Pantuwan, G., S. Fukai, M. Cooper, J.C. O'Toole and S. Sarkarung. 1997. Root traits to increase drought resistance in rainfed lowland rice. Pages 170-179. **In**: Breeding strategies for rainfed lowland rice in drought-prone environments. Proceedings of International Workshop held at Ubon Ratchatani, Thailand, 5-8 November, 1996. ACIAR, Canberra, Australia.
- Parry, M.A.J., Delgado, E., Vadell, J., Keys, A.J., D.W. Lawlor and H. Medrano, 1993. Water stress and the diurnal activity of ribulose-1, 5-bisphosphase carboxylase in field grown *Nicotiana tabacum* genotypes selected for survival at low CO₂ concentrations. **Plant Physiol. Biochem.**, **31**: 113-120.

- Parthasarathy, K., D.R.C. Balua and P.S. Rao. 1970. Studies on sandal spur. VIII Polyphenoloxidase activity and metabolism of sandal (*Santalum album*) in healthy and diseased plant. **Proc. Indian Acad. Sci.**, **72**: 277-284.
- Paryea, F.J. 1992. Fertigation in Washington orchards with liquid nitrogen fertilizers. Proc. 88th Annual Meeting held at Washington State Horticultural Association, Yakima, Washington during 7-9 December, 1992, USA. P. 289-291.
- Pathak, A.N., R.M. Upadhyay, V.R. Singh and D.D. Prasad. 1980. Yield and nutrient uptake in rice under varied water regimes and Nitrogen level. **Indian J. Agric. Chem.**, **13**: 18-21.
- Patrick, W.H. Jr. and K.R. Reddy. 1977. Chemical changes in rice soils. **In**: Soils and plant. IRRI, Los Baños, Philippines. 361-379.
- Patjoshi, A.K. and D. Lenka. 1998. Determination of water management practices and effective rainfall in direct seeded medium land rice under varying water table situation. **Oryza**, **35**: 145-147.
- *Paurd, M., P. Couchat and G. Laseve. 1989. Etude des mechanisms d adaptation du riz aux constraints du milieu. I: Modificaiton de l'anatomic cellulaire. **L' Agronomic Tropicale**, **44**: 156-173.
- Pearce, R.B., G.E., Carlson, D.K. Barnes, R.H. Hart and C. H. Hanson. 1969. Specific leaf weight and photosynthesis in alfalfa. **Crop Sci.**, **9**: 423-426.
- Pearce, R.B., R.H. Brown and R.E. Balaster. 1968. Photosynthesis of alfalfa leaves as influenced by environment. **Crop Sci.**, **36**: 677-680.
- Pearson, C.I. and A.J. Hall. 1984. Maize and pearl millet. **In**: Control of crop productivity. C.J. Pearson (Ed.), Academic Press, London.
- Peltzer, D., D. Dreyer and A. Polle. 2002. Temperature dependencies of antioxidative enzymes in two contrasting species. **Plant Physiol. Biochem.**, **40**: 141-150.
- Peng, S., F.V. Garcia, R.C. Laza and K. G. Cassman. 1993. Adjustment for specific leaf weight improves chlorophyll meter's estimate of rice leaf nitrogen concentration. **Agron. J.**, **85**: 987-990.

- Peng, Y., Wang Hua Qi and He Daogeng, 1996. Preliminary studies on radiant spectrum of the leaves of the paddy and upland rice. **Chinese Rice Res. Newsl.**, **4**: 11.
- Penning de Vries, F.W.T. 1993. Rice production and climate change. Pages 175-192. **In:** F.W.T. Penning de Vries, P.S. Teng and K. Metselaar (Eds.) Systems approaches for agricultural development. Kluwer Academic Publishers, Dordrecht, The Netherlands.
- Perur, N.G. 1962. Measurement of peroxidase activity in plant tissue. **Curr. Sci.**, **31**: 71-81.
- Phrosene, E.C. and E.P. Karlander. 1973. Effect of low-light intensity on chlorophyll content and RUDPCarboxylase activity in rice. **Plant Biochem. J.**, **6**: 102-106.
- Piccoli, P., O. Masciarelli, R. Bottini. 1999. Gbberellin production by *Azospirillum lipoferum* cultured in chemically defined medium as affected by oxygen availability and water status. **Plant Growth Regul.**, **27**: 135-145.
- Pieters, A.J. and S. El Souki. 2005. Effects of drought during grain filling on PS II activity in rice. **J. Plant Physiol.**, **162**: 903-911.
- Piper, C.S. 1966. **Soil and Plant Analysis**. Hans publishers, Mumbai. India.
- Pirttila, A.M., P. Jonesuub, H. Pospiechc, J. Jalonenb and A. Hohtolaa. 2004. Bud endophytes of Scots pine produce adenine derivatives and other compounds that affect morphology and mitigate browning of callus cultures. **Physiol. Plant.**, **121**: 305-315.
- Poorniammal, R. 2006. Studies on coculturing of bioinoculants. **M.Sc. (Ag.) thesis** submitted to Tamil Nadu Agricultural University, Coimbatore 641 003. India.
- Pospisilova, J. 2003. Participation of phytohormones in the stomatal regulation of gas exchange during water stress. **Biol. Plant.**, **46**: 491-506.
- Power, J.E., W.O. Wills, D.L. Granes and G.A. Reichman. 1967. Effect of soil temperature, phosphorus and plant age on growth analysis of barley. **Agron. J.**, **59**: 231-234.
- Prasad, T.K., M.D. Anderson, B.A. Martin and B.R. Stewart. 1999. Evidence of chilling-induced oxidative stress in maize seedlings and a regulatory role for hydrogen peroxide. **Plant Cell**, **6**: 65-74.

- Prasad, V.K. and N.N. Sharma. 1984. Response of early paddy varieties to different soil moisture regime in calcareous soil. **Indian J. Agron.**, **29**: 312-316.
- Prasertsak, A. and S. Fukai. 1997. Nitrogen availability and water stress interaction on rice growth and yield. **Field Crops Res.**, **52**: 249-260.
- Premchandra, G.S., H. Sameoka and S. Ogata. 1990. Cell osmotic membrane stability - an indication of drought tolerance, as affected by applied nitrogen in soil. **J. Agric. Res.**, **115**: 63-66.
- Radford, P.J. 1967. Growth analysis formulae - Their use and abuse. **Crop Sci.**, **7**: 171-175.
- Rai, R.S.U. and K.S. Murty. 1977. **Indian J. Agric. Res.**, **10**: 261-264.
- Rajeswari, C. 1990. Studies on the effect of seed rate and method of sowing of two green manures on succeeding rice. **M.Sc. (Ag.) thesis** submitted to Tamil Nadu Agricultural University, Coimbatore 641 003. India.
- Rajkumar, J. 2001. Development of water stress tolerant rice (*Oryza sativa* L.) genotypes by induction response technique. **Ph.D. thesis** submitted to Tamil Nadu Agricultural University, Coimbatore 641 003, India.
- Raju, R.A. 1980. Effect of irrigation regimes on agronomic characters of rice. **IRRN**, **5**: 11.
- Ramamoorthy, K. K.V. Selvaraj and K.N. Chinnaswami. 1993. Varietal response of rice (*Oryza sativa* L.) to different irrigation regimes. **Indian J. Agron.**, **38**: 468-469.
- Ramasamy, S., H.F.M. Ten Berge and S. Purushothaman. 1997. Yield formation in rice in response to drainage and nitrogen application. **Field Crops Res.**, **51**: 65-82.
- Rangamanner, K.T.V., H.K. Pande and B.N. Mitra. 1979. Effect of water table depth on rice yield in pot culture studies. **Agron. J.**, **24**: 372-373.
- Ranganathan, T.B. and S. Mohandass. 1997. Identification of critical plant traits for rice ideotype development in future climates in Tamil Nadu. India. **J. Agric. Meteorol.**, **52**: 939-944.
- Rao, Ch. and K.S. Murty. 1976. Source and sink relationships in rice. **Sci. Cult.**, **42**: 559-562.

- Reddy, A.R., K.V. Chaitanya and M. Vivekanandan. 2004. Drought induced responses of photosynthesis and antioxidant metabolism in higher plants. **J. Plant Physiol.**, **161**: 1189-1202.
- Rengel, Z., G.D. Batten and D.E. Crowley. 1999. Agronomic approaches for improving the micronutrient density in edible portions of field crops. **Field Crops Res.**, **60**: 27-40.
- Reuben, S.O.W.M. and S.D. Katuli. 1990. Path analysis of yield components and selected agronomic traits of upland rice breeding lines. **IRRN**, **14**: 11-12.
- Roberts, J.K., N.A. Dsimore, W.L. Lingle and L. Dure. 1993. Cellular concentrations and uniformity of cell type accumulation of two LEA proteins in cotton embryos. **Plant Cell**, **5**: 769-780.
- Rosegrant, M.W. 1997. Water resources in the 21st century: challenges and implications for action. Food, Agriculture and the Environment Discussion Paper 20, IFPRI, Washington, DC, USA, p.27.
- *Russo, S. 2000. Preliminary studies on rice varieties adaptability to aerobic irrigation. **Cahiers Options Méditerranéennes**, **15**:35-39.
- Russo, S.M.R. and M. S. Iside. 1998. Performance of rice cultivars in experimental trials with dry method of cultivation. **Cashiers Options Meditteraneenes**, **40**: 47-60.
- Sadasivam, S. and A. Manickam. 1996. Biochemical methods. New Age International Publishers, New Delhi. pp. 59-66 and 211.
- Sahrawat, K.L. 1981. Influence of water regime on growth, yield and nitrogen uptake of rice. **Comm. Soil Sci. Pl. Analysis**, **12**: 919-932.
- Sahu, G. and K.S. Murty. 1976. Seasonal influence on dry matter production, nitrogen uptake and yield in rice varieties. **Indian Agric.**, **20**: 43-50.
- Saini, H.S. and S. Lalonde. 1996. Inquiries to reproductive development under water stress, and their consequences for crop productivity. **J. Crop Prod.**, **1**: 223-248.
- Sairam, R.K. and S.D. Dube. 1984. Effect of moisture stress on nitrate reductase activity in rice in relation to drought tolerance. **Indian J. Plant Physiol.**, **27**: 264-270.

- *Salvatore, M.R. and M.S. Iside. 1998. Performance of rice cultivars in experimental trials with dry method of cultivation. **Cashiers Options Mediterraneenes**, **40**: 47-60.
- Sanandachari, A. 1978. Studies on factors influencing drought resistance in sugarcane varieties. **Andhra Agric. J.**, **25**: 166-167.
- Sanchez, E., P.C. Garcia, L.R. Lopez-Lefebvre, R.M. Rivero, J.M. Ruiz and L. Romero. 2002. Proline accumulation metabolism in response to higher N dosages in green bean plants. **Plant Growth Regul.**, **38**: 262-265.
- Sandhu, B.S., K.L. Kheva, S. Parihar and B. Singh. 1980. Irrigation needs and yield of rice on a sandy loam soils as affected by continuous and intermittent drainage. **Indian J. Agric. Sci.**, **50**: 492-496.
- Sangsu, K., K. Pokyeong, C. Mingyu, B. Namyun, C. Weonyoung and L. Seconyong. 1999. Effect of seedling age on growth and yield of machine transplanted rice in southern plain region. **Korean J. Crop Sci.**, **44**: 122-128.
- Sankaranarayanan, A.M. 1985. Studies on the influence of nursery manuring and main field nitrogen management on growth and yield of rice. **M.Sc. (Ag.) thesis** submitted to Tamil Nadu Agricultural University, Coimbatore 641 003. India.
- Sarker, A.M., M.S. Rahman and N.K. Paul. 1999. Effect of soil moisture on RWC, Chlorophyll, Proline and sugar accumulation in wheat, **J. Agron. Crop Sci.**, **183**: 225-229.
- Saxena, H.K., R.S. Yadav, S.L.S. Parihar, H.B. Singh and G.S. Singh. 1996. Susceptibility and recovery potential of rice genotypes to drought at different growth stages. **Indian J. Plant Physiol.**, **1 (N.S.)**: 198-202.
- Schjoerring, J.K. 1995. Nitrogen incorporation and remobilization in different shoot components of field-grown winter oilseed rape (*Brassica napus* L.) as affected by rate of nitrogen application and irrigation. **Plant and Soil**, **177**: 255-264.
- Scholander, P.F., H.J. Hammel, E.D. Bradstreet and E.A. Hemmingsen. 1965. Sap pressure in vascular plants. **Science**, **148**: 339-346.

- Schwab, K.S. and U. Herber. 1984. Thylakoid osmotic membrane stability in drought tolerant and drought susceptible plants. **Planta**, **161**: 37-41.
- Selvaraj, P. K., V.V. Krishnamurthi, P. Manikasundaram, G. James Martin and M. Ayyasamy. 1997. Effect of irrigation schedules and nitrogen levels on the yield of turmeric through drip irrigation. **Madras Agric. J.**, **84** (6):347-348
- Senthilvel, S. 1995. Hydraulic design and evaluation and automation aspects of surge furrow irrigation systems. **Ph.D. thesis** submitted to Tamil Nadu Agricultural University, Coimbatore 641 003, India. p. 35.
- Seshu, D.V., T. Woodhead, D.P. Garrity and L.R. Oldeman. 1989. Effect of weather and climate on production and vulnerability of rice. Pages 93-121. In: Climate and food security. IRRI, Los Baños, Philippines.
- Shankhdhar, D., Shankhdhar, S.C., Mani and R.C. Pant. 2000. *In vitro* selection for salt tolerance in rice. **Biol. Plant.**, **43**: 477-480.
- Sharma, J.P. and S.C. Mani. 1992. Analysis of peroxidase activity in F₁ hybrids of rice (*Oryza sativa* L.). **Acta Botanica Indica**, **20**: 214-217.
- Sharma, P.K. 1989. Effect of periodic moisture stress on water use efficiency in wetland rice. **Oryza**, **26**: 252-257.
- Shanmugam, A. 1983. Studies on *Azolla* as a partial substitute for nitrogen in lowland rice. **M.Sc. (Ag.) thesis** submitted to Tamil Nadu Agricultural University, Coimbatore 641 003. India.
- Sheela, K.R. and V.J. Alexander. 1996. Physiological response of rice varieties as influenced by soil moisture and seed hardening. **Indian J. Plant Physiol.**, **38**: 269-271.
- Shigenaga, M.K., T.M. Hagen and B.N. Ames, 1994. Oxidative damage and mitochondrial decay in ageing. **Proc. Nat. Acad. Sci. American**, **91**: 10771-10778.
- Shivashankar, K. 1996. Micro-irrigation and fertigation. Proc. National workshop on micro-irrigation and fertigation. 21-22 September, 1995, Bangalore, India.

- Shrirame, M.D., H.J. Rajgire and A.H. Rajgire. 2000. Effect of spacing and seedling number per hill on growth attributes and yield of rice hybrids under lowland conditions. **J. Soil and Crops**, **10**: 109-113.
- Sikder, H.P. and D.K. Das Gupta. 1976. Physiology of grain filling in rice. III. Effects of defoliation and spikelet removal. **Indian Agric.**, **20**: 133-141.
- Simane, B., J.M. Pea Cock and P.C. Struik. 1993. Differences in developmental plasticity and growth rate among drought resistant and susceptible cultivars of durum wheat (*Triticum turgidum* var. *durum*). **Plant and Soil**, **157**: 155-166.
- Singh, K.K. and K. Singh. 2005. Effect of nitrogen and silicon levels on growth, yield attributes and yield of rice in alfisols. **Int. Rice Res. Notes**, **30**: 40-41.
- Singh, T.N., L.G. Paleg and D. Aspinall. 1973. Stress metabolism. III. Variations in response to water deficit in barley plant. **Aust. J. Biol. Sci.**, **226**: 65-76.
- Sinha, S.K. and R. Rajagopal. 1975. Effect of moisture stress on nitrate reductase activity and accumulation of proline in sorghum. Pages 36-3. **In**: Proceedings of the symposium on, "Crop Plant Responses to Environment Stress" July 4, 1975. Vivekananda Parvatiya Krishi Anusandhan Shala, Almora (U.P).
- Sionit, N., H. Hellmers and B.R. Strain. 1980. Growth and yield of wheat under CO₂ enrichment and water stress. **Crop Sci.**, **20**: 456-458.
- Sivanappan, R.K. 1998. Status, scope and future prospects of micro irrigation and sprinkler irrigation systems. **In** : proceedings of workshop on micro irrigation and sprinkler irrigation systems. April 28-30, Central Board of Irrigation and Power, New Delhi.
- Sivanappan, R. K. 2004. Irrigation and rainwater for improving water use efficiency and production in cotton crop. Lead papers agronomy. **In**: International symposium on strategies for sustainable cotton production: a global vision 2. Crop production, 23-25. November 2004, university of agricultural sciences. Dharwad, Karnataka. India pp7-14

- Slooten, L., K. Capiou, W. Van Camp, M. Van Montagu, C. Soybesma and D. Inze. 1995. Factors affecting enhancement of oxidative stress tolerance in transgenic tobacco over expressing manganese superoxide dismutase in the chloroplasts. **Plant Physiol.**, **107**: 373-380.
- Somogyi, M. 1952. Notes on sugar determination. **J. Biol. Chem.**, **200**: 245-247.
- Soumya, V.I. 2005. Studies on the potential of pink pigmented facultative methylotrophs for cytokinins biosynthesis in association with plant tissue under *in-vitro* conditions. **Ph.D. thesis** submitted to Tamil Nadu Agricultural University, Coimbatore 641 003. India.
- Stanford, G. and L. English. 1949. Use of flame photometer in rapid soil test for K and Ca. **Agron. J.**, 41:446-447.
- Srinivas, K., D.M. Hegde and G.V. Havanagi. 1989. Irrigation studies of watermelon (*Citullus lanatus* (Thunb) Matsum et Nakai). **Irrig. Sci.**, **10**: 293-301.
- Srivastava, S.K., H.C. Meena Rani, V. Jayaraman, S. Bandyopadhyay, S.G. Phene, S. Mohandas, K. Palanisamy, S.K. Nayak and Jobi V. Paul. 2004. Dynamics of biospheric aspect of hydrological cycle (BAHC) in rice agro-ecosystems of India. ISRO-GBP Scientific Report No. 10. Indian Space Research Organization (ISRO), Bangalore, India. 92 pp.
- Stansel, J.W. and R.E. Fries. 1980. A conceptual agromet rice yield model. Pages 201-212. **In:** Agrometeorology of rice crop. World Meteorological Organization and IRRI, Los Baños, Philippines.
- Stevens, G., D. Dunn, K. Birmingham, C. Moylan and A. Sheckell. 2001. Using chlorophyll meter and plant area based to monitor plant nitrogen status on cocodrie. **Missouri Rice Res. Update**, **3**: 13-17.
- Subbiah, B.V. and G.L. Asija. 1956. A rapid procedure for estimation of available nitrogen in soils. **Curr. Sci.**, **25**: 598-609.
- Suganthi, M. P. Subbaian and S. Marimuthu. 2003. Optimization of time of planting and nitrogen levels in hybrid rice (ADTRH 1). **Madras Agric. J.**, **90**: 339-340.

- Summons, R.E., B. Entsch, D.S. Lethan, B.I. Gollnow and J.K. MacLeod. 1980. Regulators of cell division in plant tissues. XXVIII. Metabolites of zeatin in sweet-corn kernels: Purification and identifications using high-performance liquid chromatography and chemical-ionization mass spectrometry. **Planta**, **147**: 422-434.
- Surek, H. and N. Beser. 1999. The effect of water stress on grain and total biological yield and harvest index in rice (*Oryza sativa* L.). **Cahiers Options Méditerranéennes**, **40**: 61-67.
- Suresh Kumar, P. 2000. Performance evaluation of drip fertigation system with water soluble fertilizers on water, fertilizer use and yield in hybrid capsicum (*Capsicum annum* var. *gossum*). **M.Sc.(Ag) Thesis** submitted to the Tamil Nadu Agricultural University, Coimbatore 641 003, India.
- SWIM, 1997. Water saving techniques in rice irrigation. Report of the SWIM mission to Guilin prefecture, Guangxi Region, China, pp. 25-30.
- Sy, A., E. Girud, P. Jurand, N. Garcia, A. Willems, P. de Lajudie, Y. Prin, M. Neyra, M. Gills, C. Bovin-Masson and B. Dreyful. 2001. Methylophilic *Methylobacterium* bacteria nodulate and fix atmospheric nitrogen in symbiosis with legumes. **J. Bacteriol.**, **183**: 214-220.
- Tabbal, D.F. B.A.S. Bouman, S.I. Bhuiyan, E.B. Sibayan and M.A. Sattar. 2002. On-farm strategies for reducing water input in irrigated rice: case studies in the Philippines. **Agric. Water Manage.**, **56**: 93-112.
- Tabuchi, T. 1992. Water quality management in agricultural areas. **J. Irrig. Eng. Rural Plang.**, **16**: 87-94.
- Takebe, M. and T. Yoneyama, K. Inada, and T. Murakami. 1990. Spectral reflectance ratio of rice canopy for estimating crop nitrogen status. **Plant Soil**, **122**: 295-297.
- Tanguiling, V.C., E.B. Yambo, J.C. O'Toole and S.K. De Datta. 1987. Water stress effects on leaf elongation, leaf water potential, transpiration and nutrient uptake of rice, maize and soybean. **Plant Soil**, **103**: 155-168.

- Tao, H., H. Brueck, K. Dittert, C. Kreye, S. Lin and B. Sattelmacher. 2006. Grain and yield formation of rice (*Oryza sativa* L.) in the water-saving ground cover rice production system (GCRPS). **Field Crops Res.**, **95**: 1-12.
- Thangamani, G. 2005. Studies on facultative methylobacteria for increasing crop production. **Ph.D. thesis** submitted to Tamil Nadu Agricultural University, Coimbatore 641 003. India.
- Thangamani, G. and SP. Sundaram. 2005. Effect of facultative methylobacterium isolates on hybrid rice (CORH 2) seed quality. Abstr. of poster presented in 3rd Natl. Conf. of Association of Applied Microbiologists (IAAM) held at Department of Microbiology, Adiparasakthi College of Arts and Science, Kalavai, Tamil Nadu, India during 5–7 January, 2005. pp. 63–64.
- Thangaraj, M. and V. Sivasubramanian. 1990. Physiological response of rice to water stress at reproductive phase. **Oryza**, **27**: 493-495.
- Thind, H.S., M.S. Aujla and G.S. Buttar. 2008. Response of cotton to various levels of nitrogen and water applied to normal and paired sown cotton under drip irrigation in relation to check-basin. **Agric. Water Manage.**, **95**: 25-34.
- Thiyagarajan, T.M. and R. Selvaraju. 2001. Water saving rice cultivation in India. **In:** W. Neigdijk and P. Bindraban (Eds.) Proceedings of an International workshop on Water Saving Rice Production Systems at Nanjing University, China, April 2-4, 2001.
- Thiyagarajan, T.M., R. Sivasamy and M.N. Budhar. 1995. Procedure for collecting plant samples at different growth stages of transplanted rice crop. In: Nitrogen management studies in irrigated rice. Proc. of the SARP Application Workshop held at IRRI, Los Baños, Philippines.
- Thornley, J.H.M. 1976. Mathematical models in plant physiology. Academic Press, London. 318 p.
- Tien, T.M., M.H. Gaskins and D.H. Hubbell. 1979. Plant growth substances produced by *Azospirillum brasilense* and their effect on the growth of pearl millet (*Pennisetum americanum* L.). **Appl. Env. Microbiol.**, **37**: 1016-1024.

- Timpo, E.E. and C.A. Neyra. 1983. Expression of nitrate and nitrate reductase activities under various forms of nitrogen nutrition in *Phaseolus vulgaris* L. **Plant Physiol.**, **72**: 71-75.
- Tomar, J.B. and S.C. Prasad. 1996. Relationship between inheritance and linkage for drought tolerance in upland rice (*Oryza sativa* L.) varieties. **Indian J. Agric. Sci.**, **66**: 459-465.
- Traore, A. and J.W. Maranville. 1999. Nitrate reductase activity of diverse grain sorghum genotypes and its relationship to nitrogen use efficiency. **Agron. J.**, **91**: 863-869.
- Tripathi, A.K., B.M. Mishra and P. Tripathi 1998. Salinity stress responses in the plant growth promoting rhizobacteria, *Azospirillum* spp. **J. Biosci (Bangalore)**, **23**: 463-471.
- Tumbare, A.D. and S.U. Bhoite. 2002. Effect of solid soluble fertilizer applied through fertigation on growth and yield of chilli (*Capsicum annum* L.). **Indian J. Agric. Sci.**, **72**: 109-111.
- Tuong, T.P., B.A.M. Bouman and M. Mortimer. 2004. More rice, less water-integrated approaches for increasing water productivity in irrigated rice based systems in Asia. Pages. 1-13. **In** : Proceedings of the 4th International Crop Science, Congress, 26 September–1 October, 2004. Brisbane, Australia.
- Tuong, T.P., B.A.M. Bouman and M. Mortimer. 2005. More rice, less water-integrated approaches for increasing water productivity in irrigated rice-based systems in Asia. **Plant Prod. Sci.**, **8**: 231-241.
- Turner, F. T. and M.F. Jund. 1991. Chlorophyll meter to predict nitrogen topdress requirement for semidwarf rice. **Agron. J.**, **83**: 926-928.
- Tyagi, A., N Kumar and Sairam, R.K. 1999. Efficacy of RWC, membrane stability, osmotic potential, endogenous ABA and root biomass as indices for selection against water stress in rice. **Indian J. Plant Physiol.**, **4 (N.S.)**: 302-306.
- Unnayar, S., Ş.F. Topcuoğlu and A. Unyaya. 1996. A modified method for extraction and identification of indole-3-acetic acid (IAA), gibberellic acid (GA), abscisic acid (ABA) and zeatin produced by *Phanerochate chrysosporim* ME 446. **Bulg. J. Plant Physiol.**, **22**: 105-110.

- Uphoff, N. 2002. System of Rice Intensification (SRI) for enhancing the productivity of land, labour and water. **J. Agric. Resour. Mangt.**, **1**: 43-49.
- Uppal, H.S., S.S. Cheema and A.S. Walia. 1991. Irrigation need of transplanting rice (*Oryza sativa*) in non-cracking soil. **Indian J. Agric. Sci.**, **61**: 634-636.
- Upreti, D.C. and G.S. Sirohi. 1985. Effect of water stress on photosynthesis and water relation of wheat varieties. **Indian J. Plant Physiol.**, **29**: 107-114.
- Uyprasert, S., T.Toojinda, N.Udompraset, S. Tragoonrung and A.Vanavichit. 2004. Proline accumulation and rooting patterns in rice in response to water deficit under rainfed lowlands. **Science Asia**, **30**: 301-311.
- van Keulen, H. 1982. Graphical analysis of annual crop response to fertilizer application. **Agric. Syst.**, **9**: 113-126.
- Venkateshamurthy, P. 1997. Studies on fertigation in Bangalore blue grapes – comparison of sources and levels of nutrients. **Ph.D. thesis** submitted to University of Agricultural Sciences, Bangalore, India.
- Venkateswarlu, B. 1977. Influence of low-light intensity on growth and productivity of rice (*Oryza sativa* L.). **Plant and Soil**, **46**: 713-719.
- Venkateswarlu, B., A.V. Rao and P. Raina. 1984. Evaluation of phosphorus solubilization by microorganisms isolated from arid soils. **J. Indian Soc. Soil**, **32**: 273-277.
- Venkitaswamy, R. 1986. Effect of new forms of urea on nitrogen use efficiency and its interaction with weed growth and management in lowland rice. **Ph.D. thesis** submitted to Tamil Nadu Agricultural University, Coimbatore 641 003. India.
- Vijayalakshmi, C. and M. Nagarajan. 1994. Effect of rooting pattern in rice productivity under different water regimes. **J. Agron. Crop Sci.**, **173**: 113-117.
- Voetberg, G.S. and R.E. Sharp. 1991. Growth of the maize primary root at low water potential. III. Role of increased proline deposition in osmotic adjustment. **Plant Physiol.**, **96**: 1125-1130.

- Vu, J.C.V., R.W. Gesch, L.H. Allen, K.J. Boote and G. Bowes, 1999. CO₂ enrichment delays a rapid, drought induced decrease in Rubisco small subunit transcript abundance. **J. Plant Physiol.**, **155**: 139-142.
- Wahab, K. and K.V. Daniel. 1992. Water management in rice under limited water supply. **Indian J. Agron.**, **37**: 166-167.
- Walkley, A. and C.A. Black. 1934. An examination of methods for determining organic matter and nitrogen in soils. **J. Agric. Sci.**, **25**: 598-609.
- Wang H., B.A.M. Bouman, D. Zhao, W. Changgui and P.F. Moya. 2002. Aerobic rice in Northern China: Opportunities and challenges. In: B.A.M. Boumann, B. Hengsdijk, B. Hardy, P.S. Bindraban, T.P. Toung and J.K. Ladha (Eds.) Water use and rice production. pp. 143-154. International Rice Research Institute, Los Banos, Philippines.
- *Wang, M.Y., Qui, S.H., Z.J. Hua, and G. Q. Han. 1995. Effect of water stress upon the activities of protective enzyme system and the structure of membrane systems in maize. **Acta Agricultural Borealisinica**, **10**: 43-49.
- *Wang, Z.Q., J.C. Yang and Q. Zhu. 1996. Effect of soil moisture on photosynthetic rate and dry matter translocation in rice plants. **Chinese J. Rice Res.**, **10**: 235-240.
- Wann, S.S. 1978. Water management of soils for growing rice. ASPAC, **Food Fertilizer Technology Centre Bulletin No. 40**: 12.
- Wareing, P.F. and J. Patrick. 1975. Source-sink relations and the partition of assimilates in the plant. **In**: J.P. Cooper (Ed.), Photosynthesis and productivity in different environments. Cambridge University Press, Cambridge, London.
- Wareing, P.F., R. Horgan, I.E. Henson and W. Davis. 1977. Cytokinin relations in the whole plant. Pages 147-153. **In**: P.E. Pillet (Ed.) **Plant growth regulation**, Springer and Verlag, Berlin.
- Watanabe, K. and K. Hayano. 1993. Distribution and identification of proteolytic *Bacillus sp.* in paddy field soil under rice cultivation. **Can. J. Microbiol.**, **39**: 774-780.

- Watanabe, S., Y. Hataaka and K. Inada, 1980. Development SPAD Chlorophyll Meter: Structure and performance. **Japanese J. Crop Sci.**, **49**: 89-90.
- Watson, D.J. 1956. Comparative physiological studies on the growth of field crops I. Variation in net assimilation rate and leaf area between species and varieties and within and between years. **Ann. Bot.**, **2**: 41-46.
- Weatherly, P.E. 1950. Studies in the water relations of the cotton plant. I. The field measurement of water deficits in leaves. **New Phytol.**, **49**: 81-97.
- Weng, J.H., T. Takeda, W. Agata and S. Hakoyima. 1982. Studies on dry matter and grain production of rice plants. I. Influence of the reserved carbohydrates until heading stage and the assimilation production during the ripening period on grain production. **Japanese J. Crop Sci.**, **51**: 500-509.
- Whigham, D.K. 1983. Soybean. Pages 205-225. **In**: Proceedings of Symposium on potential productivity of field crops under different environments. 22-26, September 1980. IRRI, Los Baños, Philippines.
- Willekens, H., S. Chamnongpol, M.V. Montagu, D. Inze and W.V. Camp. 1995. Role of H_2O_2 and H_2O_2 scavenging enzymes in environmental stress. **Ag. Biotech News Inform.**, **7**: 189-195.
- Willett, I.R. 1982. Phosphorus availability in soils subjected to short periods of flooding and drying. **Aust. J. Soil Res.**, **20**: 131-138.
- Williams, S.R.F. 1946. Methods of growth analysis. **In**: Plant Photosynthetic Production Manual and Methods. Pages 348-391 **In**: Z. Sestak, J. Catasky and P.J. Jouris (Eds.) Drow, Jenk, N.U. Publishers. The Hague.
- Williams, R.E. and R.E. Snapter. 1955. Comparative study of growth and nutrition in barley and rye as affected by low water treatment. **Aust. J. Biol. Sci.**, **8**: 435-466.
- Witt, C., A. Dobermann, S. Abdulrachman, H.C. Gines, G. Wang, R. Nagarajan, S. Satawatananont, T. Tran, S. Pham, L. Tan, van Tiem, G.C., Simbahan and D.C. Olk. 1999. Internal nutrient deficiencies of irrigated lowland rice in tropical and subtropical Asia. **Field Crops Res.**, **63**: 113-138.

- Wopereis, M.C.S., M.J. Kropff, A.R. Maligaya and T.P. Tuong. 1996. Drought-stress responses of lowland rice cultivars to soil water status. **Field Crops Res.**, **46**: 21-39.
- Xu, D., X. Duan, B. Wang, B. Hang, T.H.D. Ho and R. Wu. 1996. Expression of a late embryogenesis abundant protein gene, HVA-1 from barley confers tolerance to water deficit and salt stress in transgenic rice. **Plan Physiol.**, **110**: 249-257.
- Yahalom, E., Y. Okon and A. Dovrat. 1987. *Azospirillum* effects on susceptibility to *Rhizobium* nodulation and on nitrogen fixation of several forage legumes. **Can. J. Microbiol.**, **33**: 510-514.
- Yamada, 1968. Some problems of irrigation and drainage practices in rice culture. **IRRN.**, **14 (3)**: 13-31
- Yamada, N., Y. Ota and K. Kushibuchi. 1957. Studies on ripening of rice. I. Role of nitrogen in the process of ripening. **Proc. Crop Sci. Jpn.**, **26**: 111-115.
- Yamamuro, S. 1983. Nitrogen cycle in paddy fields. **Jpn. Agric. Res. Q. (JARQ)**, **17**: 106-111.
- Yang, J.C., Q.S. Zhu and Z.Q. Wang. 1995a. The effects of soil moisture on the yield and physiological characteristics of rice. **Acta Agron. Sinica**, **21**: 110-114.
- Yang, J.C., Z.Q. Wang and Q.S. Zhu. 1995b. The relationship between free proline accumulation and drought resistance in rice under different soil moisture status. **Chinese J. Rice Sci.**, **9**: 92-96.
- Yang, W., S. Peng, M.L. Dionisio-Sese, R.C. Laza and R.M. Visperas. 2008. Grain filling duration, a crucial determinant of genotypic variation of grain yield in field-grown tropical irrigated rice. **Field Crops Res.**, **105**: 221-227.
- Yang, X., B.A.M. Bouman, W. Huaqi, W. Zhimin, Z. Junfang and C. Bin. 2005. Performance of temperate aerobic rice under different water regimes in North China. **Agric. Water Managt.**, **74**: 107-122.
- Yang, X., H. Wang, Z. Wang, Z. Junfang, C. Bin and B.A.M. Bouman. 2002. Yield of aerobic rice (Han Dao) under different water regimes in North China. Pages 155-163.

