

**ROOT ACTIVITY AND PRODUCTIVITY OF PUDDLED LOWLAND RICE AS
INFLUENCED BY CULTIVARS, SOIL AERATION AND PLANT GROWTH
PROMOTING SUBSTANCES**

*Thesis submitted in partial fulfilment of the requirements for the award of the degree of
Doctor of Philosophy (Agriculture) in Agronomy to the
Tamil Nadu Agricultural University, Coimbatore - 3*

By
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**DEPARTMENT OF AGRONOMY
AGRICULTURAL COLLEGE AND RESEARCH INSTITUTE
TAMIL NADU AGRICULTURAL UNIVERSITY
COIMBATORE – 641 003
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(V.MANIVANNAN)

ABSTRACT

ROOT ACTIVITY AND PRODUCTIVITY OF PUDDLED LOWLAND RICE AS INFLUENCED BY CULTIVARS, SOIL AERATION AND PLANT GROWTH PROMOTING SUBSTANCES

By

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2004

Field experiments were carried out at Tamil Nadu Agricultural University, Coimbatore to study the influence of field management through water, mechanical soil disturbances, varieties and plant growth promoting substances on root activity and productivity of puddled lowland rice ecosystem. A preliminary experiment was conducted in *Navarai* 2002-2003 in a split plot design with three replications to screen varieties. The treatments were two irrigation management practices viz., Allow aeration - Restoration of irrigation, after disappearance of previously impounded irrigation water, at the beginning of formation of hairline cracks (I_1), and Continuous submergence - Restoration 5 cm standing water well before disappearance of previously impounded irrigation water (I_2) in main plots and 14 varieties in a sub plots. The varieties were CO43, CO45, ADT38, ADT40, TRY1, White Ponni, Ponmani, Bhavani, CO47, ADT36, ADT39, ADT43, ASD20 and CORH2.

The main field experiments were carried out in two seasons namely, *Samba* and *Thaladi* in a 2 x 3 x 2 factorial randomized block design with three replications. The treatments imposed were two varieties viz., CORH2 (V₁) and ADT38 (V₂), Two plant growth promoting substances namely plant growth promoting rhizobacteria (H₁), foliar spray of salicylic acid @ 100ppm (H₂) with control (H₀) and two field management practices of soil aeration through rotary weeder (F₁) and continuous submergence (Existing practice) (F₂).

Based on the results of the preliminary experiment CORH2 and ADT38 was selected among the 14 varieties with the objective of sustaining the root activity and productivity of rice under puddled lowland ecosystem in two field management conditions, a follow up experiment in main field, was carried out during *Samba* 2003 and *Thaladi* 2003-2004.

Grain yield was higher in *Thaladi* season than in *Samba* season. The effect of hybrid CORH2 is superior in grain yield at both *Samba* and *Thaladi* season.

The response of varieties on rice growth is very distinct. Increase in grain yield in CORH2 may be due to faster development of vegetative growth and roots, which also lead to increased number of filled grains per hill and lower sterility in *Samba* and *Thaladi* seasons.

The effect of application of plant growth promoting substances is positive in both the *Samba* and *Thaladi* seasons. Foliar application of salicylic acid @ 100ppm at active tillering, panicle initiation and heading stages increased the grain yield. Foliar spray of salicylic acid prolonged the activity of roots which might be the result of longevity of functional leaves and slowed down process of senescence. Hence, the growth rate at heading was enhanced. The remobilization of stored assimilates from leaves to reproductive organs was higher when the root activity was more as evidenced up to heading in both the seasons.

The effect of soil aeration through rotary weeder performed at 10 days interval between 30-70 DAT on rice growth is distinct. Provision of aeration prolonged the activity of roots, which in turn promoted the production of functional leaves, slowed down the process of leaf senescence and extends growth rate even after heading. Soil aeration through rotary weeder improved grain yield in both *Samba* and *Thaladi* season.

Foliar application of salicylic acid and provision of soil aeration through rotary weeder is beneficial to grain yield through sustained root activity, otherwise the grain filling process may be disturbed.

Gross and net returns were higher with provision of aeration in both the seasons. For the hybrid salicylic acid and soil aeration through rotary weeder added the gross, net incomes and also the B:C ratio. Whereas, when the variety with susceptible nature to submergence is considered then the soil aeration alone is sufficient to get better B:C ratio.

CERTIFICATE

This is to certify that the thesis entitled “**ROOT ACTIVITY AND PRODUCTIVITY OF PUDDLED LOWLAND RICE AS INFLUENCED BY CULTIVARS, SOIL AERATION AND PLANT GROWTH PROMOTING SUBSTANCES**” submitted in part fulfilment of the requirements of the Degree of **DOCTOR OF PHILOSOPHY (AGRICULTURE)** in **AGRONOMY** to the Tamil Nadu Agricultural University, Coimbatore is a record of bonafide research work carried out by **Mr. V. MANIVANNAN**, under my supervision and guidance and that no part of this thesis has been submitted for the award of any degree, diploma, fellowship or other similar titles or prizes and that the work has not been published in part or full in any scientific or popular journal or magazine.

Place : Coimbatore

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CHAPTER I

INTRODUCTION

Rice, the wonder cereal is cultivated throughout the world, to feed more than 50 per cent of the world's population (Maclean *et al.*, 2002). In India, it is cultivated nearly in 44.5 m ha with varied rice growing environments namely rainfed upland, rainfed lowland, irrigated lowland, irrigated submerged lowland, deep water lowland *etc.* Rice productivity varies enormously between these environments. Most of the rice production in India is coming from irrigated lowland (51 per cent of the total rice cultivable area). Here again, the productivity varied due to seasons, climate, varieties, and management factors *etc.*, Majority of the irrigated rice eco-systems are under poorly drained field condition, either due to deltaic nature of rice belts or due to continuous submergence of the puddled double rice eco-systems. Rice yield reported in these environments are often associated with poor harvest index. The main reason believed is poor soil condition arising out of continuous rice cultivation under prolonged submergence. This situation is further complicated by poor movement of subsoil water. Sub soil water movement is responsible for the removal of toxic acids from the root zone. Accumulation of toxic acids are causing low redox condition (Govindasamy and Chandrasekaran, 1979).

Though the rice is an aquatic plant prolonged submergence also called as "flooding stress" may lead to lot of complications, within the rice rhizosphere – root – shoot growth environment. In Eastern India, submergence is the third most serious factor following drought at anthesis and weeds, out of 42 abiotic stresses that limit rice production (Widawsky and O'Toole, 1990). Setter *et al.* (1989) reported that low CO₂ concentration in water adversely affected the dry weight production of rice during submergence. Low CO₂ concentrations not only reduced photosynthesis of rice; they also lead to adverse interactions with high concentration of ethylene (Jackson *et al.*, 1987) and low O₂

(Setter *et al.*, 1989). Enrichment of floodwater with CO₂ increased growth rate of shoot during submergence in nutrient solutions but high CO₂ partial pressure (above 3 kPa) were required to produce growth rates comparable to non-submerged rice plants (Setter *et al.*, 1989).

Cytokinins produced in rice roots is responsible for initiation of cell division, delay of senescence, counteracting apical bud dominance, inducing flowering, increasing the tiller production in cereals and translocation of stored reserves to grain and improving grain filling process and grain weight (Yang *et al.*, 2002).

There are evidences under prolonged submergence that rice root loses its ability to produce cytokinins and thereby unbalanced production of abscisic acid (ABA) which in turn advances leaf senescence, reduces the photosynthesis and affects the grain filling, ultimately reduces the yield (Pandey and Sinhan, 1998). It has long been recognized that waterlogging creates anaerobic conditions in the root zone and thus causes elevated synthesis of ethylene by the shoot in many plants. This elevated ethylene production in turn causes adventitious root formation, petiole epinasty and leaf senescence.