- In:** B.A.M. Bouman, H. Hengdijik, H.Hardy, P.S. Bindraban, T.P. Tuong and J.K. Ladha (Eds.) Proceedings of the International Workshop on Water-wise Rice Production, 08-11 April, 2002, Los Baños, Philippines. IRRI, Los Baños, Philippines.
- Yogameenakshi, S. 2002. Genetic analysis for drought tolerance in rice (*Oryza sativa* L.) **M.Sc. (Ag.) thesis** submitted to Tamil Nadu Agricultural University, Coimbatore 641 003. India.
- Yoshida, S. 1972. Physiological aspects of grain yield. **Ann. Rev. Plant Physiol.**, **23**: 437-464.
- Yoshida, S. 1976. Rice. Pages 57-87. **In:** P.T. Alvim and T.T. Kozlowski (Eds.) Ecophysiology of tropical crops. Academic Press, New York, USA.
- Yoshida, S. 1981. Fundamentals of rice crop science. International Rice Research Institute, Los Baños, Philippines. 299 pp.
- Yoshida, S. and S.B. Ahn. 1968. The accumulation process of carbohydrate in rice varieties in relation to their response to nitrogen in the tropics. **Soil Sci. Plant Nutr.**, **14**: 153-161.
- Yoshida, S., D.A. Foron and J.H. Cock. 1971. Laboratory manual for physiological studies of rice. International Rice Research Institute, Los Baños, Philippines. 70 pp.
- Yoshida, T. and B.C. Padre Jr. 1975. Effect of organic matter application and water regimes on the transformation of fertilizer nitrogen in a Philippine soil. **Soil Sci. Plant Nutr.**, **21** : 281-292.
- Yoshino, M. M., T. Horie, H. Tsujii, T. Uchijima and Z. Uchijima. 1988. The effects of climate variations on agriculture in Japan. Pages 725-865. **In:** M.L. Parry, T.R. Carter and N.T. Konijn (Eds.) The impact of climate variations on agriculture. Vol. 1: Assessments in cool temperate and cold region. Kluwer, Dordrecht.
- Zhang, J. and M.B. Kirkam. 1994. Drought stress induced changes in activities of SOD, catalase and peroxidase or proline oxidase in wheat species. **Plant Cell Physiol.**, **35**: 785-791.

- Zhang, K.F., M. Qing and H.K. Huan. 1997. Effect of water deficit on physiological activities of paddy rice and upland rice seedlings. **J. Shandong Agric. Univ.**, **28**: 53-57.
- Zhang, M.Z., Y.H. Li, Y. L. Cui, L.C. Wu and R.J. Fang. 1994. Studies on the growth and physiological mechanism of rice cultivated under the condition of deficit irrigation. **Irrig. Drain.**, **13**: 6-11.
- Zhao, D., R. Reddy, V.G. Kakari and V.R. Reddy. 2005. Nitrogen deficiency effects on plant growth, leaf photosynthesis and hyperspectral reflectance properties of sorghum. **Europ. J. Agron.**, **22**: 391-403.
- Zhao, D.L., G.N. Atlin, Bastiaans and J.H.J. Spiertz. 2006. Cultivar weed competitiveness in aerobic rice: Heritability, correlated traits and the potential for induced selection in weed free environments. **Crop Sci.**, **46**: 372-380.
- Zhu, H.S. and P.S. Huang. 1994. Soil water stress and active oxygen metabolism in rice. **J. Nanjing Agric. Univ.**, **17**: 7-11.

* - Originals not seen

Table 3. Weather data prevailed during dry season (DS) (June 2007-October 2007)

Standard week	Temperature (°C)		Evaporation (mm)	Rainy days	Sun shine (h)	Wind speed (m sec ⁻¹)	Solar radiation (Cal cm ⁻² day ⁻¹)
	Max.	Min.					
25	29.3	23.3	6.3	3	09	15.4	236.1
26	29.5	23.4	4.7	3	2.9	9.7	294.0
27	28.7	23.6	4.6	4	2.4	14.5	264.9
28	30.1	24.0	6.6	1	5.3	13.0	375.0
29	30.1	22.6	5.0	2	4.8	6.9	339.4
30	29.6	22.4	3.8	1	2.1	5.3	305.1
31	29.3	22.4	3.8	1	1.9	7.6	255.4
32	28.7	22.7	4.1	3	3.6	11.3	295.5
33	32.8	21.9	5.4	-	8.3	5.8	422.6
34	30.8	22.1	4.4	2	4.7	5.1	307.3
35	30.9	22.9	5.5	-	4.7	8.5	321.7
36	31.3	22.8	5.6	-	4.7	0.2	359.9
37	32.1	23.0	4.1	1	6.1	4.4	328.9
38	30.5	23.9	5.9	1	3.3	14.6	321.3
39	31.2	22.8	6.1	1	5.0	9.7	341.8
40	32.2	21.4	5.6	-	7.4	7.3	410.3
41	33.0	22.2	5.0	1	7.2	4.6	348.7
42	30.0	22.0	3.2	3	3.0	4.3	262.9
43	28.0	22.0	2.5	4	2.7	4.7	237.5

Table 4. Details of 75 % fertilizers (112.5:37.5:37.5 NPK) applied through fertigation

DAS	Date	N %	P %	K %
21	09.07.2007	8	20	7.5
28	16.07.2007	8	20	7.5
35	23.07.2007	8	12	7.5
42	30.07.2007	8	12	7.5
49	06.08.2007	10	12	10
56	13.08.2007	10	12	10
63	20.08.2007	10	12	10
70	27.08.2007	10	0	10
77	03.09.2007	7.5	0	8.5
84	10.09.2007	7.5	0	8.5
91	17.09.2007	6.5	0	6.5
98	24.09.2007	6.5	0	6.5

(DAS: Days after sowing)

Table 5. Details of 100 % fertilizers (150:50:50 NPK) applied through fertigation

DAS	Date	N %	P %	K %
21	09.07.2007	8	20	7.5
28	16.07.2007	8	20	7.5
35	23.07.2007	8	12	7.5
42	30.07.2007	8	12	7.5
49	06.08.2007	10	12	10
56	13.08.2007	10	12	10
63	20.08.2007	10	12	10
70	27.08.2007	10	0	10
77	03.09.2007	7.5	0	8.5
84	10.09.2007	7.5	0	8.5
91	17.09.2007	6.5	0	6.5
98	24.09.2007	6.5	0	6.5

(DAS: Days after sowing)

Table 6. Details of 125 % fertilizers (187.5:62.5:62.5 NPK) applied through fertigation

DAS	Date	N %	P %	K %
21	09.07.2007	8	20	7.5
28	16.07.2007	8	20	7.5
35	23.07.2007	8	12	7.5
42	30.07.2007	8	12	7.5
49	06.08.2007	10	12	10
56	13.08.2007	10	12	10
63	20.08.2007	10	12	10
70	27.08.2007	10	0	10
77	03.09.2007	7.5	0	8.5
84	10.09.2007	7.5	0	8.5
91	17.09.2007	6.5	0	6.5
98	24.09.2007	6.5	0	6.5

(DAS: Days after sowing)

Table 7. Plant height (cm) at chosen growth stages as influenced by drip fertigation treatments in PMK (R) 3 rice under aerobic condition, DS (2007)

	Treatment	AT	PI	FF	HT	Mean
T ₁ :	Conventional method	42.5	65.0	100.2	125.9	83.4
T ₂ :	100 % PE + 75 % RDF + BF	35.4	40.8	71.7	82.5	57.6
T ₃ :	100 % PE + 100 % RDF + BF	37.5	42.7	73.9	88.6	60.7
T ₄ :	100 % PE + 125 % RDF + BF	39.8	44.6	76.3	93.1	63.5
T ₅ :	125 % PE + 75 % RDF + BF	36.3	43.5	89.0	97.0	66.5
T ₆ :	125 % PE + 100 % RDF + BF	37.9	45.3	91.2	100.9	68.8
T ₇ :	125 % PE + 125 % RDF + BF	38.4	48.1	94.5	110.6	72.9
T ₈ :	150 % PE + 75 % RDF + BF	38.1	46.2	90.3	103.8	69.6
T ₉ :	150 % PE + 100 % RDF + BF	38.1	52.8	95.5	110.6	74.3
T ₁₀ :	150 % PE + 125 % RDF + BF	40.2	55.4	98.3	119.8	78.4
	Mean	38.4	48.4	88.1	103.3	
	SEd	0.90	1.15	2.09	2.45	
	CD at 5 %	1.88	2.41	4.40	5.14	

Overall mean performance of irrigation regimes and fertilizer levels

Irrigation regime	Plant height (cm)	Fertilizer level	Plant height (cm)
100 % PE (I₁)	60.6	75 % RDF + BF (F₁)	64.6
125 % PE (I₂)	69.4	100 % RDF + BF (F₂)	67.9
150 % PE (I₃)	74.1	125 % RDF + BF (F₃)	71.6
Conventional method	83.4	Conventional method	83.4

DS : Dry season

PE : Pan evaporation level

RDF: Recommended Dose of Fertilizer

BF : Biofertilizer (*Azophosmet*)

AT: Active tillering

PI : Panicle initiation

FF: 50 % flowering

HT: Harvest

Table 8. Total root length (m hill⁻¹) at chosen growth stages as influenced by drip fertigation treatments in PMK (R) 3 rice under aerobic condition, DS (2007)

	Treatment	AT	PI	FF	HT	Mean
T ₁ :	Conventional method	14.3	38.4	41.4	39.6	33.4
T ₂ :	100 % PE + 75 % RDF + BF	12.6	21.8	48.2	41.9	31.1
T ₃ :	100 % PE + 100 % RDF + BF	14.1	28.6	51.9	45.6	35.0
T ₄ :	100 % PE + 125 % RDF + BF	13.3	33.1	55.8	48.7	37.7
T ₅ :	125 % PE + 75 % RDF + BF	12.7	27.4	46.9	42.0	32.3
T ₆ :	125 % PE + 100 % RDF + BF	14.0	32.6	48.6	42.9	34.5
T ₇ :	125 % PE + 125 % RDF + BF	15.4	30.7	50.6	48.7	36.3
T ₈ :	150 % PE + 75 % RDF + BF	9.8	20.1	45.1	30.5	26.4
T ₉ :	150 % PE + 100 % RDF + BF	11.4	22.0	49.2	38.9	30.4
T ₁₀ :	150 % PE + 125 % RDF + BF	12.3	23.5	50.3	40.1	31.5
	Mean	13.0	27.8	48.8	41.9	
	SEd	0.30	0.68	1.13	0.99	
	CD at 5 %	0.65	1.43	2.37	2.08	

Overall mean performance of irrigation regimes and fertilizer levels

Irrigation regime	Total root length (m hill⁻¹)	Fertilizer level	Total root length (m hill⁻¹)
100 % PE (I₁)	34.6	75 % RDF + BF (F₁)	29.9
125 % PE (I₂)	34.4	100 % RDF + BF (F₂)	33.3
150 % PE (I₃)	29.5	125 % RDF + BF (F₃)	35.3
Conventional method	33.4	Conventional method	33.4

DS : Dry season
PE : Pan evaporation level
RDF: Recommended Dose of Fertilizer
BF : Biofertilizer (*Azophosmet*)

AT: Active tillering
PI : Panicle initiation
FF: 50 % flowering
HT: Harvest

Table 9. Root volume (cc hill⁻¹) at chosen growth stages as influenced by drip fertigation treatments in PMK (R) 3 rice under aerobic condition, DS (2007)

	Treatment	AT	PI	FF	HT	Mean
T ₁ :	Conventional method	19.9	54.5	65.2	45.3	46.2
T ₂ :	100 % PE + 75 % RDF + BF	19.8	58.4	70.1	55.9	51.1
T ₃ :	100 % PE + 100 % RDF + BF	22.4	60.7	73.1	60.4	54.2
T ₄ :	100 % PE + 125 % RDF + BF	23.5	61.8	75.6	62.9	56.0
T ₅ :	125 % PE + 75 % RDF + BF	16.1	47.3	65.1	42.9	42.9
T ₆ :	125 % PE + 100 % RDF + BF	20.0	57.3	70.8	52.6	50.2
T ₇ :	125 % PE + 125 % RDF + BF	25.9	62.5	78.3	59.7	56.6
T ₈ :	150 % PE + 75 % RDF + BF	12.5	37.0	50.8	40.7	35.3
T ₉ :	150 % PE + 100 % RDF + BF	13.6	40.2	55.6	42.9	38.1
T ₁₀ :	150 % PE + 125 % RDF + BF	15.0	50.1	60.8	45.8	42.9
	Mean	18.9	53.0	66.5	50.9	
	SEd	0.46	1.27	1.58	1.20	
	CD at 5 %	0.97	2.67	3.32	2.52	

Overall mean performance of irrigation regimes and fertilizer levels

Irrigation regime	Root volume (cc hill⁻¹)	Fertilizer level	Root volume (cc hill⁻¹)
100 % PE (I₁)	53.8	75 % RDF + BF (F₁)	43.1
125 % PE (I₂)	49.9	100 % RDF + BF (F₂)	47.5
150 % PE (I₃)	38.8	125 % RDF + BF (F₃)	51.8
Conventional method	46.2	Conventional method	46.2

DS : Dry season
PE : Pan evaporation level
RDF: Recommended Dose of Fertilizer
BF : Biofertilizer (*Azophosmet*)

AT: Active tillering
PI : Panicle initiation
FF: 50 % flowering
HT: Harvest

Table 10. Root Length Density (RLD: cm cm⁻³) at chosen growth stages as influenced by drip fertigation treatments in PMK (R) 3 rice under aerobic condition, DS (2007)

	Treatment	AT	PI	FF	HT	Mean
T ₁ :	Conventional method	0.891	1.080	1.536	0.965	1.118
T ₂ :	100 % PE + 75 % RDF + BF	1.056	1.723	2.482	2.045	1.826
T ₃ :	100 % PE + 100 % RDF + BF	0.979	1.618	2.160	1.920	1.669
T ₄ :	100 % PE + 125 % RDF + BF	0.859	1.498	1.867	1.507	1.433
T ₅ :	125 % PE + 75 % RDF + BF	0.661	1.474	1.699	1.474	1.327
T ₆ :	125 % PE + 100 % RDF + BF	0.624	1.373	1.546	1.358	1.225
T ₇ :	125 % PE + 125 % RDF + BF	0.523	1.157	1.474	1.234	1.097
T ₈ :	150 % PE + 75 % RDF + BF	0.667	1.080	1.478	1.310	1.134
T ₉ :	150 % PE + 100 % RDF + BF	0.581	1.008	1.334	1.066	0.997
T ₁₀ :	150 % PE + 125 % RDF + BF	0.465	0.907	1.234	0.989	0.899
	Mean	0.731	1.292	1.681	1.387	
	SEd	0.0181	0.0304	0.0389	0.0333	
	CD at 5 %	0.0379	0.0638	0.0817	0.0700	

Overall mean performance of irrigation regimes and fertilizer levels

Irrigation regime	RLD (cm cm⁻³)	Fertilizer level	RLD (cm cm⁻³)
100 % PE (I₁)	1.643	75 % RDF + BF (F₁)	1.429
125 % PE (I₂)	1.216	100 % RDF + BF (F₂)	1.297
150 % PE (I₃)	1.010	125 % RDF + BF (F₃)	1.143
Conventional method	1.118	Conventional method	1.118

DS : Dry season
PE : Pan evaporation level
RDF: Recommended Dose of Fertilizer
BF : Biofertilizer (*Azophosmet*)

AT: Active tillering
PI : Panicle initiation
FF: 50 % flowering
HT: Harvest

Table 11. Root Mass Density (RMD: mg cm⁻³) at chosen growth stages as influenced by drip fertigation treatments in PMK (R) 3 rice under aerobic condition, DS (2007)

	Treatment	AT	PI	FF	HT	Mean
T ₁ :	Conventional method	0.706	0.956	1.056	1.006	0.931
T ₂ :	100 % PE + 75 % RDF + BF	0.439	0.761	0.846	0.759	0.701
T ₃ :	100 % PE + 100 % RDF + BF	0.580	1.107	1.256	1.007	0.988
T ₄ :	100 % PE + 125 % RDF + BF	0.502	0.953	1.097	0.896	0.862
T ₅ :	125 % PE + 75 % RDF + BF	0.551	1.189	1.378	1.143	1.065
T ₆ :	125 % PE + 100 % RDF + BF	0.724	1.308	1.597	1.337	1.242
T ₇ :	125 % PE + 125 % RDF + BF	0.619	1.269	1.404	1.209	1.125
T ₈ :	150 % PE + 75 % RDF + BF	0.323	0.601	0.759	0.607	0.573
T ₉ :	150 % PE + 100 % RDF + BF	0.412	0.723	0.863	0.706	0.676
T ₁₀ :	150 % PE + 125 % RDF + BF	0.450	0.904	1.058	0.856	0.817
	Mean	0.531	0.977	1.131	0.953	
	SEd	0.0145	0.0244	0.0283	0.0247	
	CD at 5 %	0.0306	0.0512	0.0595	0.0519	

Overall mean performance of irrigation regimes and fertilizer levels

Irrigation regime	RMD (mg cm⁻³)	Fertilizer level	RMD (mg cm⁻³)
100 % PE (I₁)	0.850	75 % RDF + BF (F₁)	0.780
125 % PE (I₂)	1.144	100 % RDF + BF (F₂)	0.969
150 % PE (I₃)	0.689	125 % RDF + BF (F₃)	0.935
Conventional method	0.931	Conventional method	0.931

DS : Dry season
PE : Pan evaporation level
RDF: Recommended Dose of Fertilizer
BF : Biofertilizer (*Azophosmet*)

AT: Active tillering
PI : Panicle initiation
FF: 50 % flowering
HT: Harvest

Table 12. Tiller density (No. m⁻²) at chosen growth stages as influenced by drip fertigation treatments in PMK (R) 3 rice under aerobic condition, DS (2007)

	Treatment	AT	PI	FF	HT	Mean
T ₁ :	Conventional method	125	346	542	351	341
T ₂ :	100 % PE + 75 % RDF + BF	75	171	375	258	220
T ₃ :	100 % PE + 100 % RDF + BF	87	205	413	280	246
T ₄ :	100 % PE + 125 % RDF + BF	99	221	428	289	259
T ₅ :	125 % PE + 75 % RDF + BF	105	204	497	350	289
T ₆ :	125 % PE + 100 % RDF + BF	114	257	518	407	324
T ₇ :	125 % PE + 125 % RDF + BF	129	283	568	368	337
T ₈ :	150 % PE + 75 % RDF + BF	122	299	507	357	321
T ₉ :	150 % PE + 100 % RDF + BF	125	303	538	375	335
T ₁₀ :	150 % PE + 125 % RDF + BF	132	315	578	366	348
	Mean	111	260	496	340	
	SEd	2.7	6.3	11.8	8.2	
	CD at 5 %	5.6	13.2	24.9	17.2	

Overall mean performance of irrigation regimes and fertilizer levels

Irrigation regime	Tiller Density (No. per m²)	Fertilizer level	Tiller Density (No. per m²)
100 % PE (I₁)	242	75 % RDF + BF (F₁)	277
125 % PE (I₂)	317	100 % RDF + BF (F₂)	302
150 % PE (I₃)	335	125 % RDF + BF (F₃)	315
Conventional method	341	Conventional method	341

DS : Dry season
PE : Pan evaporation level
RDF: Recommended Dose of Fertilizer
BF : Biofertilizer (*Azophosmet*)

AT: Active tillering
PI : Panicle initiation
FF: 50 % flowering
HT: Harvest

Table 13. Leaf number hill⁻¹ at chosen growth stages as influenced by drip fertigation treatments in PMK (R) 3 rice under aerobic condition, DS (2007)

Treatment		AT	PI	FF	HT	Mean
T ₁ :	Conventional method	42.5	65	125.9	100.2	83.4
T ₂ :	100 % PE + 75 % RDF + BF	35.4	40.8	82.5	71.7	57.6
T ₃ :	100 % PE + 100 % RDF + BF	37.5	42.7	88.6	73.9	60.7
T ₄ :	100 % PE + 125 % RDF + BF	39.8	44.6	93.1	76.3	63.5
T ₅ :	125 % PE + 75 % RDF + BF	36.3	43.5	97.0	89.0	66.5
T ₆ :	125 % PE + 100 % RDF + BF	37.9	45.3	100.9	91.2	68.8
T ₇ :	125 % PE + 125 % RDF + BF	38.4	48.1	110.6	94.5	72.9
T ₈ :	150 % PE + 75 % RDF + BF	38.1	46.2	103.8	90.3	69.6
T ₉ :	150 % PE + 100 % RDF + BF	38.1	52.8	110.6	95.5	74.3
T ₁₀ :	150 % PE + 125 % RDF + BF	40.2	55.4	119.8	98.3	78.4
Mean		38.4	48.4	103.3	88.1	
SEd		0.9	1.15	2.45	2.09	
CD at 5 %		1.88	2.41	5.14	4.4	

Overall mean performance of irrigation regimes and fertilizer levels

Irrigation regime	Leaf number hill ⁻¹	Fertilizer level	Leaf number hill ⁻¹
100 % PE (I₁)	60.6	75 % RDF + BF (F₁)	64.6
125 % PE (I₂)	69.4	100 % RDF + BF (F₂)	67.9
150 % PE (I₃)	74.1	125 % RDF + BF (F₃)	71.6
Conventional method	83.4	Conventional method	83.4

DS : Dry season
PE : Pan evaporation level
RDF: Recommended Dose of Fertilizer
BF : Biofertilizer (*Azophosmet*)

AT: Active tillering
PI : Panicle initiation
FF: 50 % flowering
HT: Harvest

Table 14. Total Dry Matter Accumulation (TDMA: g m⁻²) at chosen growth stages as influenced by drip fertigation treatments in PMK (R) 3 rice under aerobic condition, DS (2007)

	Treatment	AT	PI	FF	HT	Mean
T ₁ :	Conventional method	134.70	501.82	1010.20	1204.38	712.77
T ₂ :	100 % PE + 75 % RDF + BF	72.47	342.52	723.88	855.97	498.71
T ₃ :	100 % PE + 100 % RDF + BF	66.96	406.92	824.35	953.01	562.81
T ₄ :	100 % PE + 125 % RDF + BF	97.72	454.98	937.36	1016.26	626.58
T ₅ :	125 % PE + 75 % RDF + BF	79.77	427.30	931.52	1045.45	621.01
T ₆ :	125 % PE + 100 % RDF + BF	80.02	462.12	1007.59	1206.21	688.99
T ₇ :	125 % PE + 125 % RDF + BF	94.20	492.03	1063.15	1099.68	687.26
T ₈ :	150 % PE + 75 % RDF + BF	98.50	446.86	977.83	1146.40	667.40
T ₉ :	150 % PE + 100 % RDF + BF	116.56	462.83	1064.13	1282.54	731.51
T ₁₀ :	150 % PE + 125 % RDF + BF	132.12	477.59	1150.43	1335.89	774.01
	Mean	97.30	447.50	969.04	1114.58	
	SEd	2.320	10.585	22.923	26.376	
	CD at 5 %	4.873	22.240	48.161	55.415	

Overall mean performance of irrigation regimes and fertilizer levels

Irrigation regime	TDMA (g m⁻²)	Fertilizer level	TDMA (g m⁻²)
100 % PE (I₁)	562.70	75 % RDF + BF (F₁)	595.71
125 % PE (I₂)	665.75	100 % RDF + BF (F₂)	661.10
150 % PE (I₃)	724.31	125 % RDF + BF (F₃)	695.95
Conventional method	712.77	Conventional method	712.77

DS : Dry season
PE : Pan evaporation level
RDF: Recommended Dose of Fertilizer
BF : Biofertilizer (*Azophosmet*)

AT: Active tillering
PI : Panicle initiation
FF: 50 % flowering
HT: Harvest

Table 15. Root / Shoot (R/S) ratio at chosen growth stages as influenced by drip fertigation treatments in PMK (R) 3 rice under aerobic condition, DS (2007)

	Treatment	AT	PI	FF	HT	Mean
T ₁ :	Conventional method	0.394	0.144	0.094	0.061	0.173
T ₂ :	100 % PE + 75 % RDF + BF	0.365	0.078	0.178	0.132	0.188
T ₃ :	100 % PE + 100 % RDF + BF	0.207	0.191	0.187	0.118	0.176
T ₄ :	100 % PE + 125 % RDF + BF	0.283	0.169	0.169	0.114	0.184
T ₅ :	125 % PE + 75 % RDF + BF	0.214	0.056	0.118	0.072	0.115
T ₆ :	125 % PE + 100 % RDF + BF	0.239	0.146	0.141	0.079	0.151
T ₇ :	125 % PE + 125 % RDF + BF	0.323	0.181	0.146	0.096	0.187
T ₈ :	150 % PE + 75 % RDF + BF	0.156	0.046	0.084	0.049	0.084
T ₉ :	150 % PE + 100 % RDF + BF	0.260	0.057	0.084	0.054	0.114
T ₁₀ :	150 % PE + 125 % RDF + BF	0.310	0.071	0.088	0.059	0.132
	Mean	0.275	0.114	0.129	0.083	
	SEd	0.0085	0.0041	0.0044	0.0028	
	CD at 5 %	0.0179	0.0087	0.0092	0.0058	

Overall mean performance of irrigation regimes and fertilizer levels

Irrigation regime	R/S Ratio	Fertilizer level	R/S Ratio
100 % PE (I₁)	0.183	75 % RDF + BF (F₁)	0.129
125 % PE (I₂)	0.151	100 % RDF + BF (F₂)	0.147
150 % PE (I₃)	0.110	125 % RDF + BF (F₃)	0.168
Conventional method	0.173	Conventional method	0.173

DS : Dry season
PE : Pan evaporation level
RDF: Recommended Dose of Fertilizer
BF : Biofertilizer (*Azophosmet*)

AT: Active tillering
PI : Panicle initiation
FF: 50 % flowering
HT: Harvest

Table 16. Leaf Area Index (LAI) at chosen growth stages as influenced by drip fertigation treatments in PMK (R) 3 rice under aerobic condition, DS (2007)

Treatment		AT	PI	FF	GF	Mean
T ₁ :	Conventional method	2.02	3.89	5.15	5.01	4.02
T ₂ :	100 % PE + 75 % RDF + BF	0.80	2.70	3.26	2.89	2.41
T ₃ :	100 % PE + 100 % RDF + BF	0.95	3.07	3.52	3.15	2.67
T ₄ :	100 % PE + 125 % RDF + BF	1.11	3.24	3.81	3.21	2.84
T ₅ :	125 % PE + 75 % RDF + BF	1.09	3.11	4.08	3.89	3.04
T ₆ :	125 % PE + 100 % RDF + BF	1.33	3.32	4.29	4.11	3.26
T ₇ :	125 % PE + 125 % RDF + BF	1.58	3.58	4.67	4.50	3.58
T ₈ :	150 % PE + 75 % RDF + BF	1.23	3.30	4.21	4.09	3.21
T ₉ :	150 % PE + 100 % RDF + BF	1.62	3.52	4.48	4.23	3.46
T ₁₀ :	150 % PE + 125 % RDF + BF	1.99	3.78	5.05	4.82	3.91
Mean		1.37	3.35	4.25	3.99	
SEd		0.034	0.080	0.101	0.096	
CD at 5 %		0.072	0.167	0.212	0.202	

Overall mean performance of irrigation regimes and fertilizer levels

Irrigation regime	LAI	Fertilizer level	LAI
100 % PE (I₁)	2.64	75 % RDF + BF (F₁)	2.89
125 % PE (I₂)	3.29	100 % RDF + BF (F₂)	3.13
150 % PE (I₃)	3.53	125 % RDF + BF (F₃)	3.44
Conventional method	4.02	Conventional method	4.02

DS : Dry season
PE : Pan evaporation level
RDF: Recommended Dose of Fertilizer
BF : Biofertilizer (*Azophosmet*)

AT: Active tillering
PI : Panicle initiation
FF: 50 % flowering
GF: Grain filling

Table 17. Leaf Area Duration (LAD: days) at chosen growth stages as influenced by drip fertigation treatments in PMK (R) 3 rice under aerobic condition, DS (2007)

	Treatment	AT-PI	PI-FF	FF-GF	Mean
T ₁ :	Conventional method	88.65	135.60	152.40	125.55
T ₂ :	100 % PE + 75 % RDF + BF	52.50	89.40	92.25	78.05
T ₃ :	100 % PE + 100 % RDF + BF	60.30	98.85	100.05	86.40
T ₄ :	100 % PE + 125 % RDF + BF	65.25	105.75	105.30	92.10
T ₅ :	125 % PE + 75 % RDF + BF	63.00	107.85	119.55	96.80
T ₆ :	125 % PE + 100 % RDF + BF	69.75	114.15	126.00	103.30
T ₇ :	125 % PE + 125 % RDF + BF	77.40	123.75	137.55	112.90
T ₈ :	150 % PE + 75 % RDF + BF	67.95	112.65	124.50	101.70
T ₉ :	150 % PE + 100 % RDF + BF	77.10	120.00	130.65	109.25
T ₁₀ :	150 % PE + 125 % RDF + BF	86.55	132.45	148.05	122.35
	Mean	70.85	114.05	123.63	
	SEd	1.687	2.703	2.963	
	CD at 5 %	3.545	5.679	6.224	

Overall mean performance of irrigation regimes and fertilizer levels

Irrigation regime	LAD (Days)	Fertilizer level	LAD (Days)
100 % PE (I₁)	85.52	75 % RDF + BF (F₁)	92.18
125 % PE (I₂)	104.33	100 % RDF + BF (F₂)	99.65
150 % PE (I₃)	111.10	125 % RDF + BF (F₃)	109.12
Conventional method	125.55	Conventional method	125.55

DS : Dry season
PE : Pan evaporation level
RDF: Recommended Dose of Fertilizer
BF : Biofertilizer (*Azophosmet*)

AT: Active tillering
PI : Panicle initiation
FF: 50 % flowering
GF: Grain filling

Table 18. Individual Leaf Size (ILS: cm² leaf⁻¹) at chosen growth stages as influenced by drip fertigation treatments in PMK (R) 3 rice under aerobic condition, DS (2007)

	Treatment	AT	PI	FF	HT	Mean
T ₁ :	Conventional method	14.3	10.5	9.3	10.3	11.1
T ₂ :	100 % PE + 75 % RDF + BF	8.2	10.9	8.4	8.5	9.0
T ₃ :	100 % PE + 100 % RDF + BF	12.4	9.1	7.8	8.2	9.4
T ₄ :	100 % PE + 125 % RDF + BF	12.4	9.3	7.7	8.7	9.5
T ₅ :	125 % PE + 75 % RDF + BF	9.6	12.1	7.6	10.3	9.9
T ₆ :	125 % PE + 100 % RDF + BF	10.3	10.4	9.1	10.2	10.0
T ₇ :	125 % PE + 125 % RDF + BF	10.2	14.0	9.1	9.1	10.6
T ₈ :	150 % PE + 75 % RDF + BF	15.3	9.7	8.4	8.7	10.5
T ₉ :	150 % PE + 100 % RDF + BF	9.2	12.5	10.5	12.9	11.3
T ₁₀ :	150 % PE + 125 % RDF + BF	10.5	16.0	9.9	10.6	11.8
	Mean	11.2	11.5	8.8	9.8	
	SEd	0.27	0.27	0.21	0.23	
	CD at 5 %	0.56	0.56	0.43	0.49	

Overall mean performance of irrigation regimes and fertilizer levels

Irrigation regime	ILS (cm² leaf⁻¹)	Fertilizer level	ILS (cm² leaf⁻¹)
100 % PE (I₁)	9.31	75 % RDF + BF (F₁)	9.81
125 % PE (I₂)	10.16	100 % RDF + BF (F₂)	10.22
150 % PE (I₃)	11.18	125 % RDF + BF (F₃)	10.62
Conventional method	11.11	Conventional method	11.11

DS : Dry season
PE : Pan evaporation level
RDF: Recommended Dose of Fertilizer
BF : Biofertilizer (*Azophosmet*)

AT: Active tillering
PI : Panicle initiation
FF: 50 % flowering
HT: Harvest

Table 19. Individual Leaf Weight (ILW: mg leaf⁻¹) at chosen growth stages as influenced by drip fertigation treatments in PMK (R) 3 rice under aerobic condition, DS (2007)

	Treatment	AT	PI	FF	HT	Mean
T ₁ :	Conventional method	30.6	66.7	80.3	70.2	62.0
T ₂ :	100 % PE + 75 % RDF + BF	28.4	64.0	75.3	78.1	61.4
T ₃ :	100 % PE + 100 % RDF + BF	22.9	73.2	77.9	72.6	61.7
T ₄ :	100 % PE + 125 % RDF + BF	25.7	99.5	72.1	67.7	66.2
T ₅ :	125 % PE + 75 % RDF + BF	26.5	87.8	73.3	78.6	66.5
T ₆ :	125 % PE + 100 % RDF + BF	23.1	92.1	92.3	79.0	71.6
T ₇ :	125 % PE + 125 % RDF + BF	27.0	124.1	69.2	75.4	73.9
T ₈ :	150 % PE + 75 % RDF + BF	24.5	60.5	62.9	58.0	51.5
T ₉ :	150 % PE + 100 % RDF + BF	32.6	63.2	76.8	73.1	61.4
T ₁₀ :	150 % PE + 125 % RDF + BF	26.8	74.6	77.6	68.9	62.0
	Mean	26.8	80.6	75.8	72.1	
	SEd	0.62	2.00	1.80	1.71	
	CD at 5 %	1.31	4.19	3.78	3.58	

Overall mean performance of irrigation regimes and fertilizer levels

Irrigation regime	ILW (mg leaf⁻¹)	Fertilizer level	ILW (mg leaf⁻¹)
100 % PE (I₁)	63.11	75 % RDF + BF (F₁)	59.82
125 % PE (I₂)	70.70	100 % RDF + BF (F₂)	64.89
150 % PE (I₃)	58.29	125 % RDF + BF (F₃)	67.39
Conventional method	61.96	Conventional method	61.96

DS : Dry season
PE : Pan evaporation level
RDF: Recommended Dose of Fertilizer
BF : Biofertilizer (*Azophosmet*)

AT: Active tillering
PI : Panicle initiation
FF: 50 % flowering
HT: Harvest

Table 20. Specific Leaf Weight (SLW: cm² g⁻¹) at chosen growth stages as influenced by drip fertigation treatments in PMK (R) 3 rice under aerobic condition, DS (2007)

	Treatment	AT	PI	FF	HT	Mean
T ₁ :	Conventional method	2.15	6.35	8.60	6.82	5.98
T ₂ :	100 % PE + 75 % RDF + BF	2.58	7.74	7.01	7.08	6.10
T ₃ :	100 % PE + 100 % RDF + BF	2.53	7.13	7.91	7.45	6.25
T ₄ :	100 % PE + 125 % RDF + BF	3.27	6.83	8.20	7.12	6.36
T ₅ :	125 % PE + 75 % RDF + BF	2.51	7.36	8.76	6.14	6.19
T ₆ :	125 % PE + 100 % RDF + BF	2.23	7.02	8.58	7.13	6.24
T ₇ :	125 % PE + 125 % RDF + BF	1.97	6.65	8.06	7.08	5.94
T ₈ :	150 % PE + 75 % RDF + BF	2.75	7.27	9.62	7.62	6.82
T ₉ :	150 % PE + 100 % RDF + BF	2.28	6.89	9.74	9.00	6.98
T ₁₀ :	150 % PE + 125 % RDF + BF	2.14	6.50	9.18	8.38	6.55
	Mean	2.44	6.97	8.57	7.38	
	SEd	0.057	0.161	0.201	0.168	
	CD at 5 %	0.119	0.338	0.421	0.353	

Overall mean performance of irrigation regimes and fertilizer levels

Irrigation regime	SLW (cm² g⁻¹)	Fertilizer level	SLW (cm² g⁻¹)
100 % PE (I₁)	6.24	75 % RDF + BF (F₁)	6.37
125 % PE (I₂)	6.12	100 % RDF + BF (F₂)	6.49
150 % PE (I₃)	6.78	125 % RDF + BF (F₃)	6.28
Conventional method	5.98	Conventional method	5.98

DS : Dry season
PE : Pan evaporation level
RDF: Recommended Dose of Fertilizer
BF : Biofertilizer (*Azophosmet*)