Limited oxygen supply is one of the major factor responsible for reduced growth during submergence of rice (Setter *et al.*, 1989). Under conditions of anoxia, the principal hormones cytokinin, abscisic acid and ethylene are unquestionably most active morphogens in plants; their rapid and often reversible range of effects at extremely small concentrations being fully compatible with many of the developmental characteristics of flooding or submerged plants. Ethylene is intimately involved in plant responses to flooding because its rate of diffusive loss from the plant is strongly inhibited by water. Biosynthesis of ethylene is susceptible to oxygen supply particularly at the step in the pathway oxidizing 1 – aminocyclopropane – 1 – carboxylic acid (ACC) to ethylene (Jackson, 1994). Earlier studies in this area concentrated on negative hormone messages

linked with slower shoot growth and enhanced leaf senescence with decrease in the concentrations of bioassayed cytokinins in sap obtained from root systems with the shoot removed (Jackson and Drew, 1984; Jackson, 1990, 1993).

The direct promotion of plant growth by plant growth promoting rhizobacteria generally entails providing with a compound that is synthesized by the bacterium or facilitating the uptake of nutrients from the environment through the solubilization of phosphorus, nitrogen fixation, sequestering of iron from the soil by siderophores, production of phytohormones such as auxin, cytokinin and gibberellin, and the enzymatic lowering of plant ethylene concentration (Glick, 1995; Glick *et al.*, 1999). Recently, it was discovered that a number of plant growth promoting bacteria (*Pseudomonas*) contains the enzyme ACC deaminase (Glick *et al.*, 1994a) and that this enzyme can cleave the plant ethylene precursor ACC thereby lower the level of ethylene in a developing or stressed (submergence) plant. Moreover, ACC deaminase containing PGPR can in some instances protect a plant from the deleterious effects of flooding stress. Under submergence, ACC which is synthesized in roots is transported to shoot where it is converted to ethylene by ACC oxidase (Bradford and Yang, 1980). The molecular basis for the increase in ethylene production observed in shoots of continuously submerged rice plants is an increase in the activity of both ACC synthase in the submerged roots and ACC oxidase in shoots.

Hence, the present study was carried out with the following objectives

1. To screen and select rice varieties for tolerant and susceptible to continuous submergence
2. To find out strategies to sustain rice root activity for better production under lowland ecosystem
3. To understand the interaction effect of varieties, hormones and field management strategies on growth and yield formation of puddled lowland rice.

CHAPTER II

REVIEW OF LITERATURE

Past scientific research on various aspects of rice cultivation and on the rice plant itself has been responsible for remarkable gain in the productivity of rice farming systems. However, rice production must increase if it is to keep pace with population growth. The scope for expansion of rice-growing areas is limited. Most of the increase will have to come from improved plants and from production methods that are more efficient yet more environmentally sustainable.

Herd (1991) reported that submergence is one of the top 10 priorities for rice research. Plants respond to submergence stress with a series of physiological and biochemical changes leading to alterations in growth and development. In the rainfed lowland areas of eastern India, submergence is the third most important limitation to rice production of 42 biotic and abiotic stresses, and it surpasses only by drought at anthesis, and weeds (Widawsky and O'Toole, 1990).

Rice has traditionally been grown submerged in water. Clearly, rice is able to tolerate standing water. However, standing water creates hypoxic soil condition (lacking in oxygen) for the roots and hardly seems to be ideal. Rice roots have been shown to degenerate under flooded conditions, losing three fourth of their roots by the time it reaches the flowering stage. This die-back of roots under flooded conditions has been called "senescence", implying that it is a natural process. But it actually represents suffocation, which impedes plant functioning and growth (Dawn Berkelaar, 2001).

2.1. Rethinking of conventional wisdom

The SRI (System of Rice Intensification) calls into question the common belief that rice is an aquatic or at least hydrophilic plant. There are several reasons, with support from literature, for questioning this prevalent thinking. Just because, rice can survive in soil that is inundated (hypoxic) does not mean that it will thrive under such condition.

Rice has been grown under flooded conditions mostly because this makes weed control easier or even unnecessary, which saves labour.

Without scientific confirmation, if rice is able to grow in flooded paddies it has been extrapolated into an idealization, as it performs better and requires standing water to be most productive (De Datta, 1981). It is true that rice grows more abundantly in standing water than it does under upland (unirrigated) condition. But that does not make continuous flooding the best practice (Uphoff and Randriamiharisoa, 2002).

Several observable physiological features of rice grown under continuously flooded conditions suggest that these are not ideal circumstances for the best rice plant performance.

A month after transplanting, about 75 per cent of the rice roots growing in saturated soil are concentrated in the upper 6 cm of soil, as they remain near the surface to obtain whatever dissolved O₂ they can get from irrigation water (Kirk and Solivas, 1997). Such truncated root systems can access nutrients from only a limited volume of soil, having to rely mostly on nutrients provided through fertilizers. Conversely, when rice is grown with intermittent flooding method, roots extend downward 30 to 50 cm (Barison, 2002).

When rice plants are grown under continuously flooded conditions, much of the root cortex disintegrated to form aerenchyma (air pockets) (Kirk and Bouldin, 1991). The process occurs both in varieties bred for irrigated cultivation and in so-called “upland” varieties. However, neither irrigated nor upland varieties form aerenchyma when they are grown in well drained soil (Puard *et al.*, 1989). The difference between these two categories of rice is that the former is able to create larger and more regular aerenchyma that enable roots to continue functioning and to survive longer in flooded soil. Formation of aerenchyma appears to be a sub-optimizing rather than an ideal adaptation to hypoxic conditions.

By the time of flowering when grain production begins, about 75 per cent of the roots of rice plants that are growing in continuously saturated soil are degenerated, whereas, there is little or no degeneration of roots growing in soil that is well drained (Kar *et al.*, 1974).

The changes in rice plants' root systems and their capacity to take up nutrients during their growth cycle, and particularly during the reproductive phase after panicle initiation, are acknowledged in the literatures reviewed here under. Because these changes are regarded as “senescence”, something natural rather than induced by alterable growing conditions, they have not been regarded as constraints to production. Rice plants have been assumed to be well adapted for growth in flooded fields (Kirk and Bouldin, 1991; De Datta, 1981).

2.2. Effect of waterlogging on rice growth

The most characteristic management practice in paddy rice cultivation is water logging or submergence of the land surface. This brings about anaerobic conditions in the soil, due to the very slow diffusion rate of oxygen through water. When soil is saturated, air pockets (known as aerenchyma) form in the roots of submerged plants in order to transport oxygen. These air pockets form 30-40% of the roots cortex and probably impede the transport of nutrients from the roots to the rest of the plant (Dawn Berkelaar, 2001).

Alternately submerged and non-submerged (ASNS) regime (also named “intermittent irrigation” or “alternately wet and dry”) did not reduce grain yield (Choudhury *et al.*, 1991; De Dios *et al.*, 2000) or even led to an increase in yield if irrigation was carefully managed (Wu, 1999; Mao *et al.*, 2000). This yield benefit has been ascribed to better root vigour and depth (Mao *et al.*, 2000); a reduction in lodging, pests, and diseases (Yi, 1999); and better oxygenation (Wang, 1999). Cheng (1983)

reported that aerobic soil conditions favoured the removal of toxic chemicals in the rhizosphere. Other studies reported a yield decline when ASNS regimes were tested (Borell *et al.*, 1997; Lu *et al.*, 2000; Bouman and Tuong, 2001).

Greenland (1981) stated that minimum percolation rate of 10 mm d^{-1} is required for high yields. He argues that this percolation rate ensures the removal of toxic materials and an ample supply of oxygen. Ponnampetuma (1984) concluded a percolation rate of at least 1.5 mm d^{-1} as minimum necessary to meet the oxygen demands of roots in flooded soil.