AT: Active tillering
PI : Panicle initiation
FF: 50 % flowering
HT: Harvest

Table 21. Crop Growth Rate (CGR: g m⁻² day⁻¹) at chosen growth stages as influenced by drip fertigation treatments in PMK (R) 3 rice under aerobic condition, DS (2007)

Treatment		SL - AT	AT - PI	PI - FF	FF - HT	Mean
T ₁ :	Conventional method	1.69	6.49	14.40	11.10	8.42
T ₂ :	100 % PE + 75 % RDF + BF	1.03	3.59	7.01	5.12	4.19
T ₃ :	100 % PE + 100 % RDF + BF	1.07	4.07	8.69	5.45	4.82
T ₄ :	100 % PE + 125 % RDF + BF	1.10	4.36	9.34	6.01	5.20
T ₅ :	125 % PE + 75 % RDF + BF	1.06	4.85	11.22	8.99	6.53
T ₆ :	125 % PE + 100 % RDF + BF	1.11	5.36	12.29	9.26	7.00
T ₇ :	125 % PE + 125 % RDF + BF	1.27	6.28	13.98	10.54	8.02
T ₈ :	150 % PE + 75 % RDF + BF	1.34	5.07	12.17	9.27	6.96
T ₉ :	150 % PE + 100 % RDF + BF	1.49	5.90	13.57	10.70	7.91
T ₁₀ :	150 % PE + 125 % RDF + BF	1.61	6.36	14.23	10.90	8.28
Mean		1.27	5.23	11.69	8.73	
SEd		0.029	0.126	0.286	0.217	
CD at 5 %		0.062	0.2663	0.601	0.456	

Overall mean performance of irrigation regimes and fertilizer levels

Irrigation regime	Crop growth rate (g m ⁻² day ⁻¹)	Fertilizer level	Crop growth rate (g m ⁻² day ⁻¹)
100 % PE (I₁)	4.74	75 % RDF + BF (F₁)	5.89
125 % PE (I₂)	7.18	100 % RDF + BF (F₂)	6.58
150 % PE (I₃)	7.72	125 % RDF + BF (F₃)	7.17
Conventional method	8.42	Conventional method	8.42

DS : Dry season
PE : Pan evaporation level
RDF: Recommended Dose of Fertilizer
BF : Biofertilizer (*Azophosmet*)

AT: Active tillering
PI : Panicle initiation
FF: 50 % flowering
HT: Harvest

Table 22. Net Assimilation Rate (NAR: mg cm⁻² day⁻¹) at chosen growth stages as influenced by drip fertigation treatments in PMK (R) 3 rice under aerobic condition, DS (2007)

Treatment		SL - AT	AT - PI	PI - FF	FF -HT	Mean
T ₁ :	Conventional method	1.967	1.823	2.023	1.089	1.726
T ₂ :	100 % PE + 75 % RDF + BF	0.956	0.752	0.851	0.408	0.742
T ₃ :	100 % PE + 100 % RDF + BF	0.994	0.896	0.963	0.504	0.839
T ₄ :	100 % PE + 125 % RDF + BF	1.057	0.912	1.097	0.563	0.907
T ₅ :	125 % PE + 75 % RDF + BF	1.405	1.202	1.421	0.796	1.206
T ₆ :	125 % PE + 100 % RDF + BF	1.589	1.353	1.563	0.804	1.327
T ₇ :	125 % PE + 125 % RDF + BF	1.896	1.708	1.974	0.935	1.628
T ₈ :	150 % PE + 75 % RDF + BF	1.969	1.630	2.007	1.053	1.665
T ₉ :	150 % PE + 100 % RDF + BF	2.001	1.792	2.204	1.103	1.775
T ₁₀ :	150 % PE + 125 % RDF + BF	2.018	1.883	2.135	1.220	1.814
Mean		1.585	1.395	1.624	0.848	
SEd		0.0392	0.0346	0.0399	0.0206	
CD at 5 %		0.0824	0.0726	0.0838	0.0434	

Overall mean performance of irrigation regimes and fertilizer levels

Irrigation regime	NAR (mg cm ⁻² day ⁻¹)	Fertilizer level	NAR (mg cm ⁻² day ⁻¹)
100 % PE (I₁)	0.829	75 % RDF + BF (F₁)	1.204
125 % PE (I₂)	1.387	100 % RDF + BF (F₂)	1.314
150 % PE (I₃)	1.751	125 % RDF + BF (F₃)	1.450
Conventional method	1.726	Conventional method	1.726

DS : Dry season
PE : Pan evaporation level
RDF: Recommended Dose of Fertilizer
BF : Biofertilizer (*Azophosmet*)

AT: Active tillering
PI : Panicle initiation
FF: 50 % flowering
HT: Harvest

Table 23. Leaf Area Ratio (LAR: cm² g⁻¹) at chosen growth stages as influenced by drip fertigation treatments in PMK (R) 3 rice under aerobic condition, DS (2007)

Treatment		AT	PI	FF	HT	Mean
T ₁ :	Conventional method	3.00	1.55	1.02	0.88	1.61
T ₂ :	100 % PE + 75 % RDF + BF	2.21	1.58	0.90	0.60	1.32
T ₃ :	100 % PE + 100 % RDF + BF	2.84	1.51	0.85	0.60	1.45
T ₄ :	100 % PE + 125 % RDF + BF	2.27	1.42	0.81	0.60	1.28
T ₅ :	125 % PE + 75 % RDF + BF	2.73	1.46	0.88	0.74	1.45
T ₆ :	125 % PE + 100 % RDF + BF	3.32	1.44	0.85	0.68	1.57
T ₇ :	125 % PE + 125 % RDF + BF	3.35	1.46	0.88	0.73	1.61
T ₈ :	150 % PE + 75 % RDF + BF	2.50	1.48	0.86	0.70	1.38
T ₉ :	150 % PE + 100 % RDF + BF	2.75	1.52	0.84	0.66	1.44
T ₁₀ :	150 % PE + 125 % RDF + BF	3.01	1.58	0.88	0.72	1.55
Mean		2.80	1.50	0.88	0.69	
SEd		0.068	0.035	0.023	0.017	
CD at 5 %		0.142	0.073	0.048	0.035	

Overall mean performance of irrigation regimes and fertilizer levels

Irrigation regime	LAR (cm ² g ⁻¹)	Fertilizer level	LAR (cm ² g ⁻¹)
100 % PE (I₁)	1.35	75 % RDF + BF (F₁)	1.38
125 % PE (I₂)	1.54	100 % RDF + BF (F₂)	1.49
150 % PE (I₃)	1.46	125 % RDF + BF (F₃)	1.48
Conventional method	1.61	Conventional method	1.61

DS : Dry season
PE : Pan evaporation level
RDF: Recommended Dose of Fertilizer
BF : Biofertilizer (*Azophosmet*)

AT: Active tillering
PI : Panicle initiation
FF: 50 % flowering
HT: Harvest

Table 24. Light Interception Percentage (LIP) at chosen growth stages as influenced by drip fertigation treatments in PMK (R) 3 rice under aerobic condition, DS (2007)

	Treatment	AT	PI	FF	GF	Mean
T ₁ :	Conventional method	66.9	83.2	92.4	82.9	81.4
T ₂ :	100 % PE + 75 % RDF + BF	48.6	56.3	77.5	55.3	59.4
T ₃ :	100 % PE + 100 % RDF + BF	56.0	61.8	80.3	61.0	64.8
T ₄ :	100 % PE + 125 % RDF + BF	59.3	65.9	82.8	62.3	67.6
T ₅ :	125 % PE + 75 % RDF + BF	63.5	75.4	90.3	70.2	74.9
T ₆ :	125 % PE + 100 % RDF + BF	68.0	77.9	92.2	76.3	78.6
T ₇ :	125 % PE + 125 % RDF + BF	68.9	78.3	96.0	78.2	80.4
T ₈ :	150 % PE + 75 % RDF + BF	70.1	79.0	89.4	78.9	79.3
T ₉ :	150 % PE + 100 % RDF + BF	75.9	80.7	91.2	80.9	82.2
T ₁₀ :	150 % PE + 125 % RDF + BF	77.5	81.6	92.3	83.1	83.6
	Mean	65.5	74.0	88.4	72.9	
	SEd	0.97	1.23	2.30	1.21	
	CD at 5 %	2.03	2.59	4.83	2.54	

Overall mean performance of irrigation regimes and fertilizer levels

Irrigation regime	LIP	Fertilizer level	LIP
100 % PE (I₁)	63.9	75 % RDF + BF (F₁)	71.2
125 % PE (I₂)	78.0	100 % RDF + BF (F₂)	75.2
150 % PE (I₃)	81.7	125 % RDF + BF (F₃)	77.2
Conventional method	81.4	Conventional method	81.4

DS : Dry season
PE : Pan evaporation level
RDF: Recommended Dose of Fertilizer
BF : Biofertilizer (*Azophosmet*)

AT: Active tillering
PI : Panicle initiation
FF: 50 % flowering
GF: Grain filling

Table 25. Light extinction co-efficient ('k') at chosen growth stages as influenced by drip fertigation treatments in PMK (R) 3 rice under aerobic condition, DS (2007)

Treatment		PI	FF	Mean
T ₁ :	Conventional method	1.303	0.240	0.772
T ₂ :	100 % PE + 75 % RDF + BF	1.336	0.253	0.795
T ₃ :	100 % PE + 100 % RDF + BF	1.409	0.276	0.843
T ₄ :	100 % PE + 125 % RDF + BF	1.512	0.299	0.906
T ₅ :	125 % PE + 75 % RDF + BF	1.006	0.218	0.612
T ₆ :	125 % PE + 100 % RDF + BF	1.029	0.211	0.620
T ₇ :	125 % PE + 125 % RDF + BF	1.220	0.220	0.720
T ₈ :	150 % PE + 75 % RDF + BF	1.189	0.229	0.709
T ₉ :	150 % PE + 100 % RDF + BF	1.229	0.237	0.733
T ₁₀ :	150 % PE + 125 % RDF + BF	1.377	0.241	0.809
Mean		1.261	0.242	
SEd		0.0290	0.0068	
CD at 5 %		0.0609	0.0144	

Overall mean performance of irrigation regimes and fertilizer levels

Irrigation regime	'k'	Fertilizer level	'k'
100 % PE (I₁)	0.848	75 % RDF + BF (F₁)	0.705
125 % PE (I₂)	0.651	100 % RDF + BF (F₂)	0.732
150 % PE (I₃)	0.750	125 % RDF + BF (F₃)	0.812
Conventional method	0.772	Conventional method	0.772

DS : Dry season
PE : Pan evaporation level
RDF: Recommended Dose of Fertilizer

BF : Biofertilizer (*Azophosmet*)
PI : Panicle initiation
FF: 50 % flowering

Table 26. Chlorophyll ‘a’ content (mg g⁻¹) at chosen growth stages as influenced by drip fertigation treatments in PMK (R) 3 rice under aerobic condition, DS (2007)

	Treatment	AT	PI	FF	GF	Mean
T ₁ :	Conventional method	1.308	1.598	2.098	1.587	1.648
T ₂ :	100 % PE + 75 % RDF + BF	0.802	0.918	1.010	0.654	0.846
T ₃ :	100 % PE + 100 % RDF + BF	0.854	0.987	1.169	0.798	0.952
T ₄ :	100 % PE + 125 % RDF + BF	0.954	1.048	1.319	0.822	1.036
T ₅ :	125 % PE + 75 % RDF + BF	1.034	1.482	1.789	1.058	1.341
T ₆ :	125 % PE + 100 % RDF + BF	1.114	1.589	1.947	1.389	1.510
T ₇ :	125 % PE + 125 % RDF + BF	1.320	1.680	2.011	1.663	1.669
T ₈ :	150 % PE + 75 % RDF + BF	1.119	1.586	2.024	1.298	1.507
T ₉ :	150 % PE + 100 % RDF + BF	1.253	1.601	2.089	1.487	1.608
T ₁₀ :	150 % PE + 125 % RDF + BF	1.345	1.618	2.108	1.658	1.682
	Mean	1.110	1.411	1.756	1.241	
	SEd	0.0272	0.0353	0.0427	0.0307	
	CD at 5 %	0.0571	0.0742	0.0897	0.0645	

Overall mean performance of irrigation regimes and fertilizer levels

Irrigation regime	Chlorophyll ‘a’ content (mg g⁻¹)	Fertilizer level	Chlorophyll ‘a’ content (mg g⁻¹)
100 % PE (I₁)	0.945	75 % RDF + BF (F₁)	1.231
125 % PE (I₂)	1.507	100 % RDF + BF (F₂)	1.357
150 % PE (I₃)	1.599	125 % RDF + BF (F₃)	1.462
Conventional method	1.648	Conventional method	1.648

DS : Dry season
PE : Pan evaporation level
RDF: Recommended Dose of Fertilizer
BF : Biofertilizer (*Azophosmet*)

AT: Active tillering
PI : Panicle initiation
FF: 50 % flowering
GF: Grain filling

Table 27. Chlorophyll ‘b’ content (mg g⁻¹) at chosen growth stages as influenced by drip fertigation treatments in PMK (R) 3 rice under aerobic condition, DS (2007)

	Treatment	AT	PI	FF	GF	Mean
T ₁ :	Conventional method	0.451	0.535	0.701	0.555	0.561
T ₂ :	100 % PE + 75 % RDF + BF	0.390	0.612	0.848	0.550	0.600
T ₃ :	100 % PE + 100 % RDF + BF	0.411	0.594	0.879	0.681	0.641
T ₄ :	100 % PE + 125 % RDF + BF	0.449	0.564	0.710	0.600	0.581
T ₅ :	125 % PE + 75 % RDF + BF	0.401	0.601	0.693	0.455	0.537
T ₆ :	125 % PE + 100 % RDF + BF	0.440	0.552	0.699	0.513	0.551
T ₇ :	125 % PE + 125 % RDF + BF	0.459	0.566	0.711	0.607	0.586
T ₈ :	150 % PE + 75 % RDF + BF	0.415	0.549	0.696	0.461	0.530
T ₉ :	150 % PE + 100 % RDF + BF	0.418	0.552	0.700	0.522	0.548
T ₁₀ :	150 % PE + 125 % RDF + BF	0.459	0.555	0.703	0.578	0.574
	Mean	0.429	0.568	0.734	0.552	
	SEd	0.0082	0.0124	0.0167	0.0130	
	CD at 5 %	0.0172	0.0260	0.0351	0.0273	

Overall mean performance of irrigation regimes and fertilizer levels

Irrigation regime	Chlorophyll ‘b’ content (mg g⁻¹)	Fertilizer level	Chlorophyll ‘b’ content (mg g⁻¹)
100 % PE (I₁)	0.607	75 % RDF + BF (F₁)	0.556
125 % PE (I₂)	0.558	100 % RDF + BF (F₂)	0.580
150 % PE (I₃)	0.551	125 % RDF + BF (F₃)	0.580
Conventional method	0.561	Conventional method	0.561

DS : Dry season
PE : Pan evaporation level
RDF: Recommended Dose of Fertilizer
BF : Biofertilizer (*Azophosmet*)

AT: Active tillering
PI : Panicle initiation
FF: 50 % flowering
GF: Grain filling

Table 28. Total chlorophyll content (mg g⁻¹) at chosen growth stages as influenced by drip fertigation treatments in PMK (R) 3 rice under aerobic condition, DS (2007)

Treatment		AT	PI	FF	GF	Mean
T ₁ :	Conventional method	1.759	2.133	2.799	2.142	2.208
T ₂ :	100 % PE + 75 % RDF + BF	1.192	1.530	1.858	1.204	1.446
T ₃ :	100 % PE + 100 % RDF + BF	1.265	1.581	2.048	1.479	1.593
T ₄ :	100 % PE + 125 % RDF + BF	1.403	1.612	2.029	1.422	1.617
T ₅ :	125 % PE + 75 % RDF + BF	1.435	2.083	2.482	1.513	1.878
T ₆ :	125 % PE + 100 % RDF + BF	1.554	2.141	2.646	1.902	2.061
T ₇ :	125 % PE + 125 % RDF + BF	1.779	2.226	2.722	2.218	2.236
T ₈ :	150 % PE + 75 % RDF + BF	1.534	2.084	2.529	1.709	1.964
T ₉ :	150 % PE + 100 % RDF + BF	1.671	2.076	2.613	1.942	2.076
T ₁₀ :	150 % PE + 125 % RDF + BF	1.804	2.052	2.637	1.979	2.118
Mean		1.540	1.952	2.436	1.751	
SEd		0.0357	0.0478	0.0581	0.0428	
CD at 5 %		0.0749	0.1004	0.1221	0.0900	

Overall mean performance of irrigation regimes and fertilizer levels

Irrigation regime	Total chlorophyll content (mg g ⁻¹)	Fertilizer level	Total chlorophyll content (mg g ⁻¹)
100 % PE (I₁)	1.552	75 % RDF + BF (F₁)	1.763
125 % PE (I₂)	2.058	100 % RDF + BF (F₂)	1.910
150 % PE (I₃)	2.053	125 % RDF + BF (F₃)	1.990
Conventional method	2.208	Conventional method	2.208

DS : Dry season
PE : Pan evaporation level
RDF: Recommended Dose of Fertilizer
BF : Biofertilizer (*Azophosmet*)

AT: Active tillering
PI : Panicle initiation
FF: 50 % flowering
GF: Grain filling

Table 29. Chlorophyll a/b ratio at chosen growth stages as influenced by drip fertigation treatments in PMK (R) 3 rice under aerobic condition, DS (2007)

	Treatment	AT	PI	FF	GF	Mean
T ₁ :	Conventional method	2.900	2.987	2.993	2.859	2.935
T ₂ :	100 % PE + 75 % RDF + BF	2.056	1.501	1.191	1.189	1.484
T ₃ :	100 % PE + 100 % RDF + BF	2.078	1.661	1.330	1.172	1.560
T ₄ :	100 % PE + 125 % RDF + BF	2.125	1.858	1.858	1.370	1.803
T ₅ :	125 % PE + 75 % RDF + BF	2.579	2.467	2.582	2.325	2.488
T ₆ :	125 % PE + 100 % RDF + BF	2.532	2.879	2.785	2.708	2.726
T ₇ :	125 % PE + 125 % RDF + BF	2.876	2.967	2.828	2.740	2.853
T ₈ :	150 % PE + 75 % RDF + BF	2.696	2.885	2.910	2.818	2.827
T ₉ :	150 % PE + 100 % RDF + BF	2.998	2.899	2.985	2.850	2.933
T ₁₀ :	150 % PE + 125 % RDF + BF	2.930	2.915	3.000	2.867	2.928
	Mean	2.577	2.502	2.446	2.290	
	SEd	0.0617	0.0623	0.0615	0.0574	
	CD at 5 %	0.1295	0.1309	0.1292	0.1205	

Overall mean performance of irrigation regimes and fertilizer levels

Irrigation regime	Chlorophyll a/b ratio	Fertilizer level	Chlorophyll a/b ratio
100 % PE (I₁)	1.616	75 % RDF + BF (F₁)	2.267
125 % PE (I₂)	2.689	100 % RDF + BF (F₂)	2.406
150 % PE (I₃)	2.896	125 % RDF + BF (F₃)	2.528
Conventional method	2.935	Conventional method	2.935

DS : Dry season
PE : Pan evaporation level
RDF: Recommended Dose of Fertilizer
BF : Biofertilizer (*Azophosmet*)

AT: Active tillering
PI : Panicle initiation
FF: 50 % flowering
GF: Grain filling

Table 30. SPAD Chlorophyll Meter reading at chosen growth stages as influenced by drip fertigation treatments in PMK (R) 3 rice under aerobic condition, DS (2007)

	Treatment	AT	PI	FF	GF	Mean
T ₁ :	Conventional method	30.0	36.5	37.2	35.2	34.7
T ₂ :	100 % PE + 75 % RDF + BF	26.3	30.1	32.2	29.7	29.6
T ₃ :	100 % PE + 100 % RDF + BF	27.2	32.6	34.0	30.8	31.2
T ₄ :	100 % PE + 125 % RDF + BF	28.5	34.8	35.9	32.2	32.9
T ₅ :	125 % PE + 75 % RDF + BF	27.4	32.9	34.1	32.3	31.7
T ₆ :	125 % PE + 100 % RDF + BF	29.6	34.5	35.3	34.0	33.3
T ₇ :	125 % PE + 125 % RDF + BF	30.2	35.6	35.8	34.7	34.1
T ₈ :	150 % PE + 75 % RDF + BF	27.9	33.9	35.1	33.9	32.7
T ₉ :	150 % PE + 100 % RDF + BF	29.6	35.8	36.2	34.2	33.9
T ₁₀ :	150 % PE + 125 % RDF + BF	30.5	36.1	36.8	35.0	34.6
	Mean	28.7	34.3	35.3	33.2	
	SEd	0.67	0.80	0.82	0.78	
	CD at 5 %	1.41	1.68	1.73	1.64	

Overall mean performance of irrigation regimes and fertilizer levels

Irrigation regime	SPAD Chlorophyll Meter reading	Fertilizer level	SPAD Chlorophyll Meter reading
100 % PE (I₁)	31.2	75 % RDF + BF (F₁)	31.3
125 % PE (I₂)	33.0	100 % RDF + BF (F₂)	32.8
150 % PE (I₃)	33.8	125 % RDF + BF (F₃)	33.8
Conventional method	34.7	Conventional method	34.7

DS : Dry season
PE : Pan evaporation level
RDF: Recommended Dose of Fertilizer
BF : Biofertilizer (*Azophosmet*)

AT: Active tillering
PI : Panicle initiation
FF: 50 % flowering
GF: Grain filling

Table 31. Fv / Fm ratio (PS II) at chosen growth stages as influenced by drip fertigation treatments in PMK (R) 3 rice under aerobic condition, DS (2007)

	Treatment	AT	PI	FF	GF	Mean
T ₁ :	Conventional method	0.589	0.655	0.720	0.600	0.641
T ₂ :	100 % PE + 75 % RDF + BF	0.481	0.500	0.521	0.498	0.500
T ₃ :	100 % PE + 100 % RDF + BF	0.501	0.534	0.552	0.501	0.522
T ₄ :	100 % PE + 125 % RDF + BF	0.520	0.571	0.597	0.515	0.551
T ₅ :	125 % PE + 75 % RDF + BF	0.529	0.555	0.691	0.531	0.577
T ₆ :	125 % PE + 100 % RDF + BF	0.562	0.623	0.719	0.554	0.615
T ₇ :	125 % PE + 125 % RDF + BF	0.597	0.650	0.722	0.549	0.630
T ₈ :	150 % PE + 75 % RDF + BF	0.569	0.602	0.709	0.555	0.609
T ₉ :	150 % PE + 100 % RDF + BF	0.587	0.651	0.711	0.570	0.630
T ₁₀ :	150 % PE + 125 % RDF + BF	0.602	0.666	0.725	0.602	0.649
	Mean	0.554	0.601	0.667	0.548	
	SEd	0.0129	0.0138	0.0152	0.0136	
	CD at 5 %	0.0271	0.0290	0.0319	0.0286	

Overall mean performance of irrigation regimes and fertilizer levels

Irrigation regime	Fv / Fm ratio	Fertilizer level	Fv / Fm ratio
100 % PE (I₁)	0.524	75 % RDF + BF (F₁)	0.562
125 % PE (I₂)	0.607	100 % RDF + BF (F₂)	0.589
150 % PE (I₃)	0.629	125 % RDF + BF (F₃)	0.610
Conventional method	0.641	Conventional method	0.641

DS : Dry season
PE : Pan evaporation level
RDF: Recommended Dose of Fertilizer
BF : Biofertilizer (*Azophosmet*)

AT: Active tillering
PI : Panicle initiation
FF: 50 % flowering
GF: Grain filling

Table 32. Soluble protein content (mg g⁻¹) at chosen growth stages as influenced by drip fertigation treatments in PMK (R) 3 rice under aerobic condition, DS (2007)

	Treatment	AT	PI	FF	GF	Mean
T ₁ :	Conventional method	6.28	7.93	10.15	8.59	8.24
T ₂ :	100 % PE + 75 % RDF + BF	4.57	5.21	6.97	5.01	5.44
T ₃ :	100 % PE + 100 % RDF + BF	5.00	5.88	7.48	5.23	5.90
T ₄ :	100 % PE + 125 % RDF + BF	5.29	6.35	7.92	5.37	6.23
T ₅ :	125 % PE + 75 % RDF + BF	4.71	7.07	7.90	6.52	6.55
T ₆ :	125 % PE + 100 % RDF + BF	4.86	7.55	8.59	7.09	7.02
T ₇ :	125 % PE + 125 % RDF + BF	5.86	7.89	9.16	7.58	7.62
T ₈ :	150 % PE + 75 % RDF + BF	5.43	7.21	8.36	7.11	7.03
T ₉ :	150 % PE + 100 % RDF + BF	6.00	7.75	9.23	7.55	7.63
T ₁₀ :	150 % PE + 125 % RDF + BF	6.14	8.02	10.23	8.89	8.32
	Mean	5.41	7.22	8.60	6.89	
	SEd	0.127	0.170	0.203	0.167	
	CD at 5 %	0.267	0.358	0.427	0.351	

Overall mean performance of irrigation regimes and fertilizer levels

Irrigation regime	Soluble protein content (mg g⁻¹)	Fertilizer level	Soluble protein content (mg g⁻¹)
100 % PE (I₁)	5.86	75 % RDF + BF (F₁)	6.34
125 % PE (I₂)	7.06	100 % RDF + BF (F₂)	6.85
150 % PE (I₃)	7.66	125 % RDF + BF (F₃)	7.39
Conventional method	8.24	Conventional method	8.24

DS : Dry season
PE : Pan evaporation level
RDF: Recommended Dose of Fertilizer
BF : Biofertilizer (*Azophosmet*)

AT: Active tillering
PI : Panicle initiation
FF: 50 % flowering
GF: Grain filling

Table 33. Soluble nitrogen content (mg g⁻¹) at chosen growth stages as influenced by drip fertigation treatments in PMK (R) 3 rice under aerobic condition, DS (2007)

Treatment		AT	PI	FF	GF	Mean
T ₁ :	Conventional method	1.65	1.77	2.99	1.23	1.91
T ₂ :	100 % PE + 75 % RDF + BF	1.50	1.69	2.75	1.11	1.76
T ₃ :	100 % PE + 100 % RDF + BF	1.55	1.71	3.00	1.19	1.86
T ₄ :	100 % PE + 125 % RDF + BF	1.59	1.84	3.27	1.38	2.02
T ₅ :	125 % PE + 75 % RDF + BF	1.44	1.59	2.09	1.01	1.53
T ₆ :	125 % PE + 100 % RDF + BF	1.38	1.42	1.97	0.94	1.43
T ₇ :	125 % PE + 125 % RDF + BF	1.41	1.56	2.02	1.01	1.50
T ₈ :	150 % PE + 75 % RDF + BF	1.46	1.68	2.31	1.11	1.64
T ₉ :	150 % PE + 100 % RDF + BF	1.52	1.72	2.74	1.20	1.80
T ₁₀ :	150 % PE + 125 % RDF + BF	1.60	1.80	3.13	1.19	1.93
Mean		1.51	1.68	2.63	1.14	
SEd		0.035	0.038	0.059	0.027	
CD at 5 %		0.073	0.080	0.125	0.057	

Overall mean performance of irrigation regimes and fertilizer levels

Irrigation regime	Soluble nitrogen content (mg g ⁻¹)	Fertilizer level	Soluble nitrogen content (mg g ⁻¹)
100 % PE (I₁)	1.88	75 % RDF + BF (F₁)	1.65
125 % PE (I₂)	1.49	100 % RDF + BF (F₂)	1.70
150 % PE (I₃)	1.79	125 % RDF + BF (F₃)	1.82
Conventional method	1.91	Conventional method	1.91

DS : Dry season
PE : Pan evaporation level
RDF: Recommended Dose of Fertilizer
BF : Biofertilizer (*Azophosmet*)

AT: Active tillering
PI : Panicle initiation
FF: 50 % flowering
GF: Grain filling

Table 34. Reducing sugars (mg g⁻¹) at chosen growth stages as influenced by drip fertigation treatments in PMK (R) 3 rice under aerobic condition, DS (2007)

Treatment		AT	PI	FF	GF	Mean
T ₁ :	Conventional method	1.30	2.12	6.08	8.30	4.45
T ₂ :	100 % PE + 75 % RDF + BF	3.15	4.05	10.05	15.05	8.08
T ₃ :	100 % PE + 100 % RDF + BF	2.87	3.85	9.25	14.42	7.60
T ₄ :	100 % PE + 125 % RDF + BF	2.40	3.01	8.12	12.50	6.51
T ₅ :	125 % PE + 75 % RDF + BF	1.76	2.65	7.22	10.25	5.47
T ₆ :	125 % PE + 100 % RDF + BF	1.55	2.37	6.32	9.56	4.95
T ₇ :	125 % PE + 125 % RDF + BF	1.32	2.15	6.01	8.27	4.44
T ₈ :	150 % PE + 75 % RDF + BF	2.25	3.56	7.56	11.80	6.29
T ₉ :	150 % PE + 100 % RDF + BF	2.01	3.31	7.08	10.07	5.62
T ₁₀ :	150 % PE + 125 % RDF + BF	1.78	2.79	6.23	9.36	5.04
Mean		2.07	2.99	7.39	10.96	
SEd		0.046	0.067	0.169	0.250	
CD at 5 %		0.098	0.141	0.355	0.525	

Overall mean performance of irrigation regimes and fertilizer levels

Irrigation regime	Reducing sugar content (mg g ⁻¹)	Fertilizer level	Reducing sugar content (mg g ⁻¹)
100 % PE (I₁)	7.40	75 % RDF + BF (F₁)	6.61
125 % PE (I₂)	4.95	100 % RDF + BF (F₂)	6.06
150 % PE (I₃)	5.65	125 % RDF + BF (F₃)	5.33
Conventional method	4.45	Conventional method	4.45

DS : Dry season
PE : Pan evaporation level
RDF: Recommended Dose of Fertilizer
BF : Biofertilizer (*Azophosmet*)

AT: Active tillering
PI : Panicle initiation
FF: 50 % flowering
GF: Grain filling

Table 35. Total Available Carbohydrates (TAC: mg g⁻¹) at chosen growth stages as influenced by drip fertigation treatments in PMK (R) 3 rice under aerobic condition, DS (2007)

	Treatment	AT	PI	FF	GF	Mean
T ₁ :	Conventional method	89.24	120.45	279.34	197.32	171.59
T ₂ :	100 % PE + 75 % RDF + BF	65.01	89.42	119.79	90.65	91.22
T ₃ :	100 % PE + 100 % RDF + BF	70.50	90.78	137.99	107.00	101.57
T ₄ :	100 % PE + 125 % RDF + BF	78.21	100.12	158.96	112.36	112.41
T ₅ :	125 % PE + 75 % RDF + BF	90.22	109.36	278.12	157.23	158.73
T ₆ :	125 % PE + 100 % RDF + BF	95.56	138.69	309.23	178.14	180.41
T ₇ :	125 % PE + 125 % RDF + BF	89.23	121.87	286.40	166.04	165.89
T ₈ :	150 % PE + 75 % RDF + BF	91.04	110.05	270.12	161.17	158.10
T ₉ :	150 % PE + 100 % RDF + BF	92.07	115.69	288.44	159.35	163.89
T ₁₀ :	150 % PE + 125 % RDF + BF	92.12	124.16	297.20	170.23	170.93
	Mean	85.32	112.07	242.56	149.95	
	SEd	2.034	2.700	6.142	3.711	
	CD at 5 %	4.273	5.672	12.905	7.796	

Overall mean performance of irrigation regimes and fertilizer levels

Irrigation regime	TAC (mg g⁻¹)	Fertilizer level	TAC (mg g⁻¹)
100 % PE (I₁)	101.73	75 % RDF + BF (F₁)	136.02
125 % PE (I₂)	168.34	100 % RDF + BF (F₂)	148.62
150 % PE (I₃)	164.31	125 % RDF + BF (F₃)	149.74
Conventional method	171.59	Conventional method	171.59

DS : Dry season
PE : Pan evaporation level
RDF: Recommended Dose of Fertilizer
BF : Biofertilizer (*Azophosmet*)

AT: Active tillering
PI : Panicle initiation
FF: 50 % flowering
GF: Grain filling

Table 36. Total Free Aminoacids (TFA: mg g⁻¹) at chosen growth stages as influenced by drip fertigation treatments in PMK (R) 3 rice under aerobic condition, DS (2007)

	Treatment	AT	PI	FF	GF	Mean
T ₁ :	Conventional method	1.76	2.09	2.29	1.38	1.88
T ₂ :	100 % PE + 75 % RDF + BF	2.39	2.87	3.10	1.72	2.52
T ₃ :	100 % PE + 100 % RDF + BF	1.92	2.73	3.08	1.79	2.38
T ₄ :	100 % PE + 125 % RDF + BF	2.22	2.72	2.88	1.65	2.37
T ₅ :	125 % PE + 75 % RDF + BF	2.29	2.89	3.18	1.88	2.56
T ₆ :	125 % PE + 100 % RDF + BF	2.25	2.77	2.94	1.72	2.42
T ₇ :	125 % PE + 125 % RDF + BF	1.89	2.76	2.85	1.66	2.29
T ₈ :	150 % PE + 75 % RDF + BF	2.02	2.27	2.33	1.41	2.01
T ₉ :	150 % PE + 100 % RDF + BF	1.89	2.09	2.27	1.36	1.90
T ₁₀ :	150 % PE + 125 % RDF + BF	1.61	2.01	2.18	1.32	1.78
	Mean	2.02	2.52	2.71	1.59	
	SEd	0.049	0.059	0.066	0.037	
	CD at 5 %	0.102	0.124	0.138	0.078	

Overall mean performance of irrigation regimes and fertilizer levels

Irrigation regime	TFA (mg g⁻¹)	Fertilizer level	TFA (mg g⁻¹)
100 % PE (I₁)	2.42	75 % RDF + BF (F₁)	2.36
125 % PE (I₂)	2.42	100 % RDF + BF (F₂)	2.23
150 % PE (I₃)	1.90	125 % RDF + BF (F₃)	2.15
Conventional method	1.88	Conventional method	1.88

DS : Dry season
PE : Pan evaporation level
RDF: Recommended Dose of Fertilizer
BF : Biofertilizer (*Azophosmet*)

AT: Active tillering
PI : Panicle initiation
FF: 50 % flowering
GF: Grain filling

Table 37. Cytokinin content ($\mu\text{g g}^{-1}$) at chosen grow stages as influenced by drip fertigation treatments in PMK (R) 3 rice under aerobic condition, DS (2007)

Treatment		FF	10 DAF	Mean
T ₁ :	Conventional method	38.01	25.05	31.53
T ₂ :	100 % PE + 75 % RDF + BF	25.36	18.22	21.79
T ₃ :	100 % PE + 100 % RDF + BF	26.31	21.57	23.94
T ₄ :	100 % PE + 125 % RDF + BF	28.11	20.98	24.55
T ₅ :	125 % PE + 75 % RDF + BF	40.72	33.08	36.90
T ₆ :	125 % PE + 100 % RDF + BF	49.50	40.11	44.81
T ₇ :	125 % PE + 125 % RDF + BF	42.25	31.89	37.07
T ₈ :	150 % PE + 75 % RDF + BF	40.11	28.29	34.20
T ₉ :	150 % PE + 100 % RDF + BF	42.35	29.95	36.15
T ₁₀ :	150 % PE + 125 % RDF + BF	40.02	25.23	32.63
Mean		37.27	27.44	
SEd		0.919	0.687	
CD at 5 %		1.931	1.443	