2.3. General redox transformations under waterlogged condition

Water logging causes a condition of hypoxia (low oxygen concentration) in soils, because of the low solubility of oxygen in water (0.28 mol m^{-3} at 20°C), the low diffusivity of oxygen, in water filled pores [about 10,000 fold slower than through gas filled soil pores (Grable, 1966)], and the rapid use of dissolved oxygen by bacteria and roots. In addition, water logging can cause the accumulation of ethylene and products of root and bacterial anaerobic metabolism (carbon dioxide, ethanol, lactate *etc.*). In the longer-term, under the influence of anaerobic organisms, there can be reduction of NO_3^- , Mn^{IV} , Fe^{III} and SO_4^{2-} at successively lower redox potentials (Barrett-Lennard, 2003). Biologically, after the oxygen reserve in the soil is exhausted and aerobic microorganisms have all died, facultative anaerobes dominate for sometime. As the anaerobic conditions continue, these microorganisms are gradually replaced by obligate or strict anaerobes.

The biological changes are accompanied by a very characteristic succession of chemical transformation of materials. Following the disappearance of molecular oxygen, nitrate is used as a substrate for denitrifiers. Manganic oxides are solubilized as a result of reduction to manganous ions, likewise orange yellow to reddish colour iron oxides are reduced to soluble ferrous ions, decolourizing the soil. Many fermentation reactions based on various organic substrates proceed along with these mineral transformations,

producing carbon dioxide, ammoniacal nitrogen, low molecular weight organic acids, and so forth (Kazutake Kyuma, 1995).

Sekhon *et al.* (1988) reported that low redox potential (-396 mV) in paddy soils did not improve plant growth also significantly reduced tiller number, leaf area and root density compare to moderate redox condition (-97 mV). Excessive amount of ferrous ions (Fe^{2+}) released by the reduction of iron in flooded soils are toxic to rice plants (Chen *et al.*, 1980).

Soil redox potential can affect rice growth. Subsequent to flooding, plant roots encounter hypoxia and anoxic conditions as a result of the depletion of soil oxygen by microbial and plant root respiration (Gambrell and Patrick, 1978). Flooded soils can experience redox conditions ranging from well oxidized to strongly reduced. In an oxidized (aerobic) soil the redox potential (Eh) ranges from about +600 to +350 mV, whereas in most reduced (anaerobic) soils the Eh varies from about -300 to +350 mV (De Lanune *et al.*, 1990; Masscheleyn *et al.*, 1993).

Kim *et al.* (1999) reported that plant height, root length and dry weight for Nonganbyeo rice variety decreased under strongly reduced condition (-150 mV). Under strongly reduced condition (-150 mV) root porosity was less than rice grown at the two higher redox levels. Reduced soil conditions (-150 mV) decreased the net photosynthesis.

2.4. Effect of soil aeration on rice growth and development

Measuring and characterizing the aeration status of soils in terms of plant behavior is sometimes called the “problem of soil aeration” and with good reason. The literature shows many anomalies. Plants also grow well in soils thought to be deficiently aerated as they do in soils expected to be adequately aerated (Russell, 1961). Mechanical weeding leads to more aeration in the soil, and greater root growth meaning that rest of the plant will have access to more nutrients. Artificial aeration to plants growing in soils may be beneficial even though analyses indicate minor differences in the composition

of atmosphere around aerated and non-aerated roots (Boicourt and Allen, 1941). Rickman *et al.* (1965) described a poor aeration was prime limiting factor for plant growth.

Kefford (1962) reported that deficient aeration of rice seedlings increases the cellular concentration of a phenolic inhibitor of IAA oxidase and thereby increases auxin content and elongation of rice coleoptiles. Thus, both O₂ and CO₂ are potentially capable of directly regulating auxin concentration in tissues.

Carr (1961) speculates that stimulation of mesocotyl elongation by deficient aeration is an evolutionary process which permits seedlings to escape more quickly from adverse soil condition, *i.e.*, deficient aeration is one factor causing cell wall destruction and lysigenous formation of large air spaces in roots.

According to van Overbeek (1959), unclear division within cells proceeds anaerobically whereas subsequent cell elongation is a highly aerobic process. The highly reducing medium must give way to anaerobic one by the time the cell is ready to enlarge. It may be the function of ascorbic acid oxidase to bring about this change by oxidation of ascorbic acid. Apparently, high cellular auxin content is accompanied by high ascorbic acid oxidase activity. If so, the reduced cell division and plant growth associated with deficient aeration may be due to the effect of auxin on cellular oxidation potential and nuclear division. The enzymatic conversions of IAA to the highly toxic compound, 3-methylene oxindole (Still *et al.*, 1965) is due to the adverse effects of deficient soil aeration.