Overall mean performance of irrigation regimes and fertilizer levels

Irrigation regime	Cytokinin content ($\mu\text{g g}^{-1}$)	Fertilizer level	Cytokinin content ($\mu\text{g g}^{-1}$)
100 % PE (I₁)	23.43	75 % RDF + BF (F₁)	30.96
125 % PE (I₂)	39.59	100 % RDF + BF (F₂)	34.97
150 % PE (I₃)	34.33	125 % RDF + BF (F₃)	31.42
Conventional method	31.53	Conventional method	31.53

DS : Dry season

PE : Pan evaporation level

RDF: Recommended Dose of Fertilizer

BF : Biofertilizer (*Azophosmet*)

FL : Flowering

DAF: Days After Flowering

Table 38. Peroxidase (PO) activity (Δ 430 nm g⁻¹ h⁻¹) at chosen growth stages as influenced by drip fertigation treatments in PMK (R) 3 rice under aerobic condition, DS (2007)

Treatment		AT	PI	FF	HT	Mean
T ₁ :	Conventional method	0.78	1.81	4.55	2.11	2.31
T ₂ :	100 % PE + 75 % RDF + BF	1.03	7.44	8.75	5.59	5.70
T ₃ :	100 % PE + 100 % RDF + BF	0.89	6.55	7.23	4.87	4.89
T ₄ :	100 % PE + 125 % RDF + BF	0.72	6.05	6.57	4.01	4.34
T ₅ :	125 % PE + 75 % RDF + BF	0.81	5.08	6.22	4.89	4.25
T ₆ :	125 % PE + 100 % RDF + BF	0.80	4.89	6.07	4.07	3.96
T ₇ :	125 % PE + 125 % RDF + BF	0.70	4.05	5.78	3.21	3.44
T ₈ :	150 % PE + 75 % RDF + BF	0.78	3.23	5.13	3.55	3.17
T ₉ :	150 % PE + 100 % RDF + BF	0.68	2.89	5.01	2.27	2.71
T ₁₀ :	150 % PE + 125 % RDF + BF	0.68	1.96	4.58	2.09	2.33
Mean		0.79	4.40	5.99	3.67	
SEd		0.030	0.167	0.229	0.135	
CD at 5 %		0.063	0.351	0.481	0.284	

Overall mean performance of irrigation regimes and fertilizer levels

Irrigation regime	PO activity (Δ OD hr ⁻¹)	Fertilizer level	PO activity (Δ OD hr ⁻¹)
100 % PE (I₁)	4.98	75 % RDF + BF (F₁)	4.37
125 % PE (I₂)	3.88	100 % RDF + BF (F₂)	3.85
150 % PE (I₃)	2.74	125 % RDF + BF (F₃)	3.63
Conventional method	2.31	Conventional method	2.31

DS : Dry season
PE : Pan evaporation level
RDF: Recommended Dose of Fertilizer
BF : Biofertilizer (*Azophosmet*)

AT: Active tillering
PI : Panicle initiation
FF: 50 % flowering
GF: Grain filling

Table 39. Superoxide dismutase (SOD) activity (enzyme units mg^{-1} protein hr^{-1}) at chosen grow stages as influenced by drip fertigation treatments in PMK (R) 3 rice under aerobic condition, DS (2007)

	Treatment	PI	Flowering	Mean
T ₁ :	Conventional method	3.84	5.21	4.53
T ₂ :	100 % PE + 75 % RDF + BF	7.01	8.23	7.62
T ₃ :	100 % PE + 100 % RDF + BF	6.11	7.98	7.05
T ₄ :	100 % PE + 125 % RDF + BF	5.67	7.41	6.54
T ₅ :	125 % PE + 75 % RDF + BF	4.23	7.17	5.70
T ₆ :	125 % PE + 100 % RDF + BF	4.11	6.02	5.07
T ₇ :	125 % PE + 125 % RDF + BF	4.07	6.01	5.04
T ₈ :	150 % PE + 75 % RDF + BF	4.11	5.78	4.95
T ₉ :	150 % PE + 100 % RDF + BF	3.11	5.12	4.12
T ₁₀ :	150 % PE + 125 % RDF + BF	3.06	5.10	4.08
	Mean	4.53	6.40	
	SEd	0.048	0.009	
	CD at 5 %	0.100	0.019	

Overall mean performance of irrigation regimes and fertilizer levels

Irrigation regime	SOD activity (enzyme units mg^{-1} protein hr^{-1})	Fertilizer level	SOD activity (enzyme units mg^{-1} protein hr^{-1})
100 % PE (I₁)	7.07	75 % RDF + BF (F₁)	6.09
125 % PE (I₂)	5.27	100 % RDF + BF (F₂)	5.41
150 % PE (I₃)	4.38	125 % RDF + BF (F₃)	5.22
Conventional method	4.53	Conventional method	4.53

DS : Dry season
PE : Pan evaporation level
RDF: Recommended Dose of Fertilizer

BF: Biofertilizer (*Azophosmet*)
PI : Panicle initiation
FF: 50 % Flowering

Table 40. IAA Oxidase activity ($\mu\text{g g}^{-1}$) at chosen growth stages as influenced by drip fertigation treatments in PMK (R) 3 rice under aerobic condition, DS (2007)

Treatment		AT	PI	FF	GF	Mean
T ₁ :	Conventional method	4.22	13.86	12.52	8.13	9.68
T ₂ :	100 % PE + 75 % RDF + BF	1.75	5.26	3.49	1.57	3.02
T ₃ :	100 % PE + 100 % RDF + BF	2.11	7.01	5.23	3.89	4.56
T ₄ :	100 % PE + 125 % RDF + BF	2.89	8.69	7.05	4.56	5.80
T ₅ :	125 % PE + 75 % RDF + BF	3.04	9.32	8.26	5.17	6.45
T ₆ :	125 % PE + 100 % RDF + BF	3.41	10.44	9.24	6.08	7.29
T ₇ :	125 % PE + 125 % RDF + BF	3.82	12.07	10.35	7.56	8.45
T ₈ :	150 % PE + 75 % RDF + BF	3.08	11.75	9.36	6.08	7.57
T ₉ :	150 % PE + 100 % RDF + BF	3.86	12.56	10.54	7.11	8.52
T ₁₀ :	150 % PE + 125 % RDF + BF	4.10	14.01	13.28	8.26	9.91
Mean		3.33	10.50	8.93	5.84	
SEd		0.079	0.258	0.227	0.149	
CD at 5 %		0.166	0.542	0.477	0.313	

Overall mean performance of irrigation regimes and fertilizer levels

Irrigation regime	IAA Oxidase activity ($\mu\text{g g}^{-1}$)	Fertilizer level	IAA Oxidase activity ($\mu\text{g g}^{-1}$)
100 % PE (I₁)	4.46	75 % RDF + BF (F₁)	5.68
125 % PE (I₂)	7.40	100 % RDF + BF (F₂)	6.79
150 % PE (I₃)	8.67	125 % RDF + BF (F₃)	8.05
Conventional method	9.68	Conventional method	9.68

DS : Dry season
PE : Pan evaporation level
RDF: Recommended Dose of Fertilizer
BF : Biofertilizer (*Azophosmet*)

AT: Active tillering
PI : Panicle initiation
FF: 50 % flowering
GF: Grain filling

Table 41. Nitrate reductase ($\mu\text{mole g}^{-1}$) at chosen growth stages as influenced by drip fertigation treatments in PMK (R) 3 rice under aerobic condition, DS (2007)

Treatment		AT	PI	FF	GF	Mean
T ₁ :	Conventional method	0.617	0.783	0.830	0.620	0.713
T ₂ :	100 % PE + 75 % RDF + BF	0.455	0.409	0.498	0.227	0.397
T ₃ :	100 % PE + 100 % RDF + BF	0.472	0.453	0.515	0.316	0.439
T ₄ :	100 % PE + 125 % RDF + BF	0.507	0.508	0.579	0.408	0.501
T ₅ :	125 % PE + 75 % RDF + BF	0.560	0.697	0.783	0.541	0.645
T ₆ :	125 % PE + 100 % RDF + BF	0.598	0.753	0.801	0.597	0.687
T ₇ :	125 % PE + 125 % RDF + BF	0.654	0.792	0.826	0.624	0.724
T ₈ :	150 % PE + 75 % RDF + BF	0.512	0.572	0.608	0.479	0.543
T ₉ :	150 % PE + 100 % RDF + BF	0.530	0.607	0.713	0.555	0.601
T ₁₀ :	150 % PE + 125 % RDF + BF	0.557	0.638	0.739	0.582	0.629
Mean		0.546	0.621	0.689	0.495	
SEd		0.0143	0.0165	0.0168	0.0127	
CD at 5 %		0.0300	0.0348	0.0354	0.0267	

Overall mean performance of irrigation regimes and fertilizer levels

Irrigation regime	Nitrate reductase	Fertilizer level	Nitrate reductase
	activity ($\mu\text{moles g}^{-1}\text{hr}^{-1}$)		activity ($\mu\text{moles g}^{-1}\text{hr}^{-1}$)
100 % PE (I ₁)	0.446	75 % RDF + BF (F ₁)	0.528
125 % PE (I ₂)	0.686	100 % RDF + BF (F ₂)	0.576
150 % PE (I ₃)	0.591	125 % RDF + BF (F ₃)	0.618
Conventional method	0.713	Conventional method	0.713

DS : Dry season
PE : Pan evaporation level
RDF: Recommended Dose of Fertilizer
BF : Biofertilizer (*Azophosmet*)

AT: Active tillering
PI : Panicle initiation
FF: 50 % flowering
GF: Grain filling

Table 42. Oxidizing power of roots ($\gamma \text{ g}^{-1} \text{ hr}^{-1}$) at chosen growth stages as influenced by drip fertigation treatments in PMK (R) 3 rice under aerobic condition, DS (2007)

	Treatment	AT	PI	FF	GF	Mean
T ₁ :	Conventional method	152.6	125.8	100.6	80.5	114.9
T ₂ :	100 % PE + 75 % RDF + BF	85.9	80.0	70.9	59.6	74.1
T ₃ :	100 % PE + 100 % RDF + BF	92.3	85.2	75.7	62.3	78.9
T ₄ :	100 % PE + 125 % RDF + BF	110.7	92.8	78.0	64.7	86.6
T ₅ :	125 % PE + 75 % RDF + BF	135.9	111.5	90.6	82.1	105.0
T ₆ :	125 % PE + 100 % RDF + BF	146.8	120.7	92.3	85.5	111.3
T ₇ :	125 % PE + 125 % RDF + BF	156.4	130.7	95.3	87.9	117.6
T ₈ :	150 % PE + 75 % RDF + BF	125.9	90.8	81.9	70.8	92.4
T ₉ :	150 % PE + 100 % RDF + BF	145.8	100.9	88.4	79.8	103.7
T ₁₀ :	150 % PE + 125 % RDF + BF	132.7	98.1	85.6	75.3	97.9
	Mean	128.5	103.7	85.9	74.9	
	SEd	3.14	2.54	2.06	1.81	
	CD at 5 %	6.60	5.33	4.32	3.79	

Overall mean performance of irrigation regimes and fertilizer levels

Irrigation regime	Root Oxidizing Power ($\gamma \text{ g}^{-1} \text{ hr}^{-1}$)	Fertilizer level	Root Oxidizing Power ($\gamma \text{ g}^{-1} \text{ hr}^{-1}$)
100 % PE (I₁)	79.8	75 % RDF + BF (F₁)	90.5
125 % PE (I₂)	111.3	100 % RDF + BF (F₂)	98.0
150 % PE (I₃)	98.0	125 % RDF + BF (F₃)	100.7
Conventional method	114.9	Conventional method	114.9

DS : Dry season
PE : Pan evaporation level
RDF: Recommended Dose of Fertilizer
BF : Biofertilizer (*Azophosmet*)

AT: Active tillering
PI : Panicle initiation
FF: 50 % flowering
GF: Grain filling

Table 43. Cation Exchange Capacity (CEC) of roots (meq 100 g⁻¹) at chosen growth stages as influenced by drip fertigation treatments in PMK (R) 3 rice under aerobic condition, DS (2007)

	Treatment	AT	PI	FF	GF	Mean
T ₁ :	Conventional method	10.11	21.79	13.17	11.09	14.04
T ₂ :	100 % PE + 75 % RDF + BF	6.99	10.32	7.89	5.55	7.69
T ₃ :	100 % PE + 100 % RDF + BF	7.01	11.45	9.23	6.47	8.54
T ₄ :	100 % PE + 125 % RDF + BF	9.72	12.79	10.33	7.89	10.18
T ₅ :	125 % PE + 75 % RDF + BF	7.45	17.05	15.49	9.48	12.37
T ₆ :	125 % PE + 100 % RDF + BF	10.55	23.02	15.49	10.49	14.89
T ₇ :	125 % PE + 125 % RDF + BF	10.23	22.01	14.22	10.03	14.12
T ₈ :	150 % PE + 75 % RDF + BF	10.03	17.30	11.98	9.49	12.20
T ₉ :	150 % PE + 100 % RDF + BF	9.99	19.87	12.00	10.21	13.02
T ₁₀ :	150 % PE + 125 % RDF + BF	10.28	22.03	13.20	11.20	14.18
	Mean	9.24	17.76	12.30	9.19	
	SEd	0.221	0.446	0.304	0.223	
	CD at 5 %	0.464	0.936	0.639	0.469	

Overall mean performance of irrigation regimes and fertilizer levels

Irrigation regime	CEC(meq 100 g⁻¹)	Fertilizer level	CEC(meq 100 g⁻¹)
100 % PE (I₁)	8.80	75 % RDF + BF (F₁)	10.75
125 % PE (I₂)	13.79	100 % RDF + BF (F₂)	12.15
150 % PE (I₃)	13.13	125 % RDF + BF (F₃)	12.83
Conventional method	14.04	Conventional method	14.04

DS : Dry season
PE : Pan evaporation level
RDF: Recommended Dose of Fertilizer
BF : Biofertilizer (*Azophosmet*)

AT: Active tillering
PI : Panicle initiation
FF: 50 % flowering
GF: Grain filling

Table 44. Relative Water Content (RWC: %) at chosen growth stages as influenced by drip fertigation treatments in PMK (R) 3 rice under aerobic condition, DS (2007)

	Treatment	AT	PI	FF	GF	Mean
T ₁ :	Conventional method	80.04	84.79	91.70	83.23	84.94
T ₂ :	100 % PE + 75 % RDF + BF	64.09	71.28	75.69	71.89	70.74
T ₃ :	100 % PE + 100 % RDF + BF	69.87	75.69	81.54	73.23	75.08
T ₄ :	100 % PE + 125 % RDF + BF	72.11	77.89	83.56	74.56	77.03
T ₅ :	125 % PE + 75 % RDF + BF	76.05	81.42	89.45	78.69	81.40
T ₆ :	125 % PE + 100 % RDF + BF	80.72	85.27	92.56	83.41	85.49
T ₇ :	125 % PE + 125 % RDF + BF	79.56	83.47	90.69	81.56	83.82
T ₈ :	150 % PE + 75 % RDF + BF	70.47	75.98	86.36	77.45	77.57
T ₉ :	150 % PE + 100 % RDF + BF	78.69	80.56	90.02	81.56	82.71
T ₁₀ :	150 % PE + 125 % RDF + BF	74.13	79.84	89.21	80.69	80.97
	Mean	74.57	79.62	87.08	78.63	
	SEd	1.208	1.400	1.966	1.340	
	CD at 5 %	2.537	2.941	4.131	2.815	

Overall mean performance of irrigation regimes and fertilizer levels

Irrigation regime	RWC (%)	Fertilizer level	RWC (%)
100 % PE (I₁)	74.28	75 % RDF + BF (F₁)	76.57
125 % PE (I₂)	83.57	100 % RDF + BF (F₂)	81.09
150 % PE (I₃)	80.41	125 % RDF + BF (F₃)	80.61
Conventional method	84.94	Conventional method	84.94

DS : Dry season
PE : Pan evaporation level
RDF: Recommended Dose of Fertilizer
BF : Biofertilizer (*Azophosmet*)

AT: Active tillering
PI : Panicle initiation
FF: 50 % flowering
GF: Grain filling

Table 45. Membrane Stability Index (MSI: %) at chosen growth stages as influenced by drip fertigation treatments in PMK (R) 3 rice under aerobic condition, DS (2007)

	Treatment	AT	PI	FF	GF	Mean
T ₁ :	Conventional method	75.35	83.21	88.23	77.98	81.19
T ₂ :	100 % PE + 75 % RDF + BF	65.30	72.42	70.08	60.02	66.96
T ₃ :	100 % PE + 100 % RDF + BF	69.34	74.85	72.66	65.26	70.53
T ₄ :	100 % PE + 125 % RDF + BF	72.37	76.32	75.69	66.66	72.76
T ₅ :	125 % PE + 75 % RDF + BF	72.67	79.61	81.57	75.20	77.26
T ₆ :	125 % PE + 100 % RDF + BF	74.98	80.09	83.67	74.62	78.34
T ₇ :	125 % PE + 125 % RDF + BF	72.89	83.88	87.26	77.68	80.43
T ₈ :	150 % PE + 75 % RDF + BF	76.30	81.18	84.18	77.51	79.79
T ₉ :	150 % PE + 100 % RDF + BF	75.63	82.89	86.56	78.69	80.94
T ₁₀ :	150 % PE + 125 % RDF + BF	76.21	84.79	89.32	78.64	82.24
	Mean	73.10	79.92	81.92	73.23	
	SEd	1.116	1.377	1.561	1.157	
	CD at 5 %	2.344	2.894	3.281	2.432	

Overall mean performance of irrigation regimes and fertilizer levels

Irrigation regime	MSI (%)	Fertilizer level	MSI (%)
100 % PE (I₁)	70.08	75 % RDF + BF (F₁)	74.67
125 % PE (I₂)	78.68	100 % RDF + BF (F₂)	76.60
150 % PE (I₃)	80.99	125 % RDF + BF (F₃)	78.48
Conventional method	81.19	Conventional method	81.19

DS : Dry season
PE : Pan evaporation level
RDF: Recommended Dose of Fertilizer
BF : Biofertilizer (*Azophosmet*)

AT: Active tillering
PI : Panicle initiation
FF: 50 % flowering
GF: Grain filling

Table 46. Chlorophyll Stability Index (CSI: %) at chosen growth stages as influenced by drip fertigation treatments in PMK (R) 3 rice under aerobic condition, DS (2007)

	Treatment	AT	PI	FF	GF	Mean
T ₁ :	Conventional method	81.69	88.23	80.32	69.96	80.05
T ₂ :	100 % PE + 75 % RDF + BF	75.67	77.96	65.04	58.02	69.17
T ₃ :	100 % PE + 100 % RDF + BF	77.21	79.69	70.46	60.29	71.91
T ₄ :	100 % PE + 125 % RDF + BF	78.36	80.69	72.69	63.27	73.75
T ₅ :	125 % PE + 75 % RDF + BF	77.98	83.66	71.58	62.22	73.86
T ₆ :	125 % PE + 100 % RDF + BF	80.36	86.57	75.22	64.34	76.62
T ₇ :	125 % PE + 125 % RDF + BF	81.86	88.01	78.64	66.89	78.85
T ₈ :	150 % PE + 75 % RDF + BF	80.57	82.26	74.58	65.63	75.76
T ₉ :	150 % PE + 100 % RDF + BF	81.23	85.36	78.69	67.98	78.32
T ₁₀ :	150 % PE + 125 % RDF + BF	82.00	89.50	80.80	70.69	80.75
	Mean	79.69	84.19	74.80	64.93	
	SEd	1.339	1.633	1.187	0.920	
	CD at 5 %	2.813	3.432	2.493	1.932	

Overall mean performance of irrigation regimes and fertilizer levels

Irrigation regime	CSI (%)	Fertilizer level	CSI (%)
100 % PE (I₁)	71.61	75 % RDF + BF (F₁)	72.93
125 % PE (I₂)	76.44	100 % RDF + BF (F₂)	75.62
150 % PE (I₃)	78.28	125 % RDF + BF (F₃)	77.78
Conventional method	80.05	Conventional method	80.05

DS : Dry season
PE : Pan evaporation level
RDF: Recommended Dose of Fertilizer
BF : Biofertilizer (*Azophosmet*)

AT: Active tillering
PI : Panicle initiation
FF: 50 % flowering
GF: Grain filling

Table 47. Leaf Water Potential (LWP: MPa) at chosen growth stages as influenced by drip fertigation treatments in PMK (R) 3 rice under aerobic condition, DS (2007)

Treatment		AT	PI	FF	GF	Mean
T ₁ :	Conventional method	-0.88	-1.28	-1.41	-1.56	-1.28
T ₂ :	100 % PE + 75 % RDF + BF	-1.09	-1.92	-2.18	-2.39	-1.90
T ₃ :	100 % PE + 100 % RDF + BF	-0.99	-1.78	-2.07	-2.20	-1.76
T ₄ :	100 % PE + 125 % RDF + BF	-0.92	-1.65	-1.91	-1.99	-1.62
T ₅ :	125 % PE + 75 % RDF + BF	-0.95	-1.59	-1.65	-1.86	-1.51
T ₆ :	125 % PE + 100 % RDF + BF	-0.90	-1.48	-1.51	-1.68	-1.39
T ₇ :	125 % PE + 125 % RDF + BF	-0.88	-1.30	-1.48	-1.58	-1.31
T ₈ :	150 % PE + 75 % RDF + BF	-0.92	-1.36	-1.52	-1.63	-1.36
T ₉ :	150 % PE + 100 % RDF + BF	-0.87	-1.32	-1.42	-1.58	-1.30
T ₁₀ :	150 % PE + 125 % RDF + BF	-0.85	-1.25	-1.40	-1.52	-1.26
Mean		-0.93	-1.49	-1.66	-1.80	
SEd		0.023	0.035	0.039	0.043	
CD at 5 %		0.049	0.073	0.081	0.091	

Overall mean performance of irrigation regimes and fertilizer levels

Irrigation regime	LWP (MPa)	Fertilizer level	LWP (MPa)
100 % PE (I₁)	-1.76	75 % RDF + BF (F₁)	-1.59
125 % PE (I₂)	-1.41	100 % RDF + BF (F₂)	-1.48
150 % PE (I₃)	-1.30	125 % RDF + BF (F₃)	-1.39
Conventional method	-1.28	Conventional method	-1.28

DS : Dry season
PE : Pan evaporation level
RDF: Recommended Dose of Fertilizer
BF : Biofertilizer (*Azophosmet*)

AT: Active tillering
PI : Panicle initiation
FF: 50 % flowering
GF: Grain filling

Table 48. Leaf proline content ($\mu\text{mole g}^{-1}$) at chosen growth stages as influenced by drip fertigation treatments in PMK (R) 3 rice under aerobic condition, DS (2007)

	Treatment	AT	PI	FF	GF	Mean
T ₁ :	Conventional method	1.21	2.03	2.50	1.20	1.74
T ₂ :	100 % PE + 75 % RDF + BF	4.78	5.57	6.59	4.56	5.38
T ₃ :	100 % PE + 100 % RDF + BF	4.28	5.19	5.88	3.89	4.81
T ₄ :	100 % PE + 125 % RDF + BF	3.15	4.72	5.05	3.02	3.99
T ₅ :	125 % PE + 75 % RDF + BF	3.33	4.89	5.15	3.56	4.23
T ₆ :	125 % PE + 100 % RDF + BF	3.08	4.22	4.89	3.15	3.84
T ₇ :	125 % PE + 125 % RDF + BF	3.19	4.11	3.82	2.07	3.30
T ₈ :	150 % PE + 75 % RDF + BF	2.28	3.03	3.56	2.46	2.83
T ₉ :	150 % PE + 100 % RDF + BF	2.36	2.86	3.17	2.08	2.62
T ₁₀ :	150 % PE + 125 % RDF + BF	1.36	2.00	2.56	1.52	1.86
	Mean	2.90	3.86	4.32	2.75	
	SEd	0.072	0.096	0.105	0.068	
	CD at 5 %	0.151	0.201	0.221	0.142	

Overall mean performance of irrigation regimes and fertilizer levels

Irrigation regime	Leaf proline content ($\mu\text{mole g}^{-1}$)	Fertilizer level	Leaf proline content ($\mu\text{mole g}^{-1}$)
100 % PE (I₁)	4.73	75 % RDF + BF (F₁)	4.15
125 % PE (I₂)	3.79	100 % RDF + BF (F₂)	3.76
150 % PE (I₃)	2.44	125 % RDF + BF (F₃)	3.05
Conventional method	1.74	Conventional method	1.74

DS : Dry season
PE : Pan evaporation level
RDF: Recommended Dose of Fertilizer
BF : Biofertilizer (*Azophosmet*)

AT: Active tillering
PI : Panicle initiation
FF: 50 % flowering
GF: Grain filling

Table 49. Leaf Diffusive Resistance (LDR: s cm⁻¹) at chosen growth stages as influenced by drip fertigation treatments in PMK (R) 3 rice under aerobic condition, DS (2007)

	Treatment	AT	PI	FF	GF	Mean
T ₁ :	Conventional method	0.111	0.130	0.141	0.110	0.123
T ₂ :	100 % PE + 75 % RDF + BF	0.201	0.222	0.255	0.163	0.210
T ₃ :	100 % PE + 100 % RDF + BF	0.198	0.212	0.236	0.147	0.198
T ₄ :	100 % PE + 125 % RDF + BF	0.180	0.202	0.207	0.130	0.180
T ₅ :	125 % PE + 75 % RDF + BF	0.173	0.196	0.201	0.151	0.180
T ₆ :	125 % PE + 100 % RDF + BF	0.155	0.172	0.185	0.133	0.161
T ₇ :	125 % PE + 125 % RDF + BF	0.136	0.151	0.162	0.120	0.142
T ₈ :	150 % PE + 75 % RDF + BF	0.125	0.145	0.156	0.121	0.137
T ₉ :	150 % PE + 100 % RDF + BF	0.119	0.140	0.144	0.118	0.130
T ₁₀ :	150 % PE + 125 % RDF + BF	0.114	0.126	0.138	0.105	0.121
	Mean	0.151	0.170	0.183	0.130	
	SEd	0.0050	0.00395	0.0052	0.0038	
	CD at 5 %	0.0105	0.0082	0.0110	0.0079	

Overall mean performance of irrigation regimes and fertilizer levels

Irrigation regime	LDR (s cm⁻¹)	Fertilizer level	LDR (s cm⁻¹)
100 % PE (I₁)	0.196	75 % RDF + BF (F₁)	0.176
125 % PE (I₂)	0.161	100 % RDF + BF (F₂)	0.163
150 % PE (I₃)	0.129	125 % RDF + BF (F₃)	0.148
Conventional method	0.123	Conventional method	0.123

DS : Dry season
PE : Pan evaporation level
RDF: Recommended Dose of Fertilizer
BF : Biofertilizer (*Azophosmet*)

AT: Active tillering
PI : Panicle initiation
FF: 50 % flowering
GF: Grain filling

Table 50. Transpiration rate ($\mu\text{g H}_2\text{O cm}^{-2} \text{s}^{-1}$) at chosen growth stages as influenced by drip fertigation treatments in PMK (R) 3 rice under aerobic condition, DS (2007)

	Treatment	AT	PI	FF	HT	Mean
T ₁ :	Conventional method	33.36	39.05	62.23	47.19	45.46
T ₂ :	100 % PE + 75 % RDF + BF	11.17	16.38	28.01	22.89	19.61
T ₃ :	100 % PE + 100 % RDF + BF	16.59	21.89	30.17	23.14	22.95
T ₄ :	100 % PE + 125 % RDF + BF	19.45	26.54	33.56	25.56	26.28
T ₅ :	125 % PE + 75 % RDF + BF	13.69	28.05	45.69	38.16	31.40
T ₆ :	125 % PE + 100 % RDF + BF	19.47	31.60	49.69	39.47	35.06
T ₇ :	125 % PE + 125 % RDF + BF	24.21	36.35	53.21	40.17	38.49
T ₈ :	150 % PE + 75 % RDF + BF	22.21	38.33	56.02	42.55	39.78
T ₉ :	150 % PE + 100 % RDF + BF	26.89	41.35	60.36	46.15	43.69
T ₁₀ :	150 % PE + 125 % RDF + BF	33.23	42.19	62.99	47.55	46.49
	Mean	22.03	32.17	48.19	37.28	
	SEd	0.545	0.785	1.188	0.918	
	CD at 5 %	1.144	1.650	2.497	1.929	

Overall mean performance of irrigation regimes and fertilizer levels

Irrigation regime	Transpiration rate ($\mu\text{g H}_2\text{O cm}^{-2} \text{s}^{-1}$)	Fertilizer level	Transpiration rate ($\mu\text{g H}_2\text{O cm}^{-2} \text{s}^{-1}$)
100 % PE (I₁)	22.95	75 % RDF + BF (F₁)	30.26
125 % PE (I₂)	34.98	100 % RDF + BF (F₂)	33.90
150 % PE (I₃)	43.32	125 % RDF + BF (F₃)	37.09
Conventional method	45.46	Conventional method	45.46

DS : Dry season
PE : Pan evaporation level
RDF: Recommended Dose of Fertilizer
BF : Biofertilizer (*Azophosmet*)

AT: Active tillering
PI : Panicle initiation
FF: 50 % flowering
HT: Harvest

Table 51. Leaf temperature (°C) at chosen growth stages as influenced by drip fertigation treatments in PMK (R) 3 rice under aerobic condition, DS (2007)

	Treatment	AT	PI	FF	GF	Mean
T ₁ :	Conventional method	31.0	31.3	32.4	32.8	31.9
T ₂ :	100 % PE + 75 % RDF + BF	32.5	33.7	34.8	35.2	34.0
T ₃ :	100 % PE + 100 % RDF + BF	30.8	33.5	34.5	34.4	33.3
T ₄ :	100 % PE + 125 % RDF + BF	30.7	31.8	32.9	34.2	32.4
T ₅ :	125 % PE + 75 % RDF + BF	31.1	31.8	32.7	34.3	32.5
T ₆ :	125 % PE + 100 % RDF + BF	31.0	31.6	32.5	33.9	32.3
T ₇ :	125 % PE + 125 % RDF + BF	30.5	31.1	32.3	33.5	31.8
T ₈ :	150 % PE + 75 % RDF + BF	31.6	31.9	32.6	33.6	32.4
T ₉ :	150 % PE + 100 % RDF + BF	30.7	31.7	32.4	33.2	32.0
T ₁₀ :	150 % PE + 125 % RDF + BF	30.6	30.9	32.2	32.6	31.6
	Mean	31.1	31.9	33.0	33.8	
	SEd	0.72	0.74	0.76	0.78	
	CD at 5 %	NS	1.55	1.60	NS	

Overall mean performance of irrigation regimes and fertilizer levels

Irrigation regime	Leaf temperature (°C)	Fertilizer level	Leaf temperature (°C)
100 % PE (I₁)	33.2	75 % RDF + BF (F₁)	33.0
125 % PE (I₂)	32.2	100 % RDF + BF (F₂)	32.5
150 % PE (I₃)	32.0	125 % RDF + BF (F₃)	32.0
Conventional method	31.9	Conventional method	31.9

DS : Dry season
PE : Pan evaporation level
RDF: Recommended Dose of Fertilizer
BF : Biofertilizer (*Azophosmet*)

AT: Active tillering
PI : Panicle initiation
FF: 50 % flowering
GF: Grain filling

Table 52. Canopy temperature (°C) at chosen growth stages as influenced by drip fertigation treatments in PMK (R) 3 rice under aerobic condition, DS (2007)

Treatment		AT	PI	FF	GF	Mean
T ₁ :	Conventional method	27.8	29.1	30.5	31.6	29.7
T ₂ :	100 % PE + 75 % RDF + BF	29.4	31.1	32.1	33.5	31.5
T ₃ :	100 % PE + 100 % RDF + BF	28.1	30.9	31.6	33.4	31.0
T ₄ :	100 % PE + 125 % RDF + BF	27.8	30.5	31.2	32.4	30.5
T ₅ :	125 % PE + 75 % RDF + BF	28.9	30.2	31.1	32.7	30.7
T ₆ :	125 % PE + 100 % RDF + BF	27.8	29.4	30.2	32.2	29.9
T ₇ :	125 % PE + 125 % RDF + BF	27.4	29.1	29.7	31.7	29.5
T ₈ :	150 % PE + 75 % RDF + BF	28.6	29.9	30.5	32.4	30.4
T ₉ :	150 % PE + 100 % RDF + BF	27.4	29.4	30.2	31.7	29.7
T ₁₀ :	150 % PE + 125 % RDF + BF	27.2	28.9	30.0	31.3	29.3
Mean		28.0	29.8	30.7	32.3	
SEd		0.65	0.69	0.71	0.75	
CD at 5 %		1.37	1.45	NS	NS	

Overall mean performance of irrigation regimes and fertilizer levels

Irrigation regime	Canopy temperature (°C)	Fertilizer level	Canopy temperature (°C)
100 % PE (I₁)	31.0	75 % RDF + BF (F₁)	30.9
125 % PE (I₂)	30.0	100 % RDF + BF (F₂)	30.2
150 % PE (I₃)	29.8	125 % RDF + BF (F₃)	29.8
Conventional method	29.7	Conventional method	29.7

DS : Dry season
PE : Pan evaporation level
RDF: Recommended Dose of Fertilizer
BF : Biofertilizer (*Azophosmet*)

AT: Active tillering
PI : Panicle initiation
FF: 50 % flowering
GF: Grain filling

Table 53. Total nitrogen (N) uptake (kg ha⁻¹) at chosen growth stages as influenced by drip fertigation treatments in PMK (R) 3 rice under aerobic condition, DS (2007)

	Treatment	AT	PI	FF	HT	Mean
T ₁ :	Conventional method	28.56	132.98	172.74	198.72	133.25
T ₂ :	100 % PE + 75 % RDF + BF	27.75	77.78	89.91	102.37	74.45
T ₃ :	100 % PE + 100 % RDF + BF	15.58	67.82	104.96	105.28	73.41
T ₄ :	100 % PE + 125 % RDF + BF	14.06	81.79	119.53	120.08	83.87
T ₅ :	125 % PE + 75 % RDF + BF	16.91	85.89	119.23	126.50	87.13
T ₆ :	125 % PE + 100 % RDF + BF	17.44	133.55	190.43	203.85	136.32
T ₇ :	125 % PE + 125 % RDF + BF	19.97	134.82	193.49	192.44	135.18
T ₈ :	150 % PE + 75 % RDF + BF	20.49	94.73	151.56	171.96	109.69
T ₉ :	150 % PE + 100 % RDF + BF	24.71	122.65	196.86	207.77	138.00
T ₁₀ :	150 % PE + 125 % RDF + BF	28.14	130.86	213.98	233.78	151.69
	Mean	21.36	106.29	155.27	166.28	
	SEd	0.508	2.644	3.858	4.137	
	CD at 5 %	1.067	5.555	8.106	11.908	

Overall mean performance of irrigation regimes and fertilizer levels

Irrigation regime	Total N uptake (kg ha⁻¹)	Fertilizer level	Total N uptake (kg ha⁻¹)
100 % PE (I₁)	77.24	75 % RDF + BF (F₁)	90.42
125 % PE (I₂)	119.54	100 % RDF + BF (F₂)	115.91
150 % PE (I₃)	133.13	125 % RDF + BF (F₃)	123.58
Conventional method	133.25	Conventional method	133.25

DS : Dry season
PE : Pan evaporation level
RDF: Recommended Dose of Fertilizer
BF : Biofertilizer (*Azophosmet*)

AT: Active tillering
PI : Panicle initiation
FF: 50 % flowering
HT: Harvest

Table 54. Total phosphorus (P) uptake (kg ha⁻¹) at chosen growth stages as influenced by drip fertigation treatments in PMK (R) 3 rice under aerobic condition, DS (2007)

Treatment		AT	PI	FF	HT	Mean
T ₁ :	Conventional method	6.53	19.22	26.47	30.71	20.73
T ₂ :	100 % PE + 75 % RDF + BF	3.48	8.56	13.39	13.52	9.74
T ₃ :	100 % PE + 100 % RDF + BF	3.23	11.03	16.16	16.68	11.77
T ₄ :	100 % PE + 125 % RDF + BF	4.74	13.42	19.68	21.34	14.80
T ₅ :	125 % PE + 75 % RDF + BF	3.83	15.60	21.05	23.52	16.00
T ₆ :	125 % PE + 100 % RDF + BF	4.08	17.61	23.78	28.35	18.45
T ₇ :	125 % PE + 125 % RDF + BF	4.52	18.84	25.30	25.84	18.63
T ₈ :	150 % PE + 75 % RDF + BF	4.81	16.31	24.54	25.79	17.86
T ₉ :	150 % PE + 100 % RDF + BF	5.60	17.68	27.88	29.63	20.20
T ₁₀ :	150 % PE + 125 % RDF + BF	6.36	18.34	30.49	31.39	21.64
Mean		4.72	15.66	22.87	24.68	
SEd		0.113	0.386	0.553	0.606	
CD at 5 %		0.237	0.812	1.162	1.273	

Overall mean performance of irrigation regimes and fertilizer levels

Irrigation regime	Total P uptake (kg ha ⁻¹)	Fertilizer level	Total P uptake (kg ha ⁻¹)
100 % PE (I₁)	12.10	75 % RDF + BF (F₁)	14.53
125 % PE (I₂)	17.69	100 % RDF + BF (F₂)	16.81
150 % PE (I₃)	19.90	125 % RDF + BF (F₃)	18.36
Conventional method	20.73	Conventional method	20.73

DS : Dry season
PE : Pan evaporation level
RDF: Recommended Dose of Fertilizer
BF : Biofertilizer (*Azophosmet*)

AT: Active tillering
PI : Panicle initiation
FF: 50 % flowering
HT: Harvest

Table 55. Total potassium (K) uptake (kg ha⁻¹) at chosen growth stages as influenced by drip fertigation treatments in PMK (R) 3 rice under aerobic condition, DS (2007)

	Treatment	AT	PI	FF	HT	Mean
T ₁ :	Conventional method	23.57	95.35	121.22	146.93	96.77
T ₂ :	100 % PE + 75 % RDF + BF	12.68	41.44	58.63	65.05	44.45
T ₃ :	100 % PE + 100 % RDF + BF	11.99	52.90	86.56	84.82	59.06
T ₄ :	100 % PE + 125 % RDF + BF	17.59	64.61	100.30	100.61	70.78
T ₅ :	125 % PE + 75 % RDF + BF	13.16	73.92	87.56	93.05	66.92
T ₆ :	125 % PE + 100 % RDF + BF	14.80	92.89	99.75	121.83	82.32
T ₇ :	125 % PE + 125 % RDF + BF	16.67	93.49	111.63	118.77	85.14
T ₈ :	150 % PE + 75 % RDF + BF	16.25	79.54	102.67	108.91	76.84
T ₉ :	150 % PE + 100 % RDF + BF	20.75	85.62	118.12	132.10	89.15
T ₁₀ :	150 % PE + 125 % RDF + BF	23.65	93.13	133.45	145.61	98.96
	Mean	17.11	77.29	101.99	111.77	
	SEd	0.408	1.916	2.440	2.724	
	CD at 5 %	0.859	4.026	5.127	5.722	

Overall mean performance of irrigation regimes and fertilizer levels

Irrigation regime	Total K uptake (kg ha⁻¹)	Fertilizer level	Total K uptake (kg ha⁻¹)
100 % PE (I₁)	58.10	75 % RDF + BF (F₁)	62.74
125 % PE (I₂)	78.13	100 % RDF + BF (F₂)	76.84
150 % PE (I₃)	88.32	125 % RDF + BF (F₃)	84.96
Conventional method	96.77	Conventional method	96.77

DS : Dry season

PE : Pan evaporation level

RDF: Recommended Dose of Fertilizer

BF : Biofertilizer (*Azophosmet*)

AT: Active tillering

PI : Panicle initiation

FF: 50 % flowering

HT: Harvest

Table 56. Total calcium (Ca) uptake (kg ha^{-1}) at chosen growth stages as influenced by drip fertigation treatments in PMK (R) 3 rice under aerobic condition, DS (2007)

	Treatment	AT	PI	FF	HT	Mean
T ₁ :	Conventional method	2.77	12.29	20.31	34.93	17.58
T ₂ :	100 % PE + 75 % RDF + BF	1.20	7.57	11.80	17.12	9.42
T ₃ :	100 % PE + 100 % RDF + BF	1.14	7.69	14.43	19.54	10.70
T ₄ :	100 % PE + 125 % RDF + BF	1.71	8.87	16.59	21.24	12.10
T ₅ :	125 % PE + 75 % RDF + BF	1.48	10.47	17.42	26.76	14.03
T ₆ :	125 % PE + 100 % RDF + BF	1.64	11.55	20.25	34.98	17.11
T ₇ :	125 % PE + 125 % RDF + BF	1.93	12.05	20.73	32.88	16.90
T ₈ :	150 % PE + 75 % RDF + BF	1.88	11.04	18.58	29.92	15.36
T ₉ :	150 % PE + 100 % RDF + BF	2.33	11.80	22.03	37.19	18.34
T ₁₀ :	150 % PE + 125 % RDF + BF	2.71	12.32	23.93	39.41	19.59
	Mean	1.88	10.57	18.61	29.40	
	SEd	0.047	0.255	0.448	0.729	
	CD at 5 %	0.096	0.536	0.942	1.531	

Overall mean performance of irrigation regimes and fertilizer levels

Irrigation regime	Total Ca uptake (kg ha^{-1})	Fertilizer level	Total Ca uptake (kg ha^{-1})
100 % PE (I₁)	10.74	75 % RDF + BF (F₁)	12.94
125 % PE (I₂)	16.01	100 % RDF + BF (F₂)	15.38
150 % PE (I₃)	17.76	125 % RDF + BF (F₃)	16.20
Conventional method	17.58	Conventional method	17.58

DS : Dry season
PE : Pan evaporation level
RDF: Recommended Dose of Fertilizer
BF : Biofertilizer (*Azophosmet*)

AT: Active tillering
PI : Panicle initiation
FF: 50 % flowering
HT: Harvest

Table 57. Total magnesium (Mg) uptake (kg ha⁻¹) at chosen growth stages as influenced by drip fertigation treatments in PMK (R) 3 rice under aerobic condition, DS (2007)

	Treatment	AT	PI	FF	HT	Mean
T ₁ :	Conventional method	2.45	10.69	24.75	33.84	17.93
T ₂ :	100 % PE + 75 % RDF + BF	1.20	6.20	15.13	20.03	10.64
T ₃ :	100 % PE + 100 % RDF + BF	1.14	8.06	17.97	22.97	12.54
T ₄ :	100 % PE + 125 % RDF + BF	1.73	9.42	21.47	26.93	14.89
T ₅ :	125 % PE + 75 % RDF + BF	1.40	8.55	21.52	28.44	14.97
T ₆ :	125 % PE + 100 % RDF + BF	1.46	9.94	23.68	32.69	16.94
T ₇ :	125 % PE + 125 % RDF + BF	1.70	10.38	24.77	31.01	16.97
T ₈ :	150 % PE + 75 % RDF + BF	1.74	9.03	22.98	31.53	16.32
T ₉ :	150 % PE + 100 % RDF + BF	2.13	10.00	25.54	35.78	18.36
T ₁₀ :	150 % PE + 125 % RDF + BF	2.43	10.27	28.42	37.94	19.77
	Mean	1.74	9.25	22.62	30.12	
	SEd	0.040	0.222	0.540	0.723	
	CD at 5 %	0.084	0.465	1.134	1.518	

Overall mean performance of irrigation regimes and fertilizer levels

Irrigation regime	Total Mg uptake (kg ha⁻¹)	Fertilizer level	Total Mg uptake (kg ha⁻¹)
100 % PE (I₁)	12.69	75 % RDF + BF (F₁)	13.98
125 % PE (I₂)	16.29	100 % RDF + BF (F₂)	15.95
150 % PE (I₃)	18.15	125 % RDF + BF (F₃)	17.20
Conventional method	17.93	Conventional method	17.93

DS : Dry season
PE : Pan evaporation level
RDF: Recommended Dose of Fertilizer
BF : Biofertilizer (*Azophosmet*)

AT: Active tillering
PI : Panicle initiation
FF: 50 % flowering
HT: Harvest

Table 58. Total iron (Fe) uptake (g ha^{-1}) at chosen growth stages as influenced by drip fertigation treatments in PMK (R) 3 rice under aerobic condition, DS (2007)

Treatment		AT	PI	FF	HT	Mean
T ₁ :	Conventional method	0.710	2.986	3.455	3.878	2.757
T ₂ :	100 % PE + 75 % RDF + BF	0.296	1.558	2.034	2.200	1.522
T ₃ :	100 % PE + 100 % RDF + BF	0.298	1.949	2.407	2.535	1.797
T ₄ :	100 % PE + 125 % RDF + BF	0.440	2.207	2.803	2.835	2.071
T ₅ :	125 % PE + 75 % RDF + BF	0.403	2.354	2.841	3.115	2.178
T ₆ :	125 % PE + 100 % RDF + BF	0.412	2.634	3.144	3.739	2.482
T ₇ :	125 % PE + 125 % RDF + BF	0.488	2.849	3.413	3.464	2.553
T ₈ :	150 % PE + 75 % RDF + BF	0.497	2.565	3.100	3.497	2.415
T ₉ :	150 % PE + 100 % RDF + BF	0.598	2.694	3.458	3.989	2.685
T ₁₀ :	150 % PE + 125 % RDF + BF	0.694	2.856	3.900	4.342	2.948
Mean		0.484	2.465	3.056	3.359	
SEd		0.0120	0.0602	0.0741	0.0812	
CD at 5 %		0.0250	0.1250	0.1562	0.1704	

Overall mean performance of irrigation regimes and fertilizer levels

Irrigation regime	Total Fe uptake (g ha^{-1})	Fertilizer level	Total Fe uptake (g ha^{-1})
100 % PE (I₁)	1.797	75 % RDF + BF (F₁)	2.038
125 % PE (I₂)	2.405	100 % RDF + BF (F₂)	2.321
150 % PE (I₃)	2.682	125 % RDF + BF (F₃)	2.524
Conventional method	2.757	Conventional method	2.757

DS : Dry season
PE : Pan evaporation level
RDF: Recommended Dose of Fertilizer
BF : Biofertilizer (*Azophosmet*)

AT: Active tillering
PI : Panicle initiation
FF: 50 % flowering
HT: Harvest

Table 59. Total manganese (Mn) uptake (g ha^{-1}) at chosen growth stages as influenced by drip fertigation treatments in PMK (R) 3 rice under aerobic condition, DS (2007)

Treatment		AT	PI	FF	HT	Mean
T ₁ :	Conventional method	0.104	0.527	1.283	1.710	0.906
T ₂ :	100 % PE + 75 % RDF + BF	0.038	0.206	0.565	0.693	0.376
T ₃ :	100 % PE + 100 % RDF + BF	0.039	0.301	0.717	0.877	0.484
T ₄ :	100 % PE + 125 % RDF + BF	0.063	0.355	0.881	0.996	0.574
T ₅ :	125 % PE + 75 % RDF + BF	0.053	0.367	0.932	1.098	0.613
T ₆ :	125 % PE + 100 % RDF + BF	0.056	0.434	1.078	1.496	0.766
T ₇ :	125 % PE + 125 % RDF + BF	0.070	0.507	1.318	1.463	0.840
T ₈ :	150 % PE + 75 % RDF + BF	0.069	0.420	1.046	1.376	0.728
T ₉ :	150 % PE + 100 % RDF + BF	0.085	0.467	1.309	1.731	0.898
T ₁₀ :	150 % PE + 125 % RDF + BF	0.100	0.516	1.507	1.950	1.018
Mean		0.068	0.410	1.064	1.339	
SEd		0.0025	0.0105	0.0271	0.0335	
CD at 5 %		0.0053	0.0221	0.0560	0.0705	

Overall mean performance of irrigation regimes and fertilizer levels

Irrigation regime	Total Mn uptake (g ha^{-1})	Fertilizer level	Total Mn uptake (g ha^{-1})
100 % PE (I₁)	0.478	75 % RDF + BF (F₁)	0.572
125 % PE (I₂)	0.739	100 % RDF + BF (F₂)	0.716
150 % PE (I₃)	0.881	125 % RDF + BF (F₃)	0.810
Conventional method	0.906	Conventional method	0.906

DS : Dry season
PE : Pan evaporation level
RDF: Recommended Dose of Fertilizer
BF : Biofertilizer (*Azophosmet*)

AT: Active tillering
PI : Panicle initiation
FF: 50 % flowering
HT: Harvest

Table 60. Total zinc (Zn) uptake (g ha^{-1}) at chosen growth stages as influenced by drip fertigation treatments in PMK (R) 3 rice under aerobic condition, DS (2007)

	Treatment	AT	PI	FF	HT	Mean
T ₁ :	Conventional method	0.028	0.117	0.256	0.291	0.173
T ₂ :	100 % PE + 75 % RDF + BF	0.014	0.069	0.151	0.164	0.100
T ₃ :	100 % PE + 100 % RDF + BF	0.013	0.084	0.176	0.191	0.116
T ₄ :	100 % PE + 125 % RDF + BF	0.020	0.098	0.207	0.210	0.134
T ₅ :	125 % PE + 75 % RDF + BF	0.015	0.088	0.211	0.217	0.133
T ₆ :	125 % PE + 100 % RDF + BF	0.017	0.100	0.236	0.268	0.155
T ₇ :	125 % PE + 125 % RDF + BF	0.020	0.112	0.269	0.249	0.162
T ₈ :	150 % PE + 75 % RDF + BF	0.019	0.095	0.229	0.254	0.149
T ₉ :	150 % PE + 100 % RDF + BF	0.024	0.102	0.271	0.291	0.172
T ₁₀ :	150 % PE + 125 % RDF + BF	0.028	0.114	0.307	0.330	0.195
	Mean	0.020	0.098	0.231	0.247	
	SEd	0.0015	0.0034	0.0064	0.0066	
	CD at 5 %	0.0031	0.0072	0.0134	0.0139	

Overall mean performance of irrigation regimes and fertilizer levels

Irrigation regime	Total Zn uptake (g ha^{-1})	Fertilizer level	Total Zn uptake (g ha^{-1})
100 % PE (I₁)	0.116	75 % RDF + BF (F₁)	0.127
125 % PE (I₂)	0.150	100 % RDF + BF (F₂)	0.148
150 % PE (I₃)	0.172	125 % RDF + BF (F₃)	0.164
Conventional method	0.173	Conventional method	0.173

DS : Dry season
PE : Pan evaporation level
RDF: Recommended Dose of Fertilizer
BF : Biofertilizer (*Azophosmet*)

AT: Active tillering
PI : Panicle initiation
FF: 50 % flowering
HT: Harvest

Table 61. Total copper (Cu) uptake (g ha^{-1}) at chosen growth stages as influenced by drip fertigation treatments in PMK (R) 3 rice under aerobic condition, DS (2007)

Treatment		AT	PI	FF	HT	Mean
T ₁ :	Conventional method	0.020	0.068	0.121	0.137	0.087
T ₂ :	100 % PE + 75 % RDF + BF	0.009	0.038	0.072	0.078	0.049
T ₃ :	100 % PE + 100 % RDF + BF	0.009	0.049	0.087	0.093	0.060
T ₄ :	100 % PE + 125 % RDF + BF	0.013	0.059	0.108	0.110	0.073
T ₅ :	125 % PE + 75 % RDF + BF	0.010	0.048	0.093	0.096	0.062
T ₆ :	125 % PE + 100 % RDF + BF	0.011	0.057	0.111	0.121	0.075
T ₇ :	125 % PE + 125 % RDF + BF	0.014	0.066	0.128	0.121	0.082
T ₈ :	150 % PE + 75 % RDF + BF	0.013	0.054	0.103	0.109	0.070
T ₉ :	150 % PE + 100 % RDF + BF	0.016	0.058	0.117	0.131	0.081
T ₁₀ :	150 % PE + 125 % RDF + BF	0.020	0.065	0.139	0.151	0.094
Mean		0.014	0.056	0.108	0.115	
SEd		0.0015	0.0025	0.0039	0.0028	
CD at 5 %		NS	0.0053	0.0082	0.0058	

Overall mean performance of irrigation regimes and fertilizer levels

Irrigation regime	Total Cu uptake (g ha^{-1})	Fertilizer level	Total Cu uptake (g ha^{-1})
100 % PE (I₁)	0.060	75 % RDF + BF (F₁)	0.060
125 % PE (I₂)	0.073	100 % RDF + BF (F₂)	0.072
150 % PE (I₃)	0.081	125 % RDF + BF (F₃)	0.083
Conventional method	0.087	Conventional method	0.087

DS : Dry season
PE : Pan evaporation level
RDF: Recommended Dose of Fertilizer
BF : Biofertilizer (*Azophosmet*)

AT: Active tillering
PI : Panicle initiation
FF: 50 % flowering
HT: Harvest

Table 62. Rate of total nitrogen uptake ($\text{kg ha}^{-1}\text{day}^{-1}$) at chosen growth stages as influenced by drip fertigation treatments in PMK (R) 3 rice under aerobic condition, DS (2007)

	Treatment	AT-PI	PI-FF	FF-HT	Mean
T ₁ :	Conventional method	4.18	1.33	0.87	2.13
T ₂ :	100 % PE + 75 % RDF + BF	2.00	0.40	0.42	0.94
T ₃ :	100 % PE + 100 % RDF + BF	2.09	1.24	0.01	1.11
T ₄ :	100 % PE + 125 % RDF + BF	2.71	1.26	0.02	1.33
T ₅ :	125 % PE + 75 % RDF + BF	2.76	1.11	0.24	1.37
T ₆ :	125 % PE + 100 % RDF + BF	4.64	1.90	0.45	2.33
T ₇ :	125 % PE + 125 % RDF + BF	4.59	1.96	0.00	2.18
T ₈ :	150 % PE + 75 % RDF + BF	2.97	1.89	0.68	1.85
T ₉ :	150 % PE + 100 % RDF + BF	3.92	2.47	0.36	2.25
T ₁₀ :	150 % PE + 125 % RDF + BF	4.11	2.77	0.66	2.51
	Mean	3.40	1.63	0.37	
	SEd	0.087	0.042	0.012	
	CD at 5 %	0.182	0.088	0.025	

Overall mean performance of irrigation regimes and fertilizer levels

Irrigation regime	Rate of total N uptake ($\text{kg ha}^{-1}\text{day}^{-1}$)	Fertilizer level	Rate of total N uptake ($\text{kg ha}^{-1}\text{day}^{-1}$)
100 % PE (I₁)	2.13	75 % RDF + BF (F₁)	1.39
125 % PE (I₂)	1.96	100 % RDF + BF (F₂)	1.90
150 % PE (I₃)	2.20	125 % RDF + BF (F₃)	2.00
Conventional method	2.12	Conventional method	2.12

DS : Dry season
PE : Pan evaporation level
RDF: Recommended Dose of Fertilizer
BF : Biofertilizer (*Azophosmet*)

AT: Active tillering
PI : Panicle initiation
FF: 50 % flowering
HT: Harvest

Table 63. Rate of total phosphorus uptake ($\text{kg ha}^{-1}\text{day}^{-1}$) at chosen grow stages as influenced by drip fertigation treatments in PMK (R) 3 rice under aerobic condition, DS (2007)

	Treatment	AT-PI	PI-FF	FF-HT	Mean
T ₁ :	Conventional method	0.507	0.242	0.141	0.297
T ₂ :	100 % PE + 75 % RDF + BF	0.203	0.161	0.004	0.123
T ₃ :	100 % PE + 100 % RDF + BF	0.312	0.171	0.017	0.167
T ₄ :	100 % PE + 125 % RDF + BF	0.347	0.209	0.055	0.204
T ₅ :	125 % PE + 75 % RDF + BF	0.471	0.182	0.082	0.245
T ₆ :	125 % PE + 100 % RDF + BF	0.541	0.206	0.152	0.300
T ₇ :	125 % PE + 125 % RDF + BF	0.573	0.215	0.018	0.269
T ₈ :	150 % PE + 75 % RDF + BF	0.460	0.274	0.042	0.259
T ₉ :	150 % PE + 100 % RDF + BF	0.483	0.340	0.058	0.294
T ₁₀ :	150 % PE + 125 % RDF + BF	0.479	0.405	0.030	0.305
	Mean	0.438	0.240	0.060	
	SEd	0.0111	0.0073	0.0032	
	CD at 5 %	0.0242	0.0142	0.0063	

Overall mean performance of irrigation regimes and fertilizer levels

Irrigation regime	Rate of total P uptake ($\text{kg ha}^{-1}\text{day}^{-1}$)	Fertilizer level	Rate of total P uptake ($\text{kg ha}^{-1}\text{day}^{-1}$)
100 % PE (I₁)	0.164	75 % RDF + BF (F₁)	0.209
125 % PE (I₂)	0.271	100 % RDF + BF (F₂)	0.253
150 % PE (I₃)	0.286	125 % RDF + BF (F₃)	0.259
Conventional method	0.297	Conventional method	0.297

DS : Dry season
PE : Pan evaporation level
RDF: Recommended Dose of Fertilizer
BF : Biofertilizer (*Azophosmet*)

AT: Active tillering
PI : Panicle initiation
FF: 50 % flowering
HT: Harvest

Table 64. Rate of total potassium uptake ($\text{kg ha}^{-1}\text{day}^{-1}$) at chosen growth stages as influenced by drip fertigation treatments in PMK (R) 3 rice under aerobic condition, DS (2007)

	Treatment	AT-PI	PI-FF	FF-HT	Mean
T ₁ :	Conventional method	2.87	0.86	0.86	1.53
T ₂ :	100 % PE + 75 % RDF + BF	1.15	0.57	0.21	0.64
T ₃ :	100 % PE + 100 % RDF + BF	1.64	1.12	0.00	0.92
T ₄ :	100 % PE + 125 % RDF + BF	1.88	1.19	0.01	1.03
T ₅ :	125 % PE + 75 % RDF + BF	2.43	0.45	0.18	1.02
T ₆ :	125 % PE + 100 % RDF + BF	3.12	0.23	0.74	1.36
T ₇ :	125 % PE + 125 % RDF + BF	3.07	0.60	0.24	1.31
T ₈ :	150 % PE + 75 % RDF + BF	2.53	0.77	0.21	1.17
T ₉ :	150 % PE + 100 % RDF + BF	2.59	1.08	0.47	1.38
T ₁₀ :	150 % PE + 125 % RDF + BF	2.78	1.34	0.41	1.51
	Mean	2.41	0.82	0.33	
	SEd	0.060	0.020	0.012	
	CD at 5 %	0.127	0.041	0.025	

Overall mean performance of irrigation regimes and fertilizer levels

Irrigation regime	Rate of total K uptake ($\text{kg ha}^{-1}\text{day}^{-1}$)	Fertilizer level	Rate of total K uptake ($\text{kg ha}^{-1}\text{day}^{-1}$)
100 % PE (I₁)	0.86	75 % RDF + BF (F₁)	0.94
125 % PE (I₂)	1.23	100 % RDF + BF (F₂)	1.22
150 % PE (I₃)	1.35	125 % RDF + BF (F₃)	1.28
Conventional method	1.53	Conventional method	1.53

DS : Dry season
PE : Pan evaporation level
RDF: Recommended Dose of Fertilizer
BF : Biofertilizer (*Azophosmet*)

AT: Active tillering
PI : Panicle initiation
FF: 50 % flowering
HT: Harvest

Table 65. Rate of total calcium uptake ($\text{kg ha}^{-1}\text{day}^{-1}$) at chosen growth stages as influenced by drip fertigation treatments in PMK (R) 3 rice under aerobic condition, DS (2007)

	Treatment	AT-PI	PI-FF	FF-HT	Mean
T ₁ :	Conventional method	0.381	0.267	0.487	0.378
T ₂ :	100 % PE + 75 % RDF + BF	0.255	0.141	0.177	0.191
T ₃ :	100 % PE + 100 % RDF + BF	0.262	0.225	0.170	0.219
T ₄ :	100 % PE + 125 % RDF + BF	0.286	0.257	0.155	0.233
T ₅ :	125 % PE + 75 % RDF + BF	0.360	0.232	0.311	0.301
T ₆ :	125 % PE + 100 % RDF + BF	0.397	0.290	0.491	0.393
T ₇ :	125 % PE + 125 % RDF + BF	0.405	0.289	0.405	0.366
T ₈ :	150 % PE + 75 % RDF + BF	0.366	0.251	0.378	0.332
T ₉ :	150 % PE + 100 % RDF + BF	0.379	0.341	0.506	0.409
T ₁₀ :	150 % PE + 125 % RDF + BF	0.385	0.387	0.516	0.429
	Mean	0.348	0.268	0.360	
	SEd	0.0086	0.0070	0.0101	
	CD at 5 %	0.0180	0.0147	0.0202	

Overall mean performance of irrigation regimes and fertilizer levels

Irrigation regime	Rate of total Ca uptake ($\text{kg ha}^{-1}\text{day}^{-1}$)	Fertilizer level	Rate of total Ca uptake ($\text{kg ha}^{-1}\text{day}^{-1}$)
100 % PE (I₁)	0.214	75 % RDF + BF (F₁)	0.275
125 % PE (I₂)	0.353	100 % RDF + BF (F₂)	0.340
150 % PE (I₃)	0.390	125 % RDF + BF (F₃)	0.343
Conventional method	0.378	Conventional method	0.378

DS : Dry season
PE : Pan evaporation level
RDF: Recommended Dose of Fertilizer
BF : Biofertilizer (*Azophosmet*)

AT: Active tillering
PI : Panicle initiation
FF: 50 % flowering
HT: Harvest

Table 66. Rate of total magnesium uptake ($\text{kg ha}^{-1}\text{day}^{-1}$) at chosen growth stages as influenced by drip fertigation treatments in PMK (R) 3 rice under aerobic condition, DS (2007)

	Treatment	AT-PI	PI-FF	FF-HT	Mean
T ₁ :	Conventional method	0.329	0.469	0.303	0.367
T ₂ :	100 % PE + 75 % RDF + BF	0.200	0.298	0.163	0.220
T ₃ :	100 % PE + 100 % RDF + BF	0.277	0.330	0.167	0.258
T ₄ :	100 % PE + 125 % RDF + BF	0.308	0.402	0.182	0.297
T ₅ :	125 % PE + 75 % RDF + BF	0.286	0.432	0.231	0.316
T ₆ :	125 % PE + 100 % RDF + BF	0.339	0.458	0.300	0.366
T ₇ :	125 % PE + 125 % RDF + BF	0.347	0.480	0.208	0.345
T ₈ :	150 % PE + 75 % RDF + BF	0.291	0.465	0.285	0.347
T ₉ :	150 % PE + 100 % RDF + BF	0.315	0.518	0.341	0.391
T ₁₀ :	150 % PE + 125 % RDF + BF	0.313	0.605	0.317	0.412
	Mean	0.301	0.446	0.250	
	SEd	0.0072	0.0103	0.0066	
	CD at 5 %	0.0152	0.0216	0.0138	

Overall mean performance of irrigation regimes and fertilizer levels

Irrigation regime	Rate of total Mg uptake ($\text{kg ha}^{-1}\text{day}^{-1}$)	Fertilizer level	Rate of total Mg uptake ($\text{kg ha}^{-1}\text{day}^{-1}$)
100 % PE (I₁)	0.258	75 % RDF + BF (F₁)	0.295
125 % PE (I₂)	0.342	100 % RDF + BF (F₂)	0.338
150 % PE (I₃)	0.383	125 % RDF + BF (F₃)	0.351
Conventional method	0.367	Conventional method	0.367

DS : Dry season
PE : Pan evaporation level
RDF: Recommended Dose of Fertilizer
BF : Biofertilizer (*Azophosmet*)

AT: Active tillering
PI : Panicle initiation
FF: 50 % flowering
HT: Harvest

Table 67. Rate of total iron uptake ($\text{g ha}^{-1}\text{day}^{-1}$) at chosen growth stages as influenced by drip fertigation treatments in PMK (R) 3 rice under aerobic condition, DS (2007)

	Treatment	AT-PI	PI-FF	FF-HT	Mean
T ₁ :	Conventional method	91.04	18.76	16.93	42.24
T ₂ :	100 % PE + 75 % RDF + BF	50.51	19.03	6.63	25.39
T ₃ :	100 % PE + 100 % RDF + BF	66.05	18.32	5.12	29.83
T ₄ :	100 % PE + 125 % RDF + BF	70.68	23.84	1.31	31.94
T ₅ :	125 % PE + 75 % RDF + BF	78.06	19.47	10.97	36.17
T ₆ :	125 % PE + 100 % RDF + BF	88.88	20.38	23.82	44.36
T ₇ :	125 % PE + 125 % RDF + BF	94.44	22.55	2.05	39.68
T ₈ :	150 % PE + 75 % RDF + BF	82.70	21.39	15.87	39.99
T ₉ :	150 % PE + 100 % RDF + BF	83.83	30.59	21.21	45.21
T ₁₀ :	150 % PE + 125 % RDF + BF	86.49	41.76	17.67	48.64
	Mean	79.27	23.61	12.16	
	SEd	1.917	0.558	0.357	
	CD at 5 %	4.028	1.172	0.749	

Overall mean performance of irrigation regimes and fertilizer levels

Irrigation regime	Rate of total Fe uptake ($\text{g ha}^{-1}\text{day}^{-1}$)	Fertilizer level	Rate of total Fe uptake ($\text{g ha}^{-1}\text{day}^{-1}$)
100 % PE (I₁)	29.05	75 % RDF + BF (F₁)	33.85
125 % PE (I₂)	40.07	100 % RDF + BF (F₂)	39.80
150 % PE (I₃)	44.61	125 % RDF + BF (F₃)	40.09
Conventional method	42.24	Conventional method	42.24

DS : Dry season
PE : Pan evaporation level
RDF: Recommended Dose of Fertilizer
BF : Biofertilizer (*Azophosmet*)

AT: Active tillering
PI : Panicle initiation
FF: 50 % flowering
HT: Harvest

Table 68. Rate of total manganese uptake ($\text{g ha}^{-1}\text{day}^{-1}$) at chosen growth stages as influenced by drip fertigation treatments in PMK (R) 3 rice under aerobic condition, DS (2007)

	Treatment	AT-PI	PI-FF	FF-HT	Mean
T ₁ :	Conventional method	16.93	30.24	17.09	21.42
T ₂ :	100 % PE + 75 % RDF + BF	6.68	14.36	5.15	8.73
T ₃ :	100 % PE + 100 % RDF + BF	10.49	16.64	6.38	11.17
T ₄ :	100 % PE + 125 % RDF + BF	11.69	21.05	4.59	12.45
T ₅ :	125 % PE + 75 % RDF + BF	12.56	22.56	6.65	13.92
T ₆ :	125 % PE + 100 % RDF + BF	15.14	25.75	16.70	19.20
T ₇ :	125 % PE + 125 % RDF + BF	17.48	32.46	5.77	18.57
T ₈ :	150 % PE + 75 % RDF + BF	14.04	25.05	13.18	17.42
T ₉ :	150 % PE + 100 % RDF + BF	15.29	33.66	16.90	21.95
T ₁₀ :	150 % PE + 125 % RDF + BF	16.62	39.65	17.73	24.67
	Mean	13.69	26.14	11.01	
	SEd	0.337	0.644	0.299	
	CD at 5 %	0.708	1.354	0.628	

Overall mean performance of irrigation regimes and fertilizer levels

Irrigation regime	Rate of total Mn uptake ($\text{g ha}^{-1}\text{day}^{-1}$)	Fertilizer level	Rate of total Mn uptake ($\text{g ha}^{-1}\text{day}^{-1}$)
100 % PE (I₁)	10.78	75 % RDF + BF (F₁)	13.36
125 % PE (I₂)	17.23	100 % RDF + BF (F₂)	17.44
150 % PE (I₃)	21.35	125 % RDF + BF (F₃)	18.56
Conventional method	21.42	Conventional method	21.42

DS : Dry season
PE : Pan evaporation level
RDF: Recommended Dose of Fertilizer
BF : Biofertilizer (*Azophosmet*)

AT: Active tillering
PI : Panicle initiation
FF: 50 % flowering
HT: Harvest

Table 69. Rate of total zinc uptake ($\text{g ha}^{-1}\text{day}^{-1}$) at chosen growth stages as influenced by drip fertigation treatments in PMK (R) 3 rice under aerobic condition, DS (2007)

	Treatment	AT-PI	PI-FF	FF-HT	Mean
T ₁ :	Conventional method	3.55	5.57	1.39	3.50
T ₂ :	100 % PE + 75 % RDF + BF	2.18	3.27	0.55	2.00
T ₃ :	100 % PE + 100 % RDF + BF	2.83	3.67	0.62	2.37
T ₄ :	100 % PE + 125 % RDF + BF	3.12	4.37	0.13	2.54
T ₅ :	125 % PE + 75 % RDF + BF	2.92	4.91	0.25	2.69
T ₆ :	125 % PE + 100 % RDF + BF	3.31	5.48	1.25	3.35
T ₇ :	125 % PE + 125 % RDF + BF	3.68	6.31	0.00	3.33
T ₈ :	150 % PE + 75 % RDF + BF	3.05	5.34	1.00	3.13
T ₉ :	150 % PE + 100 % RDF + BF	3.12	6.75	0.79	3.56
T ₁₀ :	150 % PE + 125 % RDF + BF	3.44	7.70	0.95	4.03
	Mean	3.12	5.34	0.69	
	SEd	0.074	0.129	0.021	
	CD at 5 %	0.156	0.272	0.044	

Overall mean performance of irrigation regimes and fertilizer levels

Irrigation regime	Rate of total Zn uptake ($\text{g ha}^{-1}\text{day}^{-1}$)	Fertilizer level	Rate of total Zn uptake ($\text{g ha}^{-1}\text{day}^{-1}$)
100 % PE (I₁)	2.30	75 % RDF + BF (F₁)	2.61
125 % PE (I₂)	3.12	100 % RDF + BF (F₂)	3.09
150 % PE (I₃)	3.57	125 % RDF + BF (F₃)	3.30
Conventional method	3.50	Conventional method	3.50

DS : Dry season
PE : Pan evaporation level
RDF: Recommended Dose of Fertilizer
BF : Biofertilizer (*Azophosmet*)

AT: Active tillering
PI : Panicle initiation
FF: 50 % flowering
HT: Harvest

Table 70. Rate of total copper uptake ($\text{g ha}^{-1}\text{day}^{-1}$) at chosen growth stages as influenced by drip fertigation treatments in PMK (R) 3 rice under aerobic condition, DS (2007)

	Treatment	AT-PI	PI-FF	FF-HT	Mean
T ₁ :	Conventional method	1.91	2.14	0.64	1.56
T ₂ :	100 % PE + 75 % RDF + BF	1.13	1.39	0.22	0.91
T ₃ :	100 % PE + 100 % RDF + BF	1.60	1.51	0.27	1.13
T ₄ :	100 % PE + 125 % RDF + BF	1.81	1.96	0.08	1.28
T ₅ :	125 % PE + 75 % RDF + BF	1.50	1.81	0.12	1.14
T ₆ :	125 % PE + 100 % RDF + BF	1.83	2.16	0.39	1.46
T ₇ :	125 % PE + 125 % RDF + BF	2.11	2.45	0.00	1.52
T ₈ :	150 % PE + 75 % RDF + BF	1.61	1.96	0.25	1.27
T ₉ :	150 % PE + 100 % RDF + BF	1.66	2.37	0.55	1.53
T ₁₀ :	150 % PE + 125 % RDF + BF	1.82	2.95	0.47	1.75
	Mean	1.70	2.07	0.30	
	SEd	0.040	0.048	0.009	
	CD at 5 %	0.083	0.102	0.019	