Yamasaki (1952) reported that higher concentration of Fe, Mn and S in over moist soil was injurious to wheat and barley plants than in normal soil. Black depositions of iron sulfide in and on roots of these crops, causes tissue injury when soil temperature was high. At low temperatures, O₂ deficiency appeared to be the principal cause of plant injury. He considers that one mechanism of plant tolerance to waterlogged soils is lignifications of roots which tends to exclude reduced toxic substances. Vamos (1964)

indicated that H_2S can result in root rot and deficiency diseases of rice. van't Woudt and Hagan (1957) observed H_2S in the intercellular spaces of rice roots.

Vinaya Rai and Murty (1976) compared the growth and yield of different high yielding rice varieties under submerged condition (continuous standing water) and normal condition (well drained condition). There was a significant reduction (10%) in grain yield under submergence, caused by reduced growth, panicle number (4%) and grain per panicle (6%). The root volume was decreased in the submerged plants, it being only half of that in the control plants.

Peroxidase is known to be responsible for synthesis of coniferyl alcohol which is the precursor of lignin (Manskaya, 1948). Restricted lignin formation due to the peroxidase activity in waterlogged rice roots is due to the poor root growth observed by Vinaya Rai and Murty (1976). Peroxidase has also been considered to be involved in oxidation of reduced rhizosphere under submerged soil. Oxygen secreted through root, has a great role in oxidizing ferrous ions and hydrogen sulphide (Singh and Bhattacharjee, 1990).

The significance of peroxidase in growth and development has been reported by a number of workers (Kadam *et al.*, 1973; Murty and Nanda, 1974). The interaction between growth hormones IAA and peroxidase may be important for growth of the plant, especially for roots to sustain longer period of submergence.

Mazaredo and Vergara (1982) reported that the roots of susceptible varieties continued to release O_2 at a low rate. Probably at terminal oxidase, peroxidase releases certain amount of O_2 for survival of the plant. But in tolerant varieties, increasing activity of peroxidase on roots, leaf sheath and leaf blades may regulate CO_2 and detoxification of other toxic metabolites (Rama Krishnayya *et al.*, 1990).

Soil is flooded and all pores are filled with water, gas exchange between the soil and the atmosphere is strongly hampered (Jackson and Drew, 1984; Ponnampetuma, 1984). The trapped oxygen in the soil is chemically reduced to water, by the terminal step in the respiratory electron transport chain of microorganisms and plant roots. After complete oxygen depletion, anaerobic microorganisms use various oxidized soil components as electron acceptors, leading to a sharp decline in the soil redox potential (Etherington, 1983). The electrochemical changes in the soil, induced by over wet conditions, result in an increase of potentially toxic components like Mn^{2+} , Fe^{2+} and H_2S (Ernst, 1990; Frankenberger and Arshad, 1995).

2.4.1. Soil aeration through drainage

Habibullah *et al.* (1977) reported that drainage increased the yield of rice varieties Chandina and Iratom-24 by 28 and 49 per cent than the plots without drainage condition. Several workers have reported that continuous drainage and mid-term drainage enhances the yield of rice (Upadhyaya *et al.*, 1973; Puttaswamygowda *et al.*, 1973; Shoji *et al.*, 1974). The increased yield of rice under drainage conditions is attributed to increased activity of root and better nutrient absorption (Miyasaka, 1970; Shoji *et al.*, 1974). Patel and Ghilayal (1980) indicate that slow drainage rate under submerged conditions will be desirable in comparison with undrained conditions as it enhances rice growth and yield.