Overall mean performance of irrigation regimes and fertilizer levels

Irrigation regime	Rate of total Cu uptake ($\text{g ha}^{-1}\text{day}^{-1}$)	Fertilizer level	Rate of total Cu uptake ($\text{g ha}^{-1}\text{day}^{-1}$)
100 % PE (I₁)	1.11	75 % RDF + BF (F₁)	1.11
125 % PE (I₂)	1.37	100 % RDF + BF (F₂)	1.37
150 % PE (I₃)	1.52	125 % RDF + BF (F₃)	1.52
Conventional method	1.56	Conventional method	1.56

DS : Dry season
PE : Pan evaporation level
RDF: Recommended Dose of Fertilizer
BF : Biofertilizer (*Azophosmet*)

AT: Active tillering
PI : Panicle initiation
FF: 50 % flowering
HT: Harvest

Table 71. Nutrient Use Efficiency (%) and Agronomic Use Efficiency (AE) (kg ha⁻¹) as influenced by drip fertigation treatments in PMK (R) 3 rice under aerobic condition, DS (2007)

Treatment		Nutrient Use Efficiency			Agronomic Use Efficiency		
		N	P	K	N	P	K
T ₁ :	Conventional method	--	--	--	--	--	--
T ₂ :	100 % PE + 75 % RDF + BF	-81.13	-37.30	-177.42	-12.40	-37.20	-37.20
T ₃ :	100 % PE + 100 % RDF + BF	13.74	6.78	42.82	-6.53	-19.60	-19.60
T ₄ :	100 % PE + 125 % RDF + BF	8.31	6.44	19.36	-4.59	-13.78	-13.78
T ₅ :	125 % PE + 75 % RDF + BF	-5.93	2.68	-34.98	-0.11	-0.32	-0.32
T ₆ :	125 % PE + 100 % RDF + BF	51.57	9.65	57.57	5.19	15.57	15.57
T ₇ :	125 % PE + 125 % RDF + BF	5.99	0.86	17.45	1.29	3.86	3.86
T ₈ :	150 % PE + 75 % RDF + BF	-34.55	-6.53	-56.35	-0.52	-1.57	-1.57
T ₉ :	150 % PE + 100 % RDF + BF	21.40	6.54	41.68	2.28	6.83	6.83
T ₁₀ :	150 % PE + 125 % RDF + BF	13.98	2.87	21.82	1.13	3.39	3.39

Overall mean performance of irrigation regimes and fertilizer levels

Irrigation / Fertilizer level	Nutrient Use Efficiency			Irrigation / Fertilizer level	Agronomic Use Efficiency		
	N	P	K		N	P	K
I ₁	-19.69	-8.03	-38.41	I ₁	-7.84	-23.53	-23.53
I ₂	+17.21	+4.40	+13.35	I ₂	+2.12	+6.37	+6.37
I ₃	+0.28	+0.96	+2.38	I ₃	+0.96	+2.88	+2.88
F ₁	-40.53	-13.72	-89.58	F ₁	-4.34	-13.03	-13.03
F ₂	+28.90	+7.66	+47.36	F ₂	+0.31	+0.93	+0.93
F ₃	+9.43	+3.39	+19.54	F ₃	-0.72	-2.18	-2.18

DS : Dry season

PE : Pan evaporation level

RDF: Recommended Dose of Fertilizer

BF : Biofertilizer (*Azophosmet*)

I₁: 100 % PE

I₂: 125 % PE

I₃: 150 % PE

F₁: 75 % RDF + BF

F₂: 100 % RDF + BF

F₃: 125 % RDF + BF

Table 72. Yield and yield components as influenced by drip fertigation treatments in PMK (R) 3 rice under aerobic condition, DS (2007)

Treatment		Panicle Nos. m ⁻²	Panicle length (cm)	Spikelet Nos. m ⁻² (x10 ³)	Grain Nos. m ⁻² (x10 ³)	Filled grain (%)
T ₁ :	Conventional method	351	25.0	30.12	26.53	88.08
T ₂ :	100 % PE + 75 % RDF + BF	258	22.3	26.89	20.71	77.02
T ₃ :	100 % PE + 100 % RDF + BF	280	23.0	28.06	22.89	81.58
T ₄ :	100 % PE + 125 % RDF + BF	289	22.9	29.25	23.14	79.11
T ₅ :	125 % PE + 75 % RDF + BF	350	24.1	29.12	24.79	85.12
T ₆ :	125 % PE + 100 % RDF + BF	407	25.3	33.86	29.88	88.25
T ₇ :	125 % PE + 125 % RDF + BF	368	25.0	34.06	27.73	81.42
T ₈ :	150 % PE + 75 % RDF + BF	357	24.5	29.74	25.68	86.36
T ₉ :	150 % PE + 100 % RDF + BF	375	25.5	30.46	26.52	87.07
T ₁₀ :	150 % PE + 125 % RDF + BF	366	24.9	31.34	25.29	80.70
Mean		340	24.3	30.29	25.32	83.47
SEd		8.2	0.57	0.716	0.605	1.957
CD at 5 %		17.2	1.19	1..504	1.272	4.111

Overall mean performance of irrigation regimes and fertilizer levels

Treatment	Panicle Nos. m ⁻²	Panicle length (cm)	Spikelet Nos. m ⁻² (10 ³)	Grain Nos. m ⁻² (10 ³)	Filled grain (%)
I₁	276	22.7	28.07	22.25	79.24
I₂	375	24.8	32.35	27.47	84.93
I₃	366	25.0	30.51	25.83	84.71
F₁	322	23.6	28.58	23.73	82.83
F₂	354	24.6	30.79	26.43	85.63
F₃	341	24.3	31.55	25.39	80.41
Conventional method	351	25.0	30.12	26.53	88.08

DS : Dry season

PE : Pan evaporation level

RDF: Recommended Dose of Fertilizer

BF : Biofertilizer (*Azophosmet*)

I₁: 100 % PE

I₂: 125 % PE

I₃: 150 % PE

F₁: 75 % RDF + BF

F₂: 100 % RDF + BF

F₃: 125 % RDF + BF

Table 72. Yield and yield components as influenced by drip fertigation treatments in PMK (R) 3 rice under aerobic condition, DS (2007) (Cont'd)

Treatment		Mean Panicle Weight (g)	Panicle Harvest Index (%)	1000 grain weight (g)	Straw yield (kg ha ⁻¹)	Grain Yield (kg ha ⁻¹)	Harvest Index (%)
T ₁ :	Conventional method	2.85	82.71	24.55	6543	4865	42.64
T ₂ :	100 % PE + 75 % RDF + BF	2.07	75.56	22.41	5989	3470	36.30
T ₃ :	100 % PE + 100 % RDF + BF	2.28	76.36	22.86	6684	3885	36.76
T ₄ :	100 % PE + 125 % RDF + BF	2.31	74.01	23.01	6719	4004	37.34
T ₅ :	125 % PE + 75 % RDF + BF	2.08	84.02	24.00	5601	4853	46.42
T ₆ :	125 % PE + 100 % RDF + BF	2.31	85.12	24.78	6419	5643	46.79
T ₇ :	125 % PE + 125 % RDF + BF	2.33	84.23	24.12	7184	5107	41.55
T ₈ :	150 % PE + 75 % RDF + BF	2.67	82.69	24.56	6791	4806	40.91
T ₉ :	150 % PE + 100 % RDF + BF	2.80	84.28	24.55	7652	5207	40.49
T ₁₀ :	150 % PE + 125 % RDF + BF	2.92	80.36	24.08	8325	5077	37.88
Mean		2.46	80.93	23.89	6791	4692	40.71
SEd		0.058	1.901	0.559	157.2	113.0	0.970
CD at 5 %		0.121	3.994	1.174	330.2	237.4	2.039

Overall mean performance of irrigation regimes and fertilizer levels

Treatment	Mean Panicle Weight (g)	Panicle Harvest Index (%)	1000 grain weight (g)	Straw yield (kg ha ⁻¹)	Grain Yield (kg ha ⁻¹)	Harvest Index (%)
I ₁	2.22	75.31	22.76	6464	3786	36.80
I ₂	2.24	84.46	24.30	6401	5201	44.92
I ₃	2.80	82.44	24.40	7589	5030	39.76
F ₁	2.27	80.76	23.66	6127	4376	41.21
F ₂	2.46	81.92	24.06	6918	4912	41.35
F ₃	2.52	79.53	23.74	7409	4729	38.92
Conventional method	2.85	82.71	24.55	6543	4865	42.64

DS : Dry season
PE : Pan evaporation level
RDF: Recommended Dose of Fertilizer
BF : Biofertilizer (*Azophosmet*)

I₁: 100 % PE
I₂: 125 % PE
I₃: 150 % PE
F₁: 75 % RDF + BF
F₂: 100 % RDF + BF
F₃: 125 % RDF + BF

Table 73. Nutrient Harvest Index (%) at harvest as influenced by drip fertigation treatments in PMK (R) 3 rice under aerobic condition, DS (2007)

	Treatment	N	P	K	Ca	Mg	Fe	Mn	Zn	Cu
T ₁ :	Conventional method	55.24	36.08	10.92	52.43	68.68	41.33	54.55	63.94	32.21
T ₂ :	100 % PE + 75 % RDF + BF	48.98	31.25	9.14	49.70	64.85	38.97	56.79	55.29	23.26
T ₃ :	100 % PE + 100 % RDF + BF	47.26	32.30	9.39	51.46	65.88	37.30	53.79	59.50	24.81
T ₄ :	100 % PE + 125 % RDF + BF	48.52	32.78	9.78	51.43	64.97	38.02	51.41	60.80	25.36
T ₅ :	125 % PE + 75 % RDF + BF	54.67	35.63	11.21	58.38	70.86	33.47	49.25	58.45	25.38
T ₆ :	125 % PE + 100 % RDF + BF	55.28	38.24	11.46	53.66	71.43	51.55	57.14	79.33	30.00
T ₇ :	125 % PE + 125 % RDF + BF	56.65	38.54	11.81	54.15	71.11	51.49	55.54	79.33	37.67
T ₈ :	150 % PE + 75 % RDF + BF	56.44	37.91	11.52	57.59	59.32	37.13	43.57	74.22	25.93
T ₉ :	150 % PE + 100 % RDF + BF	56.60	39.58	11.57	56.00	65.03	48.34	58.90	75.24	33.33
T ₁₀ :	150 % PE + 125 % RDF + BF	56.43	39.92	11.68	55.12	67.93	47.85	59.47	73.13	34.67
	Mean	53.61	36.22	10.85	53.99	67.01	42.54	54.04	67.92	29.26
	SEd	1.260	0.853	0.256	1.260	1.580	1.020	1.266	1.617	0.701
	CD at 5 %	2.647	1.792	0.537	2.641	3.320	2.143	2.660	3.398	1.473

Overall mean performance of irrigation regimes and fertilizer levels

Treatment	N	P	K	Ca	Mg	Fe	Mn	Zn	Cu
I₁	48.25	32.11	9.44	50.86	65.23	38.10	54.00	58.53	24.48
I₂	55.53	37.47	11.49	55.39	71.13	45.50	53.98	72.37	31.02
I₃	56.49	39.14	11.59	56.24	64.09	44.44	53.98	74.20	31.31
F₁	53.36	34.93	10.62	55.22	65.01	36.52	49.87	62.65	24.86
F₂	53.05	36.71	10.81	53.71	67.45	45.73	56.61	71.36	29.38
F₃	53.87	37.08	11.09	53.57	68.01	45.79	55.47	71.08	32.57
Conventional method	55.24	36.08	10.92	52.43	68.68	41.33	54.55	63.94	32.21

DS : Dry season

PE : Pan evaporation level

RDF: Recommended Dose of Fertilizer

BF : Biofertilizer (*Azophosmet*)

I₁: 100 % PE

I₂: 125 % PE

I₃: 150 % PE

F₁: 75 % RDF + BF

F₂: 100 % RDF + BF

F₃: 125 % RDF + BF

Table 74. Parameters of water input and its use as influenced by drip fertigation treatments in PMK (R) 3 rice under aerobic condition, DS (2007)

Treatment		Irrigation water applied (mm)	Effective rainfall (mm)	Total water applied (mm)	Water productivity (g grains kg ⁻¹ water)
T ₁ :	Conventional method	390	121	511	0.952
T ₂ :	100 % PE + 75 % RDF + BF	345	121	466	0.745
T ₃ :	100 % PE + 100 % RDF + BF	345	121	466	0.834
T ₄ :	100 % PE + 125 % RDF + BF	345	121	466	0.859
T ₅ :	125 % PE + 75 % RDF + BF	416	121	537	0.904
T ₆ :	125 % PE + 100 % RDF + BF	416	121	537	1.051
T ₇ :	125 % PE + 125 % RDF + BF	416	121	537	0.951
T ₈ :	150 % PE + 75 % RDF + BF	487	121	608	0.790
T ₉ :	150 % PE + 100 % RDF + BF	487	121	608	0.856
T ₁₀ :	150 % PE + 125 % RDF + BF	487	121	608	0.835

Overall mean performance of irrigation regimes and fertilizer levels

Irrigation regime	Water productivity (g grains kg ⁻¹ water)	Fertilizer level	Water productivity (g grains kg ⁻¹ water)
100 % PE (I ₁)	0.813	75 % RDF + BF (F ₁)	0.813
125 % PE (I ₂)	0.969	100 % RDF + BF (F ₂)	0.914
150 % PE (I ₃)	0.827	125 % RDF + BF (F ₃)	0.882
Conventional method	0.952	Conventional method	0.952

DS : Dry season
PE : Pan evaporation level

RDF: Recommended Dose of Fertilizer
BF : Biofertilizer (*Azophosmet*)

Table 84. Economics of rice cultivation as influenced by drip fertigation treatments in PMK (R) 3 rice under aerobic condition, DS (2007)

	Treatment	Cost of cultivation (Rs. ha ⁻¹)	Yield (Kg ha ⁻¹)	Gross return (Rs. ha ⁻¹)	Net return (Rs. ha ⁻¹)	Benefit : Cost ratio
T ₁ :	Conventional method	16271	4865	38920	23399	2.39
T ₂ :	100 % PE + 75 % RDF + BF	16775	3470	27760	11735	1.65
T ₃ :	100 % PE + 100 % RDF + BF	18715	3885	31080	13115	1.66
T ₄ :	100 % PE + 125 % RDF + BF	20800	4004	32032	11982	1.54
T ₅ :	125 % PE + 75 % RDF + BF	16775	4853	38824	22799	2.31
T ₆ :	125 % PE + 100 % RDF + BF	18715	5643	45144	27179	2.41
T ₇ :	125 % PE + 125 % RDF + BF	20800	5107	40856	20806	1.96
T ₈ :	150 % PE + 75 % RDF + BF	16775	4806	38448	22423	2.29
T ₉ :	150 % PE + 100 % RDF + BF	18715	5207	41656	23691	2.23
T ₁₀ :	150 % PE + 125 % RDF + BF	20800	5077	40616	20566	1.95

Table 75. Correlation for morpho-physiological characters and yield as influenced by drip fertigation treatments (n = 30)

Parameter	TD	LAI	LAD	OP	RV	RLD	RMD	SLW	PS II	CGR	NAR	TDMA
TD	1											
LAI	0.939**	1										
LAD	0.949**	0.996**	1									
OP	0.911**	0.853**	0.867**	1								
RV	-0.287	-0.256	-0.290	-0.153	1							
RLD	-0.907**	-0.837**	-0.843**	-0.827**	0.478**	1						
RMD	0.203	0.099	0.104	0.345	0.635**	-0.069	1					
SLW	0.553**	0.504**	0.485**	0.482**	-0.569**	-0.706**	-0.205	1				
PS II	0.959**	0.882**	0.900**	0.939**	-0.362*	-0.899**	0.220	0.643**	1			
CGR	0.982**	0.965**	0.973**	0.921**	-0.330	-0.917**	0.130	0.567**	0.946**	1		
NAR	0.928**	0.889**	0.903**	0.822**	-0.549**	-0.912**	-0.142	0.641**	0.898**	0.951**	1	
TDMA	0.877**	0.796**	0.788**	0.696**	-0.321	-0.846**	0.057	0.642**	0.802**	0.850**	0.860**	1
YIELD	0.893**	0.765**	0.788**	0.911**	-0.272	-0.848**	0.396*	0.563**	0.944**	0.866**	0.793**	0.799**

****** : Significant at 0.01 level

TD : Tiller density

LAI : Leaf area index

LAD : Leaf area duration

OP : Oxidizing power of roots

RV : Root volume

RLD : Root length density

***** : Significant at 0.05 level

RMD : Root mass density

SLW : Specific leaf weight

PS II : Fv / Fm ratio

CGR : Crop growth rate

NAR : Net assimilation rate

TDMA : Total dry matter accumulation

Table 76. Correlation for biochemical characters and yield as influenced by drip fertigation treatments (n = 30)

Parameter	Ca	Cb	Ct	a/b	TFA	SP	PO	SOD	IAA-Ox	NRase	RS	SN	TAC	CK
Ca	1													
Cb	-0.766**	1												
Ct	0.969**	-0.583**	1											
a/b	0.914**	-0.937**	0.795**	1										
TFA	0.950**	-0.689**	0.936**	0.856**	1									
SP	0.850**	-0.573**	0.853**	0.749**	0.758**	1								
PO	-0.860**	0.524**	-0.886**	-0.654**	-0.802**	-0.822**	1							
SOD	-0.917**	0.782**	-0.858**	-0.874**	-0.792**	-0.870**	0.848**	1						
IAA-Ox	0.932**	-0.710**	0.904**	0.845**	0.848**	0.965**	-0.893**	-0.923**	1					
NRase	0.827**	-0.355	0.908**	0.550**	0.805**	0.740**	-0.873**	-0.704**	0.789**	1				
RS	-0.892**	0.594**	-0.898**	-0.703**	-0.840**	-0.808**	0.984**	0.872**	-0.898**	-0.899**	1			
SN	-0.321	0.097	-0.368*	-0.167	-0.466**	0.132	0.263	0.129	-0.021	-0.435*	0.336	1		
TAC	0.967**	-0.695**	0.955**	0.843**	0.944**	0.756**	-0.848**	-0.855**	0.862**	0.883**	-0.900**	-0.480**	1	
CK	0.942**	-0.645**	0.942**	0.811**	0.866**	0.772**	-0.813**	-0.883**	0.840**	0.869**	-0.861**	-0.411*	0.968**	1
YIELD	0.913**	-0.606**	0.921**	0.773**	0.892**	0.709**	-0.818**	-0.806**	0.793**	0.859**	-0.857**	-0.489**	0.966**	0.964**

** : Significant at 0.01 level

Ca : Chlorophyll 'a'

Cb : Chlorophyll 'b'

Ct : Total chlorophyll

a/b : Chlorophyll a/b ratio

TFA : Total free amino acid

SP : Soluble protein

PO : Peroxidase

* : Significant at 0.05 level

SOD : Superoxide dismutase

IAA-Ox : Indole acetic acid oxidase

NRase : Nitrate reductase

RS : Reducing suger

SN : Soluble nitrogen

TAC : Total available carbohydrate

CK : Cytokinins

Table 77. Correlation for plant water relations and yield as influenced by drip fertigation treatments (n = 30)

Parameter	RWC	LWP	MSI	CSI	PLN	LDR	TR	LT	CT
RWC	1								
LWP	0.783**	1							
MSI	0.903**	0.892**	1						
CSI	0.902**	0.715**	0.928**	1					
PLN	-0.634**	-0.896**	-0.856**	-0.683**	1				
LDR	-0.696**	-0.958**	-0.883**	-0.689**	0.980**	1			
TR	0.791**	0.944**	0.956**	0.808**	-0.934**	-0.955**	1		
LT	-0.316	-0.767**	-0.431*	-0.202	0.641**	0.716**	-0.559**	1	
CT	-0.273	-0.741**	-0.402*	-0.199	0.617**	0.694**	-0.531**	0.939**	1
YIELD	0.926**	0.870**	0.877**	0.814**	-0.641**	-0.748**	0.826**	-0.485**	-0.486**

** : Significant at 0.01 level

RWC : Relative water content

LWP : Leaf water potential

MSI : Membrane stability index

CSI : Chlorophyll stability index

PLN : Proline

* : Significant at 0.05 level

LDR : Leaf diffusive resistance

TR : Transpiration rate

LT : Leaf temperature

CT : Canopy temperature

Table 78. Correlation for uptake of nutrients and yield as influenced by drip fertigation treatments (n = 30)

Parameter	N	P	K	Ca	Mg	Fe	Mn	Zn	Cu
N	1								
P	0.955**	1							
K	0.946**	0.952**	1						
Ca	0.982**	0.962**	0.918**	1					
Mg	0.968**	0.972**	0.936**	0.967**	1				
Fe	0.982**	0.974**	0.944**	0.984**	0.993**	1			
Mn	0.979**	0.964**	0.965**	0.977**	0.975**	0.990**	1		
Zn	0.970**	0.946**	0.957**	0.957**	0.976**	0.988**	0.991**	1	
Cu	0.924**	0.889**	0.969**	0.875**	0.920**	0.920**	0.935**	0.951**	1
YIELD	0.851**	0.899**	0.762**	0.900**	0.848**	0.863**	0.817**	0.787**	0.662**

** : Significant at 0.01 level
N : Nitrogen
P : Phosphorus
K : Potassium
Ca : Calcium

Mg : Magnesium
Fe : Iron
Mn : Manganese
Zn : Zinc
Cu : Copper

Table 79. Correlation for nutrient harvest index and yield as influenced by drip fertigation treatments (n = 30)

Parameter	N	P	K	Ca	Mg	Fe	Mn	Zn	Cu
N	1								
P	0.939**	1							
K	0.969**	0.965**	1						
Ca	0.771**	0.710**	0.788**	1					
Mg	0.337	0.296	0.362*	0.186	1				
Fe	0.550**	0.690**	0.581**	0.066	0.456*	1			
Mn	0.138	0.263	0.098	-0.219	0.528**	0.703**	1		
Zn	0.769**	0.881**	0.829**	0.458*	0.212	0.826**	0.238	1	
Cu	0.718**	0.792**	0.741**	0.268	0.468**	0.832**	0.539**	0.750**	1
YIELD	0.880**	0.914**	0.934**	0.645**	0.469**	0.666**	0.205	0.835**	0.711**

** : Significant at 0.01 level

N : Nitrogen

P : Phosphorus

K : Potassium

Ca : Calcium

Mg : Magnesium

* : Significant at 0.05 level

Fe : Iron

Mn : Manganese

Zn : Zinc

Cu : Copper

Table 80. Correlations for yield attributes and yield as influenced by drip fertigation treatments (n = 30)

Parameter	PAN	SPK	GRN	FGP	PL	MPW	TGW	PHI	TDMA	HI
PAN	1									
SPK	0.831**	1								
GRN	0.943**	0.911**	1							
FGP	0.738**	0.490**	0.756**	1						
PL	0.914**	0.803**	0.887**	0.816**	1					
MPW	0.489**	0.298	0.391*	0.453*	0.641**	1				
TGW	0.861**	0.722**	0.844**	0.898**	0.958**	0.578**	1			
PHI	0.883**	0.721**	0.849**	0.841**	0.916**	0.360	0.918**	1		
TDMA	0.795**	0.742**	0.710**	0.451*	0.837**	0.771**	0.706**	0.608**	1	
HI	0.748**	0.578**	0.759**	0.775**	0.649**	-0.021	0.721**	0.829**	0.230	1
YIELD	0.997**	0.841**	0.946**	0.729**	0.914**	0.484**	0.849**	0.873**	0.799**	0.747**

** : Significant at 0.01 level

PAN : Number of panicles

SPK : Number of spikelets

GRN : Number of grains

FGP : Filled grain percentage

PL : Panicle length

* : Significant at 0.05 level

MPW : Mean panicle weight

TGW : Thousand grain weight

PHI : Panicle harvest index

TDMA : Total dry matter accumulation

HI : Grain harvest index

Table 81. Direct and indirect effects of morpho-physiological characters on rice grain yield as influenced by drip fertigation treatments (n = 30)

Parameter	TD	LAI	LAD	OP	RV	RLD	RMD	SLW	PS II	CGR	NAR	TDMA	YIELD
TD	-0.500	-0.469	-0.474	-0.455	0.177	0.484	-0.091	-0.262	-0.479	-0.493	-0.467	-0.436	0.888**
LAI	-0.480	-0.512	-0.510	-0.435	0.163	0.457	-0.038	-0.242	-0.449	-0.495	-0.457	-0.402	0.755**
LAD	-0.113	-0.118	-0.119	-0.103	0.041	0.106	-0.010	-0.054	-0.107	-0.116	-0.108	-0.093	0.779**
OP	0.528	0.493	0.502	0.581	-0.114	-0.504	0.192	0.268	0.547	0.534	0.477	0.400	0.909**
RV	0.137	0.123	0.135	0.076	-0.387	-0.180	-0.243	0.267	0.173	0.145	0.228	0.160	-0.335
RLD	-0.053	-0.049	-0.049	-0.048	0.026	0.055	-0.005	-0.044	-0.054	-0.052	-0.052	-0.051	-0.903**
RMD	-0.024	-0.010	-0.011	-0.044	-0.083	0.012	-0.132	0.034	-0.026	-0.015	0.021	-0.003	0.381
SLW	-0.139	-0.126	-0.122	-0.123	0.183	0.210	0.069	-0.266	-0.163	-0.148	-0.171	-0.161	0.537
PS II	0.956	0.876	0.896	0.940	-0.446	-0.972	0.195	0.614	0.999**	0.950	0.907	0.786	0.942**
CGR	1.426	1.399	1.409	1.331	-0.543	-1.379	0.166	0.806	1.378	1.448**	1.377	1.236	0.864**
NAR	-1.553	-1.485	-1.506	-1.366	0.981	1.558	0.261	-1.074	-1.510	-1.582	-1.663**	-1.451	0.794*
TDMA	0.702	0.632	0.628	0.554	-0.333	-0.749	0.017	0.489	0.634	0.688	0.703	0.805*	0.789*

****** : Significant at 0.01 level

TD : Tiller density

LAI : Leaf area index

LAD : Leaf area duration

OP : Oxidizing power of roots

RV : Root volume

RLD : Root length density

***** : Significant at 0.05 level

RMD : Root mass density

SLW : Specific leaf weight

PS II : Fv / Fm ratio

CGR : Crop growth rate

NAR : Net assimilation rate

TDMA : Total dry matter accumulation

Table 82. Direct and indirect effects of uptake of nutrients as influenced by drip fertigation treatments in aerobic rice (n = 30)

Parameter	N	P	K	Ca	Mg	Fe	Mn	Zn	Cu	Yield
N	-0.804*	-0.768	-0.761	-0.789	-0.781	-0.791	-0.787	-0.785	-0.740	0.852**
P	-0.817	-0.856**	-0.814	-0.823	-0.832	-0.833	-0.825	-0.811	-0.755	0.897**
K	2.185	2.197	2.311**	2.118	2.161	2.178	2.229	2.217	2.231	0.756*
Ca	1.105	1.083	1.032	1.126**	1.090	1.109	1.100	1.082	0.981	0.901**
Mg	-1.616	-1.618	-1.556	-1.611	-1.664**	-1.652	-1.627	-1.621	-1.529	0.842**
Fe	7.110	7.031	6.812	7.116	7.172	7.226**	7.166	7.143	6.613	0.858**
Mn	-3.890	-3.832	-3.834	-3.883	-3.888	-3.942	-3.975**	-3.953	-3.714	0.817*
Zn	-1.606	-1.558	-1.577	-1.579	-1.601	-1.625	-1.635	-1.644**	-1.557	0.788**
Cu	-0.816	-0.783	-0.856	-0.773	-0.815	-0.812	-0.828	-0.840	-0.887**	0.644*

** : Significant at 0.01 level

N : Nitrogen

P : Phosphorus

K : Potassium

Ca : Calcium

Mg : Magnesium

* : Significant at 0.05 level

Fe : Iron

Mn : Manganese

Zn : Zinc

Cu : Copper

Table 83. Direct and indirect effects of yield attributes on rice grain yield as influenced by drip fertigation treatments (n = 30)

Parameter	PAN	SPK	GRN	FGP	PL	MPW	TGW	PHI	TDMA	HI	YIELD
PAN	-0.208	-0.172	-0.195	-0.159	-0.205	-0.096	-0.212	-0.193	-0.163	-0.152	0.997**
SPK	-0.768	-0.928**	-0.839	-0.329	-0.713	-0.212	-0.626	-0.610	-0.661	-0.479	0.840**
GRN	1.200	1.152	1.275**	0.956	1.171	0.439	1.193	1.095	0.870	0.937	0.945**
FGP	-0.459	-0.212	-0.450	-0.600	-0.436	-0.241	-0.515	-0.465	-0.220	-0.456	0.757*
PL	0.251	0.196	0.234	0.185	0.255	0.162	0.243	0.224	0.218	0.152	0.990**
MPW	-0.072	-0.036	-0.054	-0.063	-0.100	-0.157	-0.096	-0.045	-0.119	0.016	0.457
TGW	0.227	0.150	0.208	0.191	0.212	0.136	0.222	0.200	0.166	0.162	1.011**
PHI	-0.104	-0.073	-0.096	-0.087	-0.098	-0.032	-0.101	-0.112	-0.063	-0.091	0.922**
TDMA	0.532	0.484	0.464	0.250	0.581	0.514	0.507	0.382	0.680*	0.102	0.789*
HI	0.398	0.280	0.399	0.412	0.325	-0.057	0.396	0.445	0.082	0.542	0.734*

** : Significant at 0.01 level

PAN : Number of panicles

SPK : Number of spikelets

GRN : Number of grains

FGP : Filled grain percentage

PL : Panicle length

* : Significant at 0.05 level

MPW : Mean panicle weight

TGW : Thousand grain weight

PHI : Panicle harvest index

TDMA : Total dry matter accumulation

HI : Grain harvest index

Appendix 3. Abbreviations used in the listings of ORYZA2000 model

Variable	Description	Used In subroutine Units
AIAI	Apparent leaf area index (including stem area)	ORVZA1ha leaf ha ⁻¹ soil
ALB	Albedo, reflection coefficient for short-wave radiation	ET
AMAX	C assimilation rate at light saturation	SGPC1,SGPC2,SGPCDT,ORVZA1 kg CO ₂ ha ⁻¹ leaf h ⁻¹
AMAX1	Uncorrected CO ₂ assimilation rate at light saturation	SGPL kg CO ₂ ha ⁻¹ leaf h ⁻¹
AMAX2	Corrected C assimilation rate at light saturation	SGPL kg CO ₂ ha ⁻¹ leaf h ⁻¹
ANCR	Amount of N in crop (live and dead material)	NCROP kg N ha ⁻¹
ANCRF	Amount of N in crop till flowering	NCROP kg N ha ⁻¹
ANCRPT	Potential amount of N in crop	NCROP kg N ha ⁻¹
ANGA	Angstrom parameter A	ET, MODELS
ANGB	AngstrOm parameter B	ET, MODELS
ANGOT	Daily extraterrestrial radiation	SASTRO, SGPCDT J m d ⁻¹
ANLD	Amount of N in dead leaves	NCROP kg N ha ⁻¹
ANLV	Amount of N in leaves	NCROP kg N ha ⁻¹
ANLVA	Amount of N in leaves till flowering	NCROP kg N ha ⁻¹
ANSO	Amount of N in storage organs	NCROP kg N ha ⁻¹
ANST	Amount of N in stems	NCROP kg N ha ⁻¹
ANSTA	Amount of N in stems till flowering	NCROP kg N ha ⁻¹
AOB	Intermediate variable	SASTRO
ASLA	A parameter of funCtion to calculate SLA	ORYZA1
ATMTR	Atmospheric transmission coefficient	SSKYC
ATN	Total available N for translocation from leaves, stems, and roots	NCROP kg N ha ⁻¹
ATNLV	Total available N for translocation from leaves	NCROP kg N ha ⁻¹
ATNRT	Total available N for translocation from roots	NCROP kg N ha ⁻¹
ATNST	Total available N for translocation from stems	NCROP kg N ha ⁻¹
BSLA	B parameter of function to calculate SLA	ORYZA1
CAPRI	Array of capillary rise, per soil layer	PADDY mmcr'
CAPTOT	Total capillary rise	PADDY mmcr'
CBCHK	Carbon balance check, relative value to sums of CKIN and CKCFL	
CKCFL	Sum of integrated carbon fluxes into and out of crop	ORVZA1, SUCBC kg C ha ⁻¹
CKCIN	Carbon in crop accumulated since simulation started	ORVZA1, SUCBC kg C ha ⁻¹
CKWFL	Total of external contribution to system water content	PADDY mm
CKWIN	Total change in system water content	PADDY mm
CLUSTF	Cluster factor	SRDPRF
C02	Ambient CO ₂ concentration	ORVZA1ppm
C02EFF	Relative effect of CO ₂ on inniallight-use efficiency	ORVZA1
C02LV	C production factor for growth of leaves	ORYZA1 kg CO ₂ kg ⁻¹ DM
C02REF	Reference level of atmospheric C (340 ppm)	ORVZA1ppm
C02RT	C production factor for growth of roots	ORVZA1 kg CO ₂ kg ⁻¹ DM
C02S0	C production factor for growth of storage organs	ORVZA1 kg CO ₂ kg ⁻¹ DM
C02ST	C production factor for growth of stems	ORVZA1kg C kg ⁻¹ DM
C02STR	C production factor for growth of stem reserves	ORVZA1kg CO ₂ kg ⁻¹ DM
COLDTT	Accumulated cold degree days	SUBGRN "Cd
C05LD	Intermediate variable in calculating solar height	SASTRO, SGPCDT, SSKYC
CRACKS	Logical indicating if cracks penetrate through puddle topsoil	PADDY
CRGCR	Carbohydrate (CH ₂ O) requirement for dry matter production	ORYZA1kg CH ₂ O kg ⁻¹ DM
CRGLV	Carbohydrate requirement for leaf dry matter production	ORYZA1kg CH ₂ O kg ⁻¹ DM
CRGRT	Carbohydrate requirement for root dry matter production	ORYZA1kg CH ₂ O kg ⁻¹ DM
CRGSO	Carbohydrate requirement for storage organ dry matter production	ORYZA1kg CH ₂ O kg ⁻¹ DM

CRGST	Carbohydrate requirement for stem dry matter production	ORYZA1kg CH ₂ O kg ⁻¹ DM
CRGSTR	Carbohydrate requirement for stem reserves production	ORYZA1kg CH ₂ O kg ⁻¹ DM
CSLA	C parameter of function to calculate SLA	SGPC1, SGPCDT,SGPC2, SGPL, SRDPRF
CSLV	Scattering coefficient of leaves for photosynthetically active radiation	ORYZA1 kg C ha ⁻¹
CTAN	Carbon losses at transplanting	
CTT DAE	Cold degree day	SUBGRN Cd
DAYL	Days after emergence	MODELS, NSOIL, ORYZA1d
	Astronomic day length (base = 0 degrees)	ORYZA1, PHENOL, SGPCDT, SASTRO SASTRO radians h
DAYLP	Photoperiodic astronomic day length (base = -4 degrees	ORVZA1, PHENOL, SGPCDT, SASTRO h
DEC	Declination of sun	SASTRO
	Conversion factor from degrees to radians	
DEGTRAD		SASTRO radians degree-'SGPC2
DEL	Intermediate variable for numerical integration	Most subroutines d
DELT	Time interval of integration	PHENOL h MODELS kg DM ha ⁻¹ d ⁻¹
DL DLDR	Photoperiod day length	NCROP, ORYZA1, SUBLAI2
DLDRT	Death rate of leaves caused by drought	ORYZA1kg DM ha ⁻¹ d ⁻¹
DLEA"F	Total death rate of leaves caused by drought	ORYZA1 kg DM ha ⁻¹ d ⁻¹
DOY	Control variable for start of leaf senescence by drought Day number (January 1 = 1)	GW TAB, IRRIG, d MODELS, ORYZA 1, PADDY, SASTRO
DPAR	Daily incoming photo synthetically active radiation	ORYZA1 MJ m ⁻² a'
	The amount of photo synthetically active radiation that is absorbed in a day by canopy	
DPARI		ORYZA1 MJ m ⁻² a'
	Flux of water to drain soil layer to field capacity Cumulative outflow from deepest soil layer, from main field Cumulative outflow from deepest soil layer, since start of simulation	
DRAIN		PADDY mma'
DRAINC		PADDY mm
DRAICU		PADDY mm
DRLVT	Table for leaf death coefficient as function of DVS Control	ORYZA1 -, d-' ORYZA1
DROUT	variable Indicating drought/no drought	SASTRO sa' SASTRO
DSINB	Daily total of sine of solar height	, SGPCDT, sa' SSKYC
	As DSINB, bu1 with a correction for lower atmospheric transmission at lower solar elevations	
DSINBE		ORYZA1
DSL A	D parameter of function to calculate SLA	PADDY d ET .C
DTGA	Daily total gross CO. assimilation of crop	ORYZA1 J m ⁻² a'
DTR DV~	Daily total global radiation	ORYZA1 .Ca'

	Effect of water stress on development rate	
DVR DVRI	Development rate of crop	ORYZA1, PHENOL ORYZA1, PHENOL .Ca'
DVRJ	Development rate during photoperiod-sensitive phase	ORYZA1, PHENOL .Ca'
DVRP	Development rate during juvenile phase	ORYZA1, PHENOL .Ca'
DVRR DVS	Development rate during panicle development phase	ORYZA1, PHENOL .Ca'
DVRR DVS	Development rate in reproductive phase (post anthesis) Development stage of crop	ORVZA1, PHENOL .cer'
DVSF DVSI	Development stage of crop at flowering Initial value of development stage of crop	Most subroutines SUBGRN ORVZA 1
DVSPi	Development stage of crop at panicle initiation	SUBGRN SRDPRF
ECPBL	Extinction coefficient for direct radiation	SGPC1, SGPC2, SGPL, SGPCDT, SRDPRF SRDPRF
ECPDF	Extinction coefficient for diffuse radiation	SGPC1, kg C02 ha-' leaf
ECPTD EFF	Extinction coefficient for direct component of direct radiation Initial light-use efficiency	SGPC2, h-')(W m ⁻² leafr' SGPCDT,ORVZA1SGPL (kg C02 tia-' leaf h-')(W m ⁻² leafr' SGPL (kg C02 ha-' leaf h-') W m ⁻² leafr'
EFF1	Uncorrected initial light-use efficiency	ORVZA1 EFF, .C MODELS d MODELS Y
EFF2	Corrected inniallight-use efficiency	SGPC2
EFFTB	Table of EFF as function of temperature Day of emergence	MODELS,ORVZA1, PADDY, SUBLAI2
EMD	Year of emergence	ET
EMYR	Intermediate variable for numerical integration	ET, MODELS ET, MODELS
EPS ESTAB	Method of crop establishment	ET mmer'
ETAe	Dryness-driven part of reference evapotranspiration rate	ET, MODELS, PADDY mmer'
ETD	Reference evapotranspiration rate	PADDY mmer'
ETMOD	Name of evapotranspiration procedure	PADDY mmer'
ETRD	Radiation-driven part of reference evapotranspiration rate	PADDY PADDY mmer'
EVSC	Potential evaporation rate of soil or ponded water layer	PADDY mmer'
EVSD	Actual evaporation rate of soil if DSPW > 1	PADDY mmd-'
EVSH	Actual evaporation rate of soil if DSPW = 1	BACKFL,
EVSW	Actual evaporation rate of soil	DOWNFL, PADDY mmer'
EVSWC	Cumulative actual evaporation, from main field Cumulative	PADDY mm
EVSWCU	actual evaporation, since start of simulation	ET, MODELS mm mmer'
EVSWs	Actual evaporation rate of soil layer 1	ORVZA1 kg C kg-' DM
FACT	Soil-water tension	kg C kg-' DM pF
FAOF	FAO correction factor on potential evapotranspiration rate	kg C kg-' DM
FCLV	Mass fraction of carbon in leaves	kg C kg-' DM
FCRT	Mass fraction of carbon in roots	kg C kg-' DM
FCsO	Mass fraction of carbon in storage organs	kg C kg-' DM
FCST	Mass fraction of carbon In stems	NSOIL kg N ha-' d-'
FCSTR	Mass fraction of carbon in stem reserves	NSOIL d, kg N ha-' d-'
FERT	Daily fertilizer N application rate	MODELS, NCROP, NNOSTRESS,ORVZA1, WSTRESS
FERTIL	Table of daily fertilizer N application as function of time	MODELS, PADDY
FILEI1	Name of crop data file	MODELS
FILEI2	Name of soil data file	MODELS
FILEI3	Name of input file no. 3	MODELS
FILEI4	Name of input file no. 4	IRRIG, MODELS, NSOIL, - NNOSTRESS,ORVZA1
FILEI5	Name of input file no. 5	PADDY mm d-'

FILE IT	Name of experimental data file	
FIXPERC	Constant percolation rate	
FUN	Flux into soH layer	BACKFL, DOWNFL mmo'
FLNEW	Boundary flow between soil layers recalculated via subroutine BACKFL	BACKFL, PADDY mmo'
FLOUT	Flux out of soil layer	BACKFL, DOWNFL mmo'
FLOW FLV	Capillary rise calculated by subroutine SUBSL2	PADDY
FL VTB	Fraction of shoot dry mailer allocated to leaves	ORVZA1 kg N kg-' DM
FNLV	Table of FL V as function of DVS	ORVZA1 kg N kg-' DM
FNLVI	Fraction of N in leaves on weight basis Innial fraction of N In leaves on weight basis	NCROP kg N kg-' DM
FNSO	Fraction of N in storage organs	NCROP kg N kg-' DM
FNST	Fraction of N in stems	NCROP
FNTRT	Fraction of N translocated from stems and leaves, which is translocated from roots to storage organs	NCROP
FRDIF	Fraction of diffuse radiation	NCROP
FRPAR	Fraction of short-wave radiation that is photosynthetically active	SSKYC
FRT	Fraction of total dry mailer allocated to roots	ORVZA1, SGPCDT, SSKYC
FSH	Fraction of total dry mailer allocated to shoots	ORYZA 1
FSHTB	Table of FSH as function of DVS	ORYZA 1
FSLLA	Fraction of leaf area that is sun ln	ORYZA 1
FSO	Fraction of shoot dry mailer allocated to storage organs	SGPL, SRDPRF
FSOTB	Table of FSO as function of DVS	ORYZA1
FST	Fraction of shoot dry mailer allocated to stems	ORYZA1
FSTR	Fraction of carbohydrates allocated to stems, stored as reserves	ORYZA1
FSTTB	Table of FST as function of DVS	ORYZA1
		ORYZA1SGPC1, ha leaf ha-' soil
GAI	Green area index	SGPC2, SGPCDT, SGPL SGPC1, ha leaf ha ⁻¹
GAID	Green area index above selected height	soil SGPL, SRDPRF ORVZA1, kg DM ha-' 0' SUBGRN
GCR	Gross growth rate of crop	MODELS, kg DM ha-' 0' ORVZA1 MODELS
GGR	Rate of increase in grain weight	ORYZA1, haha-'d-' SUBLAI2
GIVEN	Logical parameter	SUBLAI2 ha ha-' 0'
GLA	Growth rate of leaf area Index	SUBLAI2 ha ha-' d-'
GLAI1	Intermediate value of GLAI	MODELS, kg ha-' 0'
		ORYZA1, NCROP
		ORYZA1, no. ha-'d-'
GLAI2	Intermediate value of GLAI	SUBGRN
		ORYZA1, no. ha-'d-'
GLV	Growth rate of leaves	SUBGRN
GNGR	Rate of increase In grain number	SGPC1, kg C~ ha-' h-'
GNSP	Rate of increase In spikelet number	SGPC2, SGPCDT
GPC	Instantaneous C02 assimilation rate of canopy	SGPCDT kg C02 ha-' d-'
GPCDT	Daily total gross assimilation	SGPC2
GPCO	Intermediate variable for numerical integration	SGPC2
GPCT	Intermediate variable for numerical integration	SGPC2
GPCTO	Intermediate variable for numerical integration	
		SGPL, kg C02 ha-' leaf h-'
GPL	Instantaneous ~ assimilation rate of leaves at depth GAI	SGPC1

Variable	Description	Used In subroutine	Units
GPL1	Intennediate variable for numerical integration	SGPC2	
GPL2	Intennediate variable for numerical integration	SGPC2	
GPSHL	Gross C02 assimilation rate of shaded leaves	SGPL kg Co. ha ⁻¹ leaf h ⁻¹	
GPSLL	Gross C02 assimilation rate of sunlh leaves	SGPL kg C02 ha ⁻¹ leaf h ⁻¹	
GRAINS	Logical parameter indicating whether grains are fonned	ORVZA1, SUBGRN	
GRWAT	Logical parameter indicating if groundwater Is in soil profile	PADDY	
GRT	Growth rate of roots	ORVZA1 kg DM ha ⁻¹ cr'	
GRT1	Reduction in root weight at transplanting	ORVZA1 kg DM ha ⁻¹	
GSO	Growth rate of storage organs	MODELS,kgDMha ⁻¹ cr'	
		NCROP,ORVZA1	
		MODELS,kgDMha ⁻¹ cr'	
GST	Growth rate of stems	NCROP,ORVZA1	
		ORVZA1 kg DM ha ⁻¹	
GST1	Reduction in stem weight at transplanting	ORVZA1 kg DM ha ⁻¹ cr'	
GSTR	Growth rate of stem reserves	SGPC1,SGPCDT, SGPL	
GSW	Array of 3 weighting factors for Gaussian integration	SGPC1,SGPCDT, SGPL	
GSX	Array of 3 locations/points for Gaussian integration	PADDY	
		PADDY mm	
GWCHK	Check variable for presence of groundwater in soil	PADDY	
GWCU	layers Cumulative contribution of water flux to groundwater,since start of simulation	PADDY	
GWFILL	Water flux to "fill up" soil layer if in groundwater	ORVZA1	mmcr'
GWTOT	Total contribution of water flux from groundwater	BACKFL	mmcr'
GZRT	Growth rate of root length	SGPCDT, SSKYC ORVZA1,	md ⁻¹
HLP	Intennediate variable	PHENOL, SUBDD	mm
HOUR HU	Hour for which calculations should be done	ORVZA1, SUBLAI2 .Cd cr'	
	Daily heat unhs effective for phenological development	Many subroutines	h
		Many subroutines	.Cd cr'
		PADDY	
		SGPCDT	
		MODELS	
	Daily heat unhs effective for leaf area development	ET, MODELS, ORYZA 1, d	
HULV I	Counter	SASTRO, SGPC1, SGPCDT	
11	Counter	SGPC1,SGPCDT, SGPL	
12 IACC	Counter	GWTAB, PADDY	
IDATE	Switch to detennine the accuracy of assimilation calculations	ORVZA1	
IDOY	Return value of function DTFSECMF, indicating whether the day of simulation has reached the emergence day	ORVZA 1	
IGSN	Day number whhin year of simulation	NSOIL	
IGW	Parameter value for Gaussian integration	ORVZA1	
ILDRLV		ORVZA1	
ILEFFT	Number of shallowest soil layer in groundwater	ORVZA1	
ILFERT	Length of array DRLVT	ORVZA1	
ILFLVT	Length of array EFFTB	ORVZA1	
ILFSHT	Length of array FERTIL	ORVZA1	
ILFSOT	Length of array FLVTB	NCROP, NNOSTRESS	
ILFSTT	Length of array FSHTB	NCROP	
ILKDFT	Length of array FSOTB	NCROP	
ILKNFT	Length of array FSTTB	NCROP	
ILNFLV	Length of array KDFTB		
ILNMAX	Length of array KNFTB		
ILNMIN	Length of array NFLVTB		
ILNMNS	Length of array NMAXL T		
	Length of array NMINL T		
	Length of array NMINSOT		

Variable	Description	Used In subroutine	Units
ZRTMCW	Maximum root length/depth as crop characteristic without drought	ORVZA1	m
ZRTMS	Maximum depth that roots can penetrate into soil	MODELS, ORYZA1, PADDY	m
ZRTTR	Root length/depth at transplanting	ORVZA1	m
ZW	Depth of groundwater table below soil surface	GWTAB, PADDY	em
ZWPREV	Depth of groundwater table below soil surface of previous day	GWTAB	em
ZWA	Depth that groundwater table recedes in case of no recharge	PADDY	cm
ZWB	Sensitivity factor of recharge of groundwater table	PADDY	
ZWL	Difference between summed root depths of previous soil layers	GWTAB	cm
	(ZLL) and groundwater depth at previous day (ZWPREV)		
ZWPREV	Groundwater table depth of previous day	PADDY	em
ZWTB	Table with groundwater table depth as function of day number	PADDY	d,m
ZWTBI	Initial depth of groundwater table below soil surface	PADDY	cm
ZZA	Intermediate variable	SASTRO	
ZZCOS	Cosine of ZZA	SASTRO	
ZZSIN	Sine of ZZA	SASTRO	

Common blocks

COMMON_GWT.INC: Common block groundwater table parameters	PADDY
COMMON_NUCHT.INC: Common block van Genuchten parameters	PADDY
COMMON_HYDCON.INC: Common block hydrological parameters	PADDY
COMMON_POWER.INC: Common block power function parameters	PADDY
COMMON_SWIT.INC: Common block hydraulic conductivity	PADDY

Subroutines and functions

Name	Description	Called In subroutine
BACKFL	Subroutine to calculate backflow of water	PADDY PADDY
DOWNFL	Subroutine to calculate downflow of water	MODELS MODELS
DTFSECM	Function to determine crop emergence	ORYZA1,
P ET	Subroutine to calculate potential evaporation and transpiration	PADDY SGPL
GETOBS	Function to retrieve observed values from data file	
GPPARGE	Subroutine to calculate corrected assimilation rate at light saturation and initial light-use efficiency	ORVZA1 PADDY ORVZA1, PADDY MODELS
GPPARSET		
GWTAB	Subroutine to store variables in common block	ORVZA1, PADDY
INOBS	Subroutine to calculate the groundwater table depth	NNOSTRESS, ORVZA1,
IRRIG	Function to query for the presence of observed variables	PADDY NCROP, NSOIL
INSW	Subroutine to calculate daily irrigation amounts	ORVZA1, PADDY
INTGR2	Function to select variable value	NCROP, WSTRESS
INTGR	Function to do integration	Many subroutines ORVZA2000
LIMI	Function to do	
LINT	Integration	MODEL
MODEL	Function to limit variable value to minimum/maximum	
	Function for "near interpolation	
NCRO	Subroutine, interface between FSE subroutine and simulation models that make up the model ORVZA2000	
	Subroutine to calculate the N dynamics in crop and the nitrogen-stress factors	

Variable	Description	Used In subroutine	Units
WLOW	Array of amount of water, per soil layer	SHRINK	mm
WLST	Array of amount of water at saturation, per soil layer	BACKFL, PADDY, SHRINK	mm
WLSTRP	Array of water amount at saturation of ripened soil, per soil layer	SHRINK	mm
WLV	Dry weight of leaves	ORVZA1	kg ha ⁻¹
WLVD	Dry weight of dead leaves	ORVZA1	kg ha ⁻¹
WLVG	Dry weight of green leaves	MODELS, NCROP, kg ha ⁻¹ ORVZA1, SUBLAI2	
WLVGEXP	Value of WLVG at end of exponential growth phase after transplanting	SUBLAI2	kg ha ⁻¹
WLVGEXS	Value of WL VG at end of exponential growth phase in seedbed	SUBLAI2	kg ha ⁻¹
WLVGI	Initial dry weight of leaves	ORVZA1	kg ha ⁻¹
WLVGIT	Temporary storage variable of WL VG	ORVZA1	kg ha ⁻¹
WN	Average wind speed	ET, MODELS	ms ⁻¹
WRR	Dry weight of rough rice (final yield)	ORYZA1	kg ha ⁻¹
WRR14	Dry weight of rough rice (14% moisture)	ORVZA1	kg ha ⁻¹
WRT	Dry weight of roots	ORVZA1	kg ha ⁻¹
WRTI	Initial dry weight of roots	ORVZA1	kg ha ⁻¹
WSO	Dry weight of storage organs	MODELS	kg ha ⁻¹
WSOI	Initial dry weight of storage organs	NCROP, ORVZA1	
WST	Dry weight of stems	ORVZA1	kg ha ⁻¹
WSTAT	Status code from weather system	MODELS, NCROP, kg ha ⁻¹	
WSTI	Initial dry weight of stems	ORVZA1	kg ha ⁻¹
WSTR	Dry weight of stem reserves	ORVZA1	kg ha ⁻¹
WSTS	Dry weight of structural stems	ORVZA1	kg ha ⁻¹
WTRTER	Flag whether weather can be used by model	MODELS	
WUSED	Flag indicating which weather data are required in model	MODELS	
X	Intermediate variable for numerical integration	SGPC2	
X	Counter for number of days that the difference between simulated and imposed SLA is larger than TESTSET	SUBLAI2	d
XFERT	Net fertilizer N rate that can be taken up by crop	NSOIL	kg N ha ⁻¹ d ⁻¹
xGAI	Total leaf area index	GPPARGET	
xGAID	Leaf area Index above point of calculation	ha leaf ha ⁻¹ soil	
xAmaxIn	Uncorrected assimilation rate at light saturation	GPPARGET	kg CO ₂ ha ⁻¹ leaf h ⁻¹
xAmaxOut	Corrected assimilation rate at light saturation	GPPARGET	kg CO ₂ ha ⁻¹ leaf h ⁻¹
xEffIn	Uncorrected initial light-use efficiency	GPPARGET (kg CO ₂ ha ⁻¹ leaf h ⁻¹)(W m ⁻² leaf h ⁻¹)	
xEffOut	Corrected initial light-use efficiency	GPPARGET (kg CO ₂ ha ⁻¹ leaf h ⁻¹)(W m ⁻² leaf h ⁻¹)	
YEAR	Year of simulation	MODELS	y
ZL	Array of depth of top of soil layers, per soil layer	PADDY	cm
ZLL	Summed root depths of preceding soil layers	GWTAB, WSTRESS	m
ZRT	Root length or rooting depth	MODELS	m
ZRTI	Initial root length/depth at emergence	ORVZA1, WSTRESS	
ZRTL	Array of root length in a soil layer, per soil layer	ORVZA1	m
ZRTM	Maximum root length/depth	WSTRESS	m
ZRTMCD	Maximum root length/depth as crop characteristic under drought	ORVZA1	m

Variable	Description	Used In subroutine	Units
UPRICU	Cumulative capillary rise, since start of simulation	PADDY	
VGA	van Genuchten alpha parameter	PADDY	
VGL	van Genuchten lambda parameter	PADDY	
VGN	van Genuchten n parameter	PADDY	
VGR	van Genuchten residual water content	PADDY	
VL	Array of thickness of soil layers after shrinkage, per soil layer	PADDY, SHRINK	mm
VP WAG	Early morning vapor pressure	ET, MODELS	kPa
WAGT	Total aboveground green dry matter	ORVZA1	kg DM
WCAAD	Total aboveground dry matter	ORVZA1	ha-' kg
WCAD	Array of soil water content at air dryness, per soil layer	PADDY	DM ha-'
WCCR	Array of soil water content at air dryness, per soil layer	MODELS, PADDY	m3 m-3
WCFC	Critical water content at which cracks break through soil layer	PADDY	m3 m-3
WCL	Array of soil water content at field capacity, per soil layer	MODELS, PADDY	m3 m-3
WCLI	Array of actual soil water content, per soil layer	PADDY, SHRINK	m3m-3
WCLINT	Array of initial water content of soil layer	PADDY	m3m-3
WCLQT	Interpolation table for water content of soil layers	PADDY	m3m-3
	Array of actual soil water content, per soil layer	ET, IRRIG, MODELS, WSTRESS	m3 m-3
WCMIN	Minimum soil water content in soil layer SLMIN at which to apply Irrigation	IRRIG	m3 m-3
WCST	Array of soil water content at saturation, per soil layer	ET, MODELS, PADDY, SHRINK, WSTRESS	m3m-3
WCSTRP	Array of saturated water content of ripened soil, per soil layer	PADDY, SHRINK	m3 m-3
WCUM	Amount of stored water in soil profile	3	mm
WCUMCH	Rate of change in amount of stored soil water	PADDY	mm cr'
WCUMCO	Contribution of soil storage term to overall water balance	PADDY	mm
WCUMI	Initial amount of stored water in soil profile	PADDY	mm
WCWP	Array of soil water content at wilting point, per soil layer	PADDY, MODELS, PADDY, WSTRESS	m3 m-3
WGR	Maximum individual grain weight	ORYZA1	kg grain-'
MX WL	Array of amount of water, per soil layer	BACKFL, DOWNFL, PADDY, SHRINK, WSTRESS	mm
WLA	Array of total amount of water that can be extracted by roots in each soil layer	ET, IRRIG, MODELS, PADDY	mm
WLO	Depth of ponded water at soil surface	PADDY	mm
WLOCH	Rate of change of depth of ponded water	PADDY	mm d'''
WLOCNT	Number of days after disappearance of ponded water	IRRIG	d
WLOCO	Contribution of surface storage term (ponded water) to overall water balance	PADDY	mm
WLODAY	Number of days after disappearance of ponded water at which to apply irrigation	IRRIG	d
WLOFCU	Cumulative amount of water stored at surface caused by groundwater	PADDY	mm
WLOFILL	Rate of change in ponded water depth when groundwater is at soil surface	PADDY	mm d'''
WLOI	Initial depth of ponded water	PADDY mm IRRIG mm	
WLOMIN	Minimum ponded water depth at which to apply irrigation	PADDY mm PADDY	
WLOMX	Maximum depth of ponded water (= bund height)	mm	
WLAD	Array of amount of water at air dryness, per soil layer	PADDY	mm cr'
WLCH	Array of change in amount of water, per soil layer	PADDY, DOWNFL	mm
WLFC	Array of amount of water at field capacity, per soil layer	GWTAB, PADDY	mm cr'
WLFL	Array of water flux at boundaries of soil layer, per soil layer		

Variable	Description	Used in subroutine	Units
TFERT	Average daily maximum temperature during flowering	SUBGRN	.C
TIME	time of simulation	Many subroutines	d
TINCR	Temperature increase because of leaf rolling	SUBGRN	.C
TINY	Parameter with very small value (to avoid division by 0)	PADDY, WSTRESS	
TKL	Array of thickness of soil layers, per soil layer	GWTAB, MODELS, PADDY, SHRINK, WSTRESS	m
TKLP	Array of thickness of puddled soil layers, per layer	PADDY	m
TKLT	Thickness of combined soil layers	MODELS, ORVZA1, PADDY	m
TM	Mean daily temperature	SUBDD	.C
TMAX	Daily maximum temperature	ORVZA1, SUBDD, SUBGRN	.C
TMCTB	Table for temperature increase (e.g., as climate change study)	ORVZA 1	d, .C
TMD	Maximum temperature for development	ORVZA1, SUBDD	.C
TMDA	Average daily temperature	ET, MODELS	.C
TMIN	Daily minimum temperature	ORVZA 1, SUBDD	.C
TMMN	Daily minimum temperature	MODELS, ORVZA1	.C
TMMX	Daily maximum temperature	MODELS, ORVZA1	.C
TMPCOV	Temperature increase caused by greenhouse use (over seedbed)	ORVZA 1	.C
TMPR1	Intermediate variable	SGPL, SRDPRF, SSKYC	
TMPSB	Temperature increase caused by greenhouse use (over seedbed)	ORVZA 1	.C
TNASS	Total net Co, assimilation	ORVZA1	kg C02 ha-'
TNM	Intermediate variable for numerical integration	SGPC2	
TNSOIL	Daily amount of N available for uptake from soil	MODELS, NCROP	kg N ha-1 d-'
TOD	Optimum temperature for development	ORVZA1, SUBDD	.C
TOTPOR	Array of total porosity, per soil layer	PADDY, SHRINK	m3m-3
TRC	Potential transpiration rate of crop with given LAI	ET, MODELS, WSTRESS	mmcr'
TREF	Reference temperature	ORVZA1	.C
TRR	Array of relative transpiration ratios, per soil layer	WSTRESS	mmcr'
TRRM	Potential transpiration rate of crop with given LAI, per unit root length	WSTRESS	mmcr'm-'
TRW	Actual transpiration rate of crop with given LAI	MODELS, PADDY, WNOSTRESS, WSTRESS	mm cr'
TRWC	Cumulative actual transpiration, from main field	PADDY	mm
TRWCU	Cumulative actual transpiration since start of simulation	MODELS, PADDY	mm
TRWL	Array of actual water withdrawal by transpiration, per soil layer	BACKFL, DOWNFL, MODELS, PADDY, WNOSTRESS, WSTRESS	mmcr'
TS	Temperature sum for phenological development	ORVZA1, PHENOL	.Cd
TSHCKD	Transplanting shock for phenological development	ORVZA1, PHENOL	.Cd
TSHCKL	Transplanting shock for leaf area development	ORVZA1, SUBLAI2	.Cd
TSLV	Temperature sum for leaf area development	ORVZA1, SUBLAI2	.Cd
TSL VTR	Temperature sum for leaf area development at transplanting	SUBLAI2	.Cd
TSTR	Temperature sum for phenological development at transplanting	PHENOL	.Cd
TT	Daily increment in heat units	SUBDD	.Cd cr'
ULDL	Upper limit of drought-induced dead leaves	WSTRESS	pF
ULLE	Upper limit of leaf expansion	WSTRESS	pF
ULLS	Upper limit of leaf rolling	WSTRESS	pF
ULRT	Upper limit of relative transpiration	WSTRESS	pF

Variable	Description	Used In subroutine	Units
SHCKL	Delay parameter in development	ORVZA1, SUBLAF2	'Cd ('Cdt'
SINB	Sine of solar height	SGPC1, SGPC2, SGPCDT, SGPL, SRDPRF, SSKYC SASTRO,	
SINLD	Intermediate variable in calculating solar declination	SGPCDT, SSKYC ORVZA1, ha leaf kg ⁻¹ leaf SUBLAI2	ha leaf kg ⁻¹ leaf
SLA	Specific leaf area	ORVZA1	-, ha leaf
SLAMAX	Maximum value of specific leaf area	ORVZA1	kg ⁻¹ leaf
SLATB	Table of SLA as function of DVS		
SLMIN	Number of soil layer that serves as determinant for irrigation application	IRRIG	
SOILSP	Nitrogen mineralization rate	NSOIL	kg N ha ⁻¹ d ⁻¹
SOLCON	Solar constant at day = IDOY	SASTRO,	W m ⁻²
SOLHM	Hour of day at which solar height is maximum	SGPCDT, SSKYC SSKYC	h
SPFERT	Spikelet fertility factor	ORVZA1, SUBGRN	no. kg ⁻¹
SPGF	Spikelet growth factor	ORVZA1	ha stem kg-I stem
SSGA	Specific green stem area	ORVZA1	
SSGA	Table of SSGA as function of DVS	MODELS	
TB	Start day of simulation	SGPC2	d
STTIME	Intermediate variable for numerical integration	SGPC2	
SUM1	Intermediate variable for numerical integration	PADDY	
SUM2	Contribution of stored surface water to water flux	WSTRESS	
SURREL	Switch to select calculation mode for relative transpiration ratio	ORVZA1	
SWIRTR	Switch to select method of imposed	GWTAB, PADDY	
SWISLA	SLA calculation	IRRIG	
SWITGW	Groundwater switch	PADDY	
SWITIR	Switch defining method of irrigation application	PADDY	
SWITIR	Hydraulic conductivity switch	PADDY	
SWITKH	Puddled/nonpuddled soil switch	PADDY	
SWITPD	Water retention curve switch	PADDY	
SWITPF	Switch for calculation of percolation rate	MODELS	
SWITVP	Year of simulation (switch into real number)	ORVZA1, SUBCD,	y 'C
SWR	Average daily temperature	SUBGRN	
TAV	Average daytime temperature	ORVZA1	
TAVD	Base temperature for development	ORVZA1, SUBDD	'C
TBD	Base temperature for juvenile leaf area growth	ORVZA1	'C
TBLV	Time coefficient for loss of stem reserves	ORVZA1	'C
TCLSTR	Time coefficient for N translocation to grains	NCROP	d'
TCNTRF	Temperature increase (e.g., as used in climate change study)	ORVZA1	d
TCOR TO	Hourly temperature	SUBDD	'C
TDRW	Total aboveground and belowground dry biomass	ORVZA1	'C kg
TEFF	Factor accounting for effect of temperature on respiration	ORVZA1	ha-'
TERMNL	Flag to indicate if simulation is to stop	MODELS, NCROP,	
TEST	Difference between simulated and user-supplied SLA	ORVZA1, SUCBC	
TESTL	Logical variable to indicate whether the difference between simulated and imposed SLA is smaller than	SUBLAF2	ha leaf kg ⁻¹ leaf
TESTSET	TESTSET Maximum difference between simulated and user-supplied SLA	SUBLAI2	
		SUBLAI2	ha leaf kg ⁻¹ leaf

Variable	Description	Used In subroutine	Units
RDD	Daily short-wave radiation	ET, MODELS, ORYZA1, SGPCDT, SSKYC	J m ⁻² d ⁻¹
RDPDF	Flux of diffuse radiation at particular time of day	SGPCDT	W m ⁻²
RDPDF	Instantaneous flux of diffuse photosynthetically active radiation	SGPC1, SGPC2, SGPL, SRDPRF, SSKYC	W m ⁻²
RECNIT	Instantaneous flux of direct photosynthetically active radiation	SGPC1, SGPC2, SGPCDT, SGPL, SRDPRF, SSKYC	W m ⁻²
RECOV	Table of N recovery fraction (RECOV) vs. development stage	(DVS) NSOIL	
REDFT	Recovery fraction of fertilizer N in the soil	NSOIL	
REDFT	Factor accounting for effect of temperature on AMAX	ORYZA 1	
REDFT	Table of REDFT as function of temperature	ORYZA 1	.C,
T REST	Rest of water component in top soil layer calculated by subroutine BACKFL	PADDY	mm
RF RFLH	Surface reflection coefficient	ET SRDPRF	kg N kg ⁻¹
RFLS	Reflection coefficient of crop with horizontal leaf angle distribution	SRDPRF	DM kg N
RFNLV	Reflection coefficient of crop with spherical leaf angle distribution	NCROP	kg ⁻¹ DM
RFNST	Residual N fraction of leaves	NCROP ET	
RFS	Residual N fraction of stems	ORYZA1	kg CO. ha ⁻¹ d ⁻¹
RGCR	Surface reflection coefficient	ORYZA1, SUBLAI2	.cer'
RGRL	Growth respiration rate of crop	ORYZA1, SUBLAI2	.cer'
RGRLMN	Relative growth rate for leaf development	ORYZA1, SUBLAI2	.cer'
RGRLMX	Maximum value of relative growth rate of leaf area	IRRIG	d, mm
RIRRI	Minimum value of relative growth rate of leaf area	PADDY	
RIWCLI	Table of irrigation water application, as function of day number	ORYZA1	kg CH.o ha ⁻¹ er'
RMCR	Switch to indicate resetting of ponded water depth at transplanting	PADDY	
RNOFCU	Maintenance respiration rate of crop	MODELS, NCROP, NNOSTRESS, ORYZA 1, SUBLAI2	mm
RNSTRS	Cumulative runoff, since start of simulation	ORYZA1	kg CO. ha ⁻¹ er'
RTNASS	Reduction factor on relative leaf growth rate caused by N stress	MODELS	
RUN		PADDY	
MODE	Net rate of total CO. assimilation by crop	PADDY	mmd ⁻¹
RUNOF	Name of mode in which ORYZA2000 is run	PADDY	mm
RUNOFC	Runoff rate		
RWCLI	Cumulative runoff, from main field	ORYZA 1,	kg ha ⁻¹ d ⁻¹
RWLVG	Logical switch to indicate resetting or not of ponded water depth at transplanting	SUBLAI2	
RWLVG1	Growth rate of green leaves	ORYZA1	kg ha ⁻¹
RWSTR	Reduction in leaf weight at transplanting	ORVZA1	kg ha ⁻¹ er'
RWSTR1	Net growth rate of stem reserves	ORYZA1	kg ha ⁻¹
SAI SBDUR	Reduction in stem reserve weight at transplanting	ORYZA1	ha leaf ha ⁻¹
SCODE	Stem area index	MODELS	soil
SCP	Duration of seedbed	PADDY	d
SF1	Name of soil-water balance model	ORYZA1	
SF2	Scattering coefficient of leaves for photosynthetically active radiation	ORYZA1, SUBGRN	
SHCK	Spikelet sterility factor because of low temperatures	ORYZA1, SUBGRN	
D	Spikelet fertility factor because of high temperatures	ORYZA1,	.Cd (.Cd'
	Delay parameter in phenology		

Variable	Description	Used In subroutine	Units
NTSO	Actual N translocation rate to storage organs from leaves, stems, and roots	NCROP	kg N ha ⁻¹ d ⁻¹
NTST	Actual N translocation rate to storage organs from stems	NCROP	kg N ha ⁻¹ d ⁻¹
OUTPUT	Flag to indicate if output should be done	Many subroutines	
PARCM1	Cumulative amount of radiation absorbed by canopy based on simple calculation of daily absorbed radiation	ORVZA1	MJ m ⁻²
PARCUM	Cumulative amount of radiation absorbed by canopy based on detailed calculation of daily absorbed radiation	ORVZA1	
PARI1	Amount of photosynthetically active radiation absorbed on a day b y canopy	ORVZA1	MJ m ⁻² d ⁻¹
PCEW	Effect of drought stress on daily total gross CO ₂ assimilation of crop; reduction in potential transpiration rate	MODELS, ORVZA1, WNOSTRESS, WSTRESS	
PERC	Actual percolation rate	PADDY	
PERCC	Cumulative percolation, from main field	PADDY	mm
PERCOL	Constant percolation rate	PADDY	mm d ⁻¹
PERTB	Table of constant percolation rate as function of groundwater table depth	PADDY	cm, mm d ⁻¹
PFGR	Critical soil-water tension at which cracks break through soil layer	PADDY	pF
PI	Ratio of circumference to diameter of circle	SASTRO	
PLTR	Intermediate variable for change in plant density at transplanting	MODELS, NCROP, ORVZA 1	
PN	Parameter n in power function for hydraulic conductivity	PADDY	
PPFAC	Factor determining photoperiod sensitivity	PHENOL	
PPSE	Photoperiod sensitivity	ORVZA1, PHENOL h ⁻¹	
PRODENV	Name of production environment with respect to water	MODELS	
PROREL	Contribution of profile storage to water balance	PADDY	mm d ⁻¹
PUDDLD	Logical switch indicating if profile is puddled/nonpuddled	PADDY	
PWRR	Potential weight of rough rice	ORVZA1	kg ha ⁻¹
Q10	Factor accounting for increase in maintenance respiration with a 10 °C rise in temperature	ORVZA 1	
RAIN	Daily amount of rainfall	MODELS, PADDY	mm d ⁻¹
RAINC	Cumulative rainfall, on main field	PADDY	mm
RAINCUM	Cumulative amount of rainfall since start of simulation	MODELS, PADDY	mm
RAPC	Instantaneous absorbed photosynthetically active radiation	SGPC1,	W m ⁻² leaf
RAPCDT	Daily rate of absorbed photosynthetically active radiation	SGPCDT, ORVZA 1, SGPCDT	
RAPCO	Intermediate variable for numerical integration	SGPC2	
RAPCT	Intermediate variable for numerical integration	SGPC2	
RAPCTO	Intermediate variable for numerical integration	SGPC2	
RAPDDL	Absorbed flux of direct component of direct radiation	SRDPRF	W m ⁻²
RAPDFL	Absorbed flux of diffuse radiation	SRDPRF	leaf W m ⁻²
RAPL RAPI	Absorbed photosynthetically active radiation in canopy	SGPC1	2 leaf W
RAPL 1	Absorbed radiation at depth GAl	SGPL	m ⁻² soil
RAPL2	Intermediate variable for numerical integration	SGPC2	W m ⁻²
RAPPL	Intermediate variable for numerical integration	SGPC2	leaf
	Direct flux absorbed by leaves perpendicular on direct beam	SGPL, SRDPRF	W m ⁻² leaf
		SGPL, SRDPRF	W m ⁻² leaf
RAPSHL	Absorbed flux for shaded leaves	SGPL	W m ⁻² leaf
RAPSL	Total absorbed radiation	SRDPRF	W m ⁻² leaf
RAPTDL	Absorbed flux of total direct radiation	ORVZA 1	d ⁻¹
RDAE	Rate to calculate days after emergence		