2.5. Poor soil aeration and plant hormonal relationship

Some plant hormones were responsible for morphological adaptation under flooding or submergence. The five principal hormones, auxin, gibberellins, cytokinins, abscisic acid and ethylene, are unquestionably the most active morphogens in plants; their rapid and often reversible range of effects, extremely small concentrations being fully compatible with many of the developmental characteristics of flooded or submerged plants. Ethylene is intimately involved in plant responses to flooding, because its rate of diffusive loss from the plant is strongly inhibited by water, and because the biosynthesis is susceptible to oxygen supply, particularly at the last step in the pathway oxidizing

1-aminocyclopropane-1-carboxylic acid (ACC) to ethylene by ACC oxidase enzyme (Yang and Hoffman, 1984).

Deprivation of oxygen to the roots of plants is the main consequence of flooding (Jackson and Campbell, 1976). Under normal conditions water dissolves about 230 mmol m⁻³ oxygen, and hypoxia occurs when the oxygen level falls below 50 mmol m⁻³ (Nilsen and Orcutt, 1997). Within 1h of flooding, the oxygen partial pressure declines from 208 to 7.9 kPa, and further decreases to 1 kPa after 1d of flooding (Nilsen and Orcutt, 1997).

Brailsford *et al.* (1992) reported that poorly aerated roots can also contain elevated concentrations of ethylene. This additional ethylene is not only generated by water entrapment but also due to partial O₂ shortage during its biosynthesis pathway in maize roots. Roots that are partially oxygen deficient (3 kPa) showed an increase in the total amount of ACC available for ethylene formation and for regulation of ACC (Atwell *et al.*, 1988). Anaerobic conditions are known to increase ACC production in roots, probably because ACC synthase activity is promoted (Wang and Arteca, 1992).

Under seedbed or paddy conditions, germination and early growth by rice shoots under anaerobic conditions must be succeeded by entry into more oxygenated conditions if the seedling is to survive. Such conditions might be provided by oxygen containing water above soil level. However, continued fast extension growth rates would still be important for reaching the water surface where gaseous exchange could then proceed unimpeded. Extension above the anaerobic zone may help the oxidation of ACC to ethylene that accumulates in rice seedlings during the preceding period of anaerobiosis (Pearce *et al.*, 1992).

Gas diffusion into the plants is impeded, leading to low partial pressure which stimulates biosynthesis of ethylene by increasing ACC synthase activity, thus further enriching the stem with ethylene (Pearce *et al.*, 1992).

Early studies in the submerged plants concentrated on negative hormone message, and linked slowed shoot growth and enhanced leaf senescence with decrease in the concentration of bioassayed cytokinins or gibberellins in sap obtained from root systems with the shoot removed (Jackson and Drew, 1984; Jackson, 1990). Although these measurements of concentration differences were confounded by the large difference on sap flow rates between intact transpiring plants and de-topped plants, and by differences in transpiration rate between flooded and control plants, there is little doubt that substantial decrease in the amount of gibberellins and cytokinins transported from roots to shoots do occur (Neuman *et al.*, 1990).

Neuman *et al.* (1990) found that the inhibition of stomatal closure and leaf expansion brought about by soil flooding could not be rectified by exogenous supply of cytokinin to make good the endogenous deficiency. However, apart from that another hormone abscisic acid (ABA) also involved in closer of stomato. Increased concentration of this hormone under flooding situation was first reported by Hiron and Wright (1973).

Jackson and Hall (1987) found that flooding can induce stomatal closure and increased foliar ABA level in the absence of any prolonged or severe loss of leaf water potential. Zhang and Davies (1987) reported that ABA is a positive message exported in increased amount from the flooded roots to the shoots. These include measurements of increased ABA concentrations in roots of pea plants during the second, third and fourth days of flooding, at a time when stomata had partially closed and the leaves enriched with the hormones (cytokinins).

Neuman and Smit (1991) found a doubling of ABA concentrations in the xylem sap of *Phaseolus vulgaris* plants, de-topped after flooding to gain access to the sap which is expressed under pressure.

ACC transport from oxygen-starved roots is undoubtedly the clearest and most convincing example of a positive message from a stressed roots (submergence) system affecting growth and development in shoots (Jackson, 1991).