Variable	Description	Used In subroutine	Units
NDEMSX	Potential daily N demand by storage organs	NCROP	kg N ha ⁻¹ d ⁻¹
NFEEnTP	Total fertilizer N pool in soli	NSOIL	kg N ha ⁻¹
NFLV	Nttrogen fraction in leaves on leaf area basis	MODELS, NCROP, NNOSTRESS, ORVZA 1	g N m ⁻² leaf
NFLV1	Intermediate value for NFL V	NNOSTRESS	g N m ⁻² leaf
NFLV1	Inttial nttrogen fraction in leaves on leaf area basis	NCROP, NNOSTRESS	g N m ⁻² leaf
NFLVTB	Table of NFLV as function of development stage	NNOSTRESS	- g N m ⁻² leaf
NFLVP	Maximum (potentiaQ N fraction in leaves on leaf area basis	NCROP	g N m ⁻² leaf
NFLVTB	Table of NFL V as function of development stage (DVS)	NCROP	-, g N m ⁻² leaf
NGCR	Net growth rate of crop, including translocation	ORVZA1	kg ha ⁻¹ ct'
NGR	Number of grains	ORVZA1	no ha ⁻¹
NGRM2	Number of grains	ORYZA1	no m ⁻²
NH	Number of hills	ORYZA1, SUBLAI2	hills m ⁻²
NITROENV	Name of production environment with respect to nttrogen	MODELS	
NL	Number of soil layers	ET, GWTAB, IRRIG, MODELS, PADDY, WNOSTRESS, WSTRESS	
NLDLV	N loss rate because of death of leaves	NCROP	kg N ha ⁻¹ d ⁻¹
NLPUD	Number of puddled soU layers including plow sole	PADDY	
NLV	Daily net flow rate of N to the leaves	NCROP	kg N ha ⁻¹ ct'
NLVAN	Daily net flow rate of N to the leaves before flowering	NCROP	kg N ha ⁻¹ ct'
NLXM	Maximum number of soil layers	MODELS	
NMAX	Intermediate variable for numerical integration	SGPC2	
NMAXL	Maximum N fraction in leaves on weight basis	NCROP	kg N kg ⁻¹ DM
NMAXLT	Relationship between NMAXL and DVS (table)	NCROP	-, kg N kg ⁻¹ DM
NMAXSO	Maximum N fraction in storage organs	NCROP	kg N kg ⁻¹ DM
NMINL	Minimum N fraction in leaves on weight basis	NCROP	kg N kg ⁻¹ DM
NMINL T	Table of NMINL as function of development stage (DVS)	NCROP	-, kg N kg ⁻¹ DM
NMINSO	Minimum N fraction in storage organs	NCROP	kg N kg ⁻¹ DM
NMINSO T	Table of NMINSO as function of ANCRF	NCROP	kg N ha ⁻¹ , kg N kg ⁻¹ DM
NPLDS	Number of plants direct-seeded in main field	ORVZA1	pi m-2
NPLH	Number of plants per hill	ORVZA1, SUBLAI2	pi hilt'
NPLSB	Number of plants in seedbed	ORVZA 1, SUBLAI2	pi m-2
NSHKLV	Correction for leaf-N loss because of transplanting	NCROP	
NSHKST	Correction for stem-N loss because of transplanting	NCROP	
NSLLV	N stress tactor that accelerates leaf death	MODELS, NCROP, ORVZA1, NNOSTRESS	
NSLLVT	Table of NSLLV as function of NSTRES	NCROP	,
NSO	Net flow rate of N to storage organs	NCROP	kg N ha ⁻¹ ct'
NSP	Number of spikelets	ORVZA1, SUBGRN	no. ha ⁻¹
NSPM2	Number of spikelets	ORVZA 1	no. m-2
NST	Net flow rate of N to stems	NCROP	kg N ha ⁻¹ d ⁻¹
NSTAN	Net flow rate of N to stems before flowering	NCROP	kg N ha ⁻¹ ct'
NSTRES	Ratio of maximum over actual amount of N in crop	NCROP	
NTFERT	Number of days of flowering period	SUBGN	d
NTLV	Actual N translocation rate to storage organs from leaves	NCROP	kg N ha ⁻¹ ct'
NTRT	Actual N translocation rate to storage organs from roots	NCROP	kg N ha ⁻¹ ct'
NTRTS	Amount of N translocated from roots to storage organs	NCROP	kg N ha ⁻¹

Variable	Description	Used In subroutine	Units
LE	Array of drought stress factors reducing leaf expansion, per soil layer	WSTRESS	
LEAV	Drought stress factor reducing leaf expansion, mean over all soil layers	WSTRESS	
LESTRS	Drought stress factor reducing leaf expansion	MODELS, ORYZA1, SUBLAI2, WNSTRESS, WSTRESS	
LLD	Lower limit of drought-induced dead leaves	WSTRESS	pF
L	Lower limit of leaf expansion	WSTRESS	pF
LLL	Lower limit of leaf rolling	WSTRESS	pF
E	Lower limit of relative transpiration	WSTRESS	pF
LLLS	Loss rate of leaf weight	MODELS, kg DM ha ⁻¹ d ⁻¹	
LRR	Array of drought stress factors causing leaf rolling, per soil layer	NCROP, ORVZA1	
LRAV	Drought stress factor causing leaf rolling, mean over all soil layers	WSTRESS	
LRSTR	Fraction of allocated stem reserves that is available for growth	ORVZA1	
LRSTRS	Drought stress factor causing leaf rolling	MODELS, ORYZA1, SUBGRN, WSTRESS, WNSTRESS	
LSTR	Loss rate of stem reserves	ORYZA1	kg DM ha ⁻¹ d ⁻¹
MAINL	Maintenance respiration coefficient of leaves	ORYZA1	kg CH ₂ O kg ⁻¹ DM d ⁻¹
MAINRT	Maintenance respiration coefficient of roots	ORYZA1	kg CH ₂ O kg ⁻¹ DM d ⁻¹
MAINSO	Maintenance respiration coefficient of storage organs	ORYZA1	kg CH ₂ O kg ⁻¹ DM d ⁻¹
MAINST	Maintenance respiration coefficient of stems	ORYZA1	kg CH ₂ O kg ⁻¹ DM d ⁻¹
MAXGW	Maximum groundwater table depth	PADDY	cm
MINGW	Minimum groundwater table depth	PADDY	d ⁻¹
MNDVS	Factor accounting for effect of DVS on maintenance respiration	ORYZA1	cm
MNL	Maximum array length (of various array variables)	PADDY	
MOPP	Maximum optimum photoperiod	ORYZA1, PHENOL	h
MS	Maximum optimum photoperiod	PADDY	cm H ₂ O
MSKPA	Array of soil-water tension (suction), per soil layer	IRRIG, MODELS, PADDY, WSTRESS	kPa
MSUCN	Array of soil-water tension (suction), per soil layer	PADDY	cm H ₂ O
NACR	Counter	SGPC2	
	Actual nitrogen uptake rate by crop	MODELS, kg N ha ⁻¹ d ⁻¹	
		NCROP, NSOIL	
NACRS	Cumulative amount of nitrogen taken up by crop	NCROP	kg N ha ⁻¹
NALV	Actual nitrogen uptake rate by leaves	NCROP	kg N ha ⁻¹ d ⁻¹
NALVS	Cumulative amount of nitrogen taken up by leaves	NCROP	kg N ha ⁻¹
NASO	Actual nitrogen uptake rate by storage organs	NCROP	kg N ha ⁻¹ d ⁻¹
NASOS	Cumulative amount of nitrogen taken up by storage organs	NCROP	kg N ha ⁻¹
NAST	Actual nitrogen uptake rate by stems	NCROP	kg N ha ⁻¹ d ⁻¹
NASTS	Cumulative amount of nitrogen taken up by stems	NCROP	kg N ha ⁻¹
NBCHK	Balance of nitrogen balance check	NCROP	kg N ha ⁻¹
NCHCK	Balance of nitrogen uptake	NCROP	kg N ha ⁻¹
NCOLD	Number of cold days	ORYZA1, SUBCD	d
NDEMC	Potential daily N demand by crop	NCROP	kg N ha ⁻¹ d ⁻¹
NDEML	Potential daily N demand by leaves	NCROP	kg N ha ⁻¹ d ⁻¹
NDEMS	Potential daily N demand by stems	NCROP	kg N ha ⁻¹ d ⁻¹
NDEMSN	Minimum daily N demand by storage organs	NCROP	kg N ha ⁻¹ d ⁻¹

Variable	Description	Used In subroutine	Units
ILPMAX	Maximum array length of PERTB	PADDY	
ILREC	Length of array RECNT	NSOIL	
ILREDF	Length of array REDFTT	ORYZA1	
ILSLAT	Length of array SLATB	ORYZA1	
ILSSGA	Length of array SSGATB	ORYZA1	
ILmCT	Length of array TMCTB	ORVZA1	
IMX	Maximum length of array (of a number of array variables)	NCROP,ORVZA1	
IMX	Maximum length of array NFLB	NNOSTRESS	
INL	Counter	WSTRESS	
INSLLV	Length of array NSLL VT	NCROP	
INX	Maximum length of arrays (a number of variables)	NSOIL	
IPERTB	Length of array PERTB	PADDY	
IR	Amount of daily irrigation	IRRIG, MODELS, PADDY	mmd-'
IRC	Cumulative amount of irrigation water applied in main field	IRRIG	mm
IRCU	Cumulative amount of irrigation, since start of simulation	PADDY	mm
IRIRR	Number of days of irrigation application	IRRIG	d
IRRI	Amount of daily irrigation	IRRIG	mma'
ISURF	Swrch parameter to choose between surface types	ET	
IT	Counter for numerical integration	SGPC2	
IT ASK	Task that subroutine should perform	Most subroutines	
IUNITD	Unn number that can be used for input files	Most subroutines	
IUNITL	Unn number for log file messages	Most subroutines	
IUNITO	Unn number that is used for output file	MOD ELS	
IYEAR	Year of simulation	MOD ELS	y
J	Counter	SGPC2, PADDY, WSTRESS	
K	Counter	PADDY	
KDF	Extinction coefficient for leaves	ORYZA1	
KDFTB	Table of KDF as function of development stage (DVS)	ORVZA1	
KEEP	Variable to temporarily store value of LDSTRS	ORYZA1	
KNF	Extinction coefficient of nnrogn profile in canopy	ORYZA1	
KNFTB	Table of KNF as function of development stage (DVS)	ORYZA1	
KPAMIN	Minimum soil-water tension in soil layer SLMIN at which to apply irrigation	IRRIG	kPa
KSAT	Array of saturated hydraulic conductivity, per soil layer	DOWNFL, PADDY	cm d ⁻¹
KST	Array of saturated hydraulic conductivity, per soil layer	PADDY	cmd-'
LAI	Leaf area index	ET, MODELS, NCROP, ORYZA1, SUBLAI2	ha leaf ha ⁻¹ soil
LAIEXP	Value of LAI at end of exponential growth phase after transplanting	SUBLAI2	ha leaf ha ⁻¹ , soil
LAIEXS	Value of LAI at end of exponential growth phase in seedbed	SUBLAI2	ha leaf ha ⁻¹ soil
LAIROL	Rolled leaf area index caused by drought	MODELS, ha leaf ha ⁻¹ soil	
LAPE	Leaf area per plant at emergence	ORYZA1	m ² pr'
LAT	Latnude of weather station	ET, MODELS, ORYZA1, SASTRO, SGPCDT	dec. degr.
LD	Array of drought factors accelerating leaf death, per soil layer	WSTRESS	
LDIV	Drought factor accelerating leaf death, mean over all soil layers	WSTRESS	
LDSTRS	Drought stress factor accelerating leaf death	MODELS,ORYZA1, WNOSTRESS, WSTRESS	

Name	Description	Called In subroutine
NNOSTRESS	Subroutine to set nitrogen-stress factors under conditions of potential production	MODELS
NOTNUL	Function to avoid division by 0	ORYZA1, NCROP, WSTRESS
NSOIL	Subroutine to calculate the N supply from soil	MODELS
ORYZA 1	Crop growth module of ORYZA2000 model	MODELS
PADDY	Subroutine to calculate the soil water content and soil-water tension (soil-water balance)	MODELS
PHENOL	Subroutine to determine phenology of crop	ORYZA1
SASTRO	Subroutine to compute solar constant, daylength, and extraterrestrial radiation	SGPCDT, SETPTD
SATFLX	Subroutine to calculate percolation rate	PADDY
SETMKD	Subroutine to calculate Makkink evapotranspiration	ET
SETPMD	Subroutine to calculate Penman evapotranspiration	ET
SETPTD	Subroutine to calculate Priestley-Taylor evapotranspiration	ET
SGPC1	Subroutine to compute instantaneous canopy CO ₂ assimilation and instantaneous absorbed photosynthetically active radiation	SGPCDT
SGPC2	Subroutine to compute instantaneous canopy CO ₂ assimilation and instantaneous absorbed photosynthetically active radiation	SGPCDT
SGPCDT	Subroutine to calculate daily total gross assimilation	ORYZA 1
SGPL	Subroutine to calculate assimilation at a single depth in canopy	SGPC2,
SHRINK	Subroutine to calculate shrinkage of puddled soil	PADDY
SRDPRF	Subroutine to calculate absorbed flux of radiation for shaded leaves, direct flux absorbed by leaves, and fraction of sunlit leaf area	SGPL
SSKYC	Subroutine to estimate solar inclination and fluxes of diffuse and direct radiation at a particular time of day	SGPCDT
SUBCBC	Subroutine for carbon balance check	ORYZA1
SUBCD	Subroutine to calculate number of cold days	ORYZA1
SUBDD	Subroutine to calculate daily amounts of heat units	ORYZA1
SUBGRN	Subroutine to calculate grain growth rate and grain formation rate	ORYZA1
SUBLAI2	Subroutine to calculate leaf area index	NCROP
SUBNBC	Subroutine for nitrogen balance check	PADDY
SUBSL2	Subroutine to calculate capillary rise	PADDY
SUERR	Subroutine to check if a variable falls within a specified domain	PADDY
SUWCHK	Subroutine to check soil-water balance	PADDY
SUWCMS2	Subroutine to calculate Soil water content from soil-water tension	PADDY
WNOSTRESS	Subroutine to set actual transpiration and drought-stress factors under potential production situations	MODELS
WSTRESS	Subroutine to calculate actual crop transpiration and drought-stress factors	MODELS

The variables of the following subroutines are not included in the variable list, and readers are referred to the indicated references for explanation of the subroutines:

FSE: van Kraalingen (1995)

SA TFLX: Wopereis et al (1996a)

SETPTD, SETPMD, SETMKD, SVPS1: van Kraalingen and Stol (1997)

SUBSL2, SUERR, SUMSKM2, SUWCHK, SUWCMS2: Penning de Vries et al (1989) and ten Berge et al (1992)

Fig. 3. Plant height as influenced by drip fertigation treatments in PMK (R) 3 rice under aerobic condition

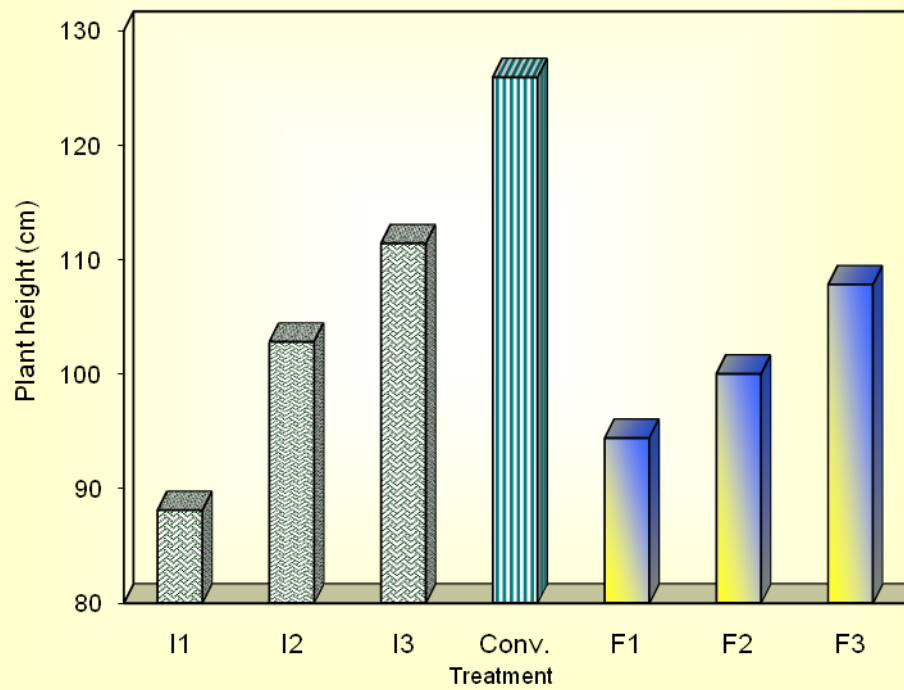


Fig. 5. Root volume as influenced by drip fertigation treatments in PMK (R) 3 rice under aerobic condition

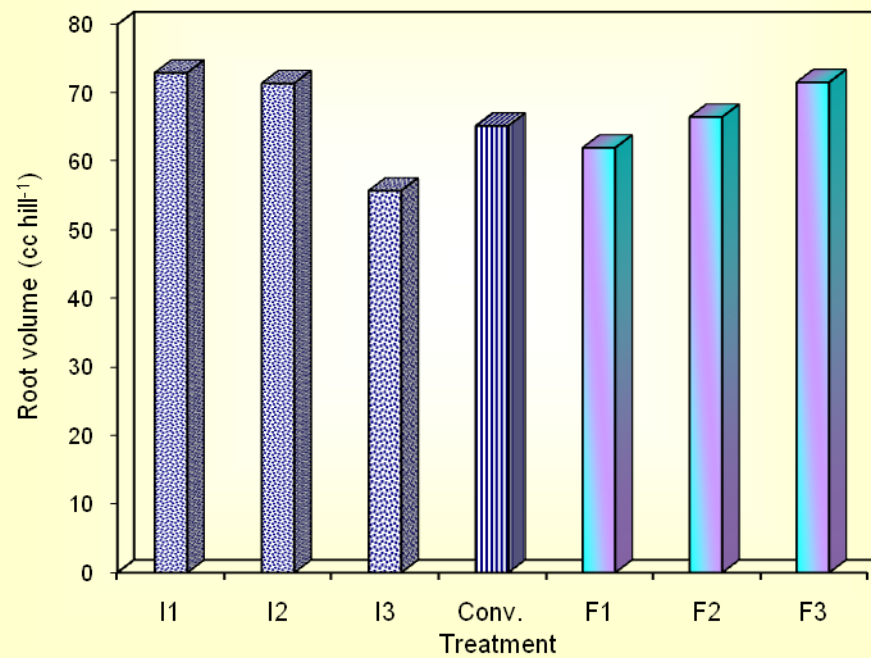


Fig. 7. Percentage of 'Lion Tail Roots' as influenced by drip fertigation treatments in PMK (R) 3 rice under aerobic condition

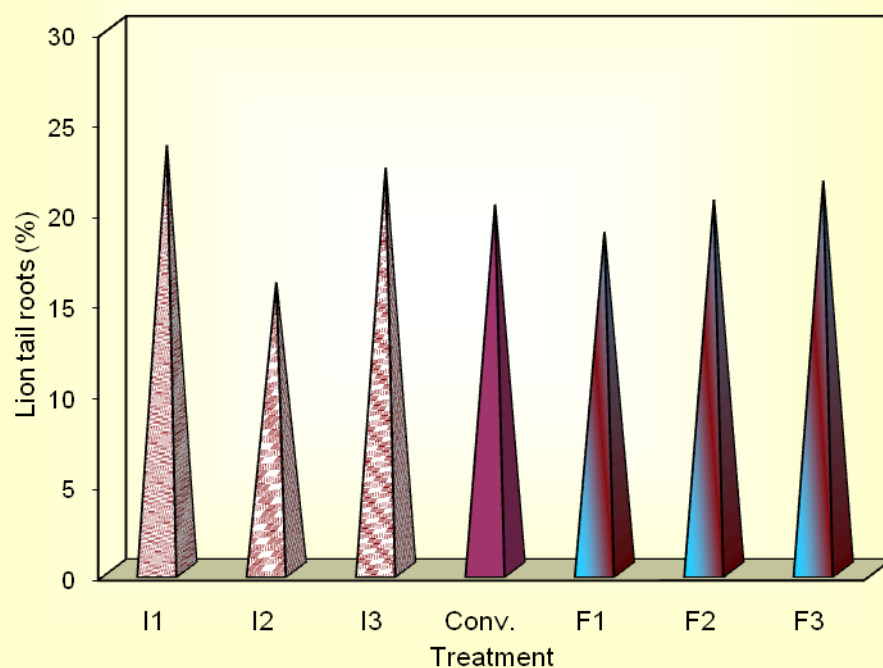


Fig. 9. Leaf Area Index (LAI) as influenced by drip fertigation treatments in PMK (R) 3 rice under aerobic condition



Fig. 8. Tiller density as influenced by drip fertigation treatments in PMK (R) 3 rice under aerobic condition

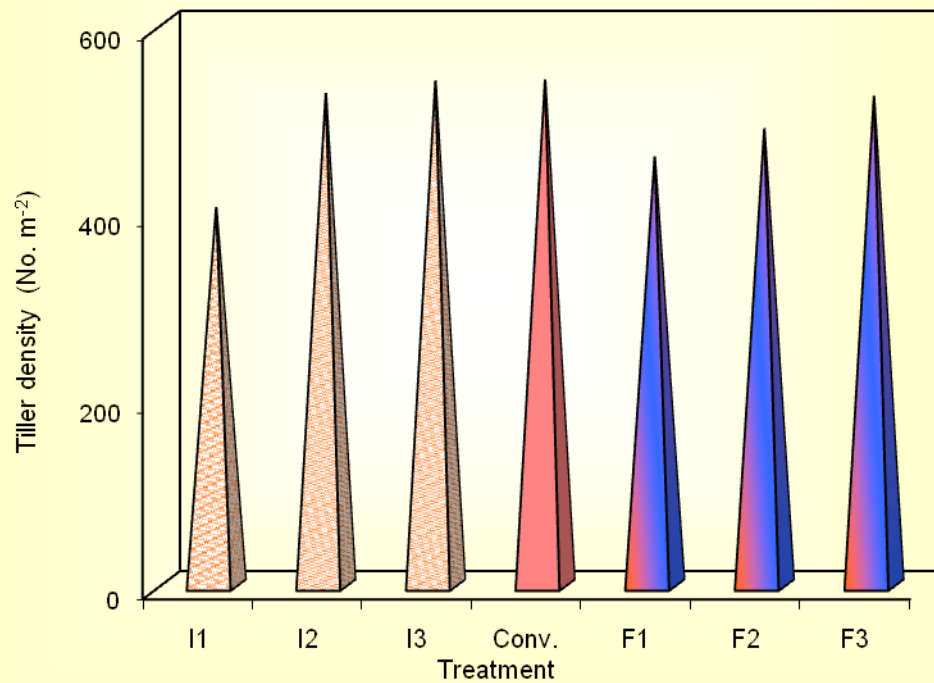


Fig. 4. Total root length as influenced by drip fertigation treatments in PMK (R) 3 rice under aerobic condition

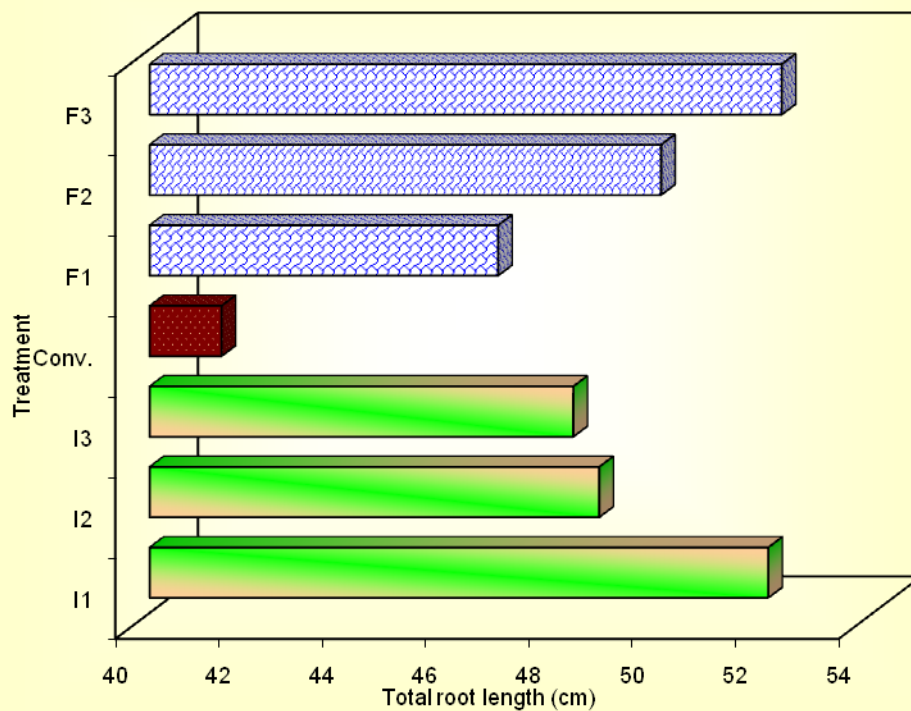


Fig. 6. Root Length Depth Index (RLDI) and Root Mass Depth Index (RMDI) as influenced by drip fertigation treatments in PMK (R) 3 rice under aerobic condition

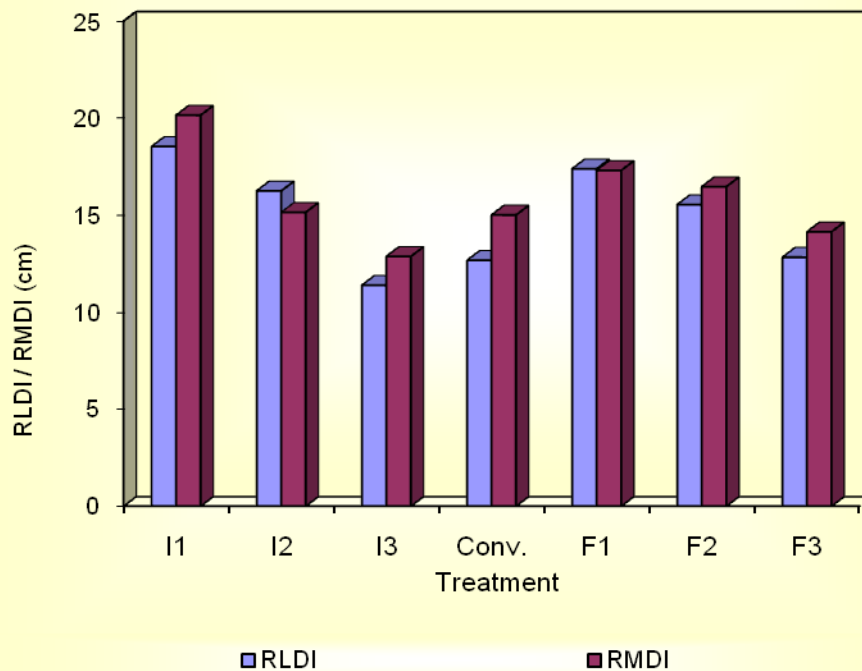


Fig. 10. TDMA as influenced by drip fertigation treatments in PMK (R) 3 rice under aerobic condition

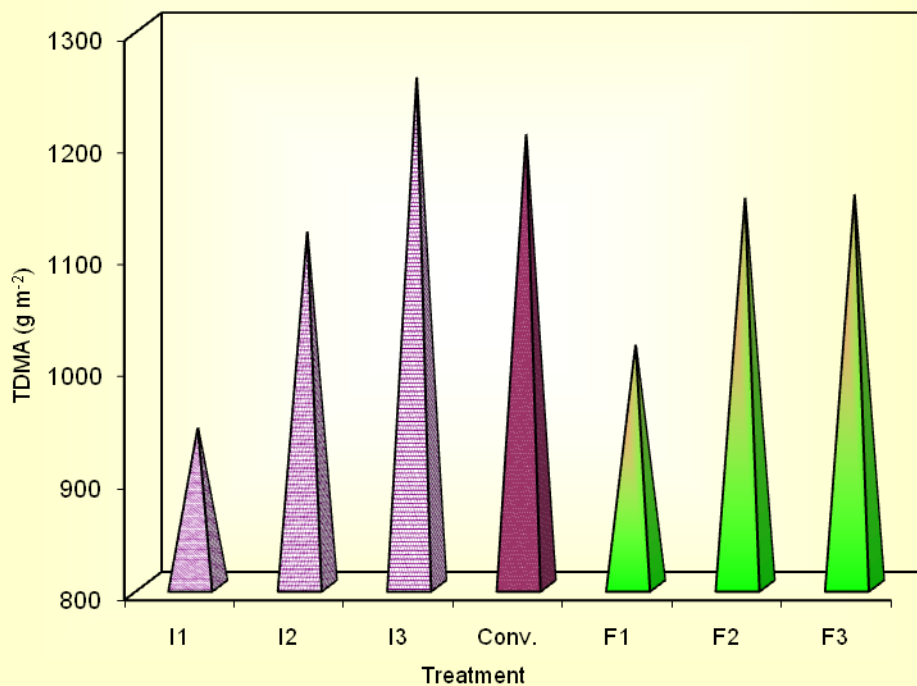


Plate 2. Fertilizer mixing tank



Plate 3. Fabricated root auger



Plate1. Lay out of the drip fertigation experiment



a) Main and Sub-main



b) Laterals

Plate 4. General field view of the drip fertigation experiment



Plate 5. Field view of the drip fertigation experiment during vegetative stage



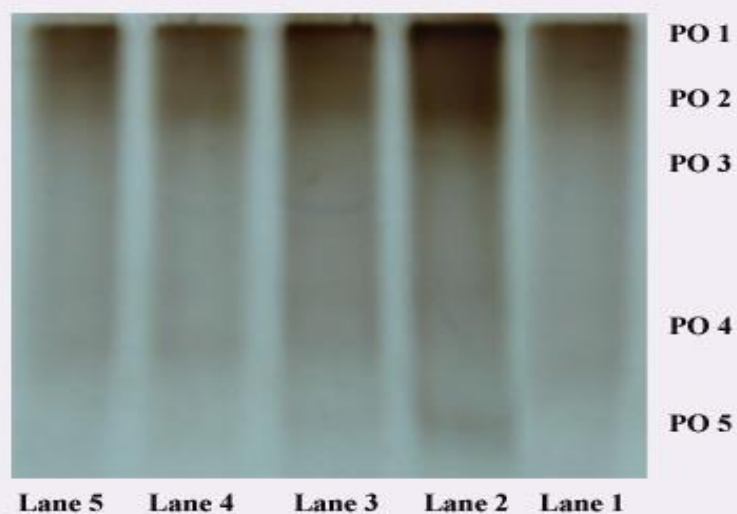
Plate 6. Field view of the drip fertigation experiment during harvest stage



Plate 7. Lion tail roots



Plate 9. Native - PAGE profile of peroxidase enzyme at FF stage



Lane 5 Lane 4 Lane 3 Lane 2 Lane 1

Lane 1 - Conventional method (T₁)

Lane 2 - 100 % PE + 75 % RDF + BF (T₂)

Lane 3 - 125 % PE + 75 % RDF + BF (T₅)

Lane 4 - 125 % PE + 100 % RDF + BF (T₆)

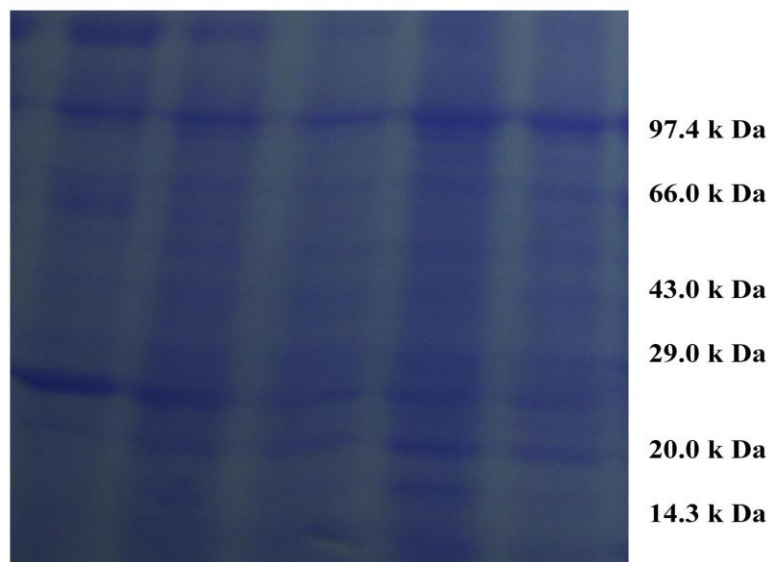
Lane 5 - 150 % PE + 125 % RDF + BF (T₁₀)

PE - Pan evaporation

RDF - Recommended dose of fertilizer

BF - Biofertilizer

Plate 8. SDS - PAGE analysis of leaf protein profile at flowering stage



Lane 1 Lane 2 Lane 3 Lane 4 Lane 5

Lane 1 - 100 % PE + 75 % RDF + BF (T₂)

Lane 2 - 125 % PE + 100 % RDF + BF (T₆)

Lane 3 - 125 % PE + 125 % RDF + BF (T₇)

Lane 4 - 150 % PE + 125 % RDF + BF (T₁₀)

Lane 5 - Conventional method (T₁)

PE - Pan evaporation

RDF - Recommended dose of fertilizer

BF - Bio fertilizer

Plate 11. Visit of VIPs to the field



a) Vice - Chancellor of TNAU



**b) Dr. Adrian Johnston, Vice - President and Asia Group
Co-ordinator of IPNI**

**Appendix 4. HPLC chromatogram of standard for trans - zeatin
equivalent cytokinin at flowering stage**