The possible role of roots in affecting shoot physiology due to the rate of cytokinin translocation from roots to shoot was demonstrated by Sitton *et al.* (1967). They reported that a reduction in cytokinin supply from the roots to the shoot was followed by rapid senescence (Carmi and Staden, 1983). Cytokinin transported from the roots via the xylem are known to delay leaf senescence (Nodden *et al.*, 1990; Garrison *et al.*, 1984; Sitton *et al.*, 1967; Soejima *et al.*, 1992).

A high oxygen consumption rate in root tip is associated with respiration, which is required for related metabolic activities, such as generation of ATP. Under flooded conditions, plant roots are in a state of hypoxia, their metabolic activity is inhibited and ATP production decreased (Saglio *et al.*, 1980). The decreased ATP production restricts the supply of energy for root growth, thus reducing vegetative growth (Chung-Ta Liao and Chin-Ho Lin, 2001).

2.5.1. Ethylene and ACC

Ethylene action induces programmed cell death in files of cells of the cortex of primary roots in association with a disorientation of microtubules in cells destined to collapse (Baluška *et al.*, 1993), cell wall degeneration (Webb and Jackson, 1986), and an increase in the activity of putative cell wall degradation cellulases (He *et al.*, 1994). High ethylene concentrations increase chlorosis and would therefore eventually limit photosynthesis and subsequent oxygen and carbohydrate production (Setter *et al.*, 1997).

Waterlogging also appears to promote an increase in the concentration of ethylene which can be extracted from various parts of the plants (Jackson *et al.*, 1978). Increased ethylene levels following waterlogging appears to be caused simply by the blockage of ethylene escape from the tissues by water. Thus while the concentration of ethylene in the tissues of waterlogged plants is increased, the actual rate of ethylene production is decreased because of oxygen deficit in the tissues (Lieberman, 1979).

Waterlogging creates anaerobic conditions in the root zone and thus causes elevated synthesis of ethylene by the shoot in many plants. This elevated ethylene production, in turn, causes adventitious root formation, petiole epinasty, and leaf senescence (Jackson and Campbell, 1976). Since ethylene is not synthesized in the anaerobic root and because of its gaseous nature cannot be transported to the shoot in significant quantities, it has been suggested that a “signal” is synthesized in the anaerobic root and transported to the shoot where it causes ethylene evolution (Yang and Hoffman, 1984). Bradford and Yang (1980) have shown that waterlogging in tomato plants not only blocks the aerobic conversion of ACC to ethylene in the root, but also causes increased synthesis of ACC which is subsequently transported through the xylem to the shoot where it is aerobically converted to ethylene.

Over production of ethylene appears to be due to an increase in ACC production (Kende, 1993). Since, CO₂ is liberated in the conversion of ACC to ethylene, the evidence that ethylene production by plant tissues is actually promoted by CO₂ calls for an explanation (Tan *et al.*, 1989). Tan *et al.* (1989) reported that respiratory CO₂ production was clearly increased by ABA.

The compartmentalization of enzymes involved in ethylene synthesis plays an important role in plant's response to flooding. Accelerated synthesis of ACC takes place in roots by hypoxia. ACC is transported in the xylem to the shoots from roots. Early

induction of ACC oxidase by ethylene in shoots is an important event, since the location of ACC oxidase determines the sites of ethylene release and action (Grichko and Glick, 2001a).

2.5.2. Cytokinins

The endosperm cell number in cereal crops is established during the early phases of grain development, it is speculated that this parameter may be regulated by cytokinins rather than by the levels of available carbohydrates during grain filling (Jones *et al.*, 1992; Brenner and Cheikh, 1995). There are many reports that cytokinins are generally found in the developing seeds of peas (*Pisum* sp.), beans (*Phaseolus* sp.), maize, wheat and rice, which coincides with the period of seed set and rapid endosperm development (Jones *et al.*, 1992; Lur and Setter, 1993; Morris *et al.*, 1993; Yang *et al.*, 2000). Low cytokinin contents results in reduced cell division activity in the endosperm, leading to a smaller endosperm cell number and low grain weight for inferior spikelets (Yang *et al.*, 2002). Yang *et al.* (2002) reported that changes in Z + ZR (Zeatin + Zeatin riboside) contents in the roots coincided with those in the endosperms, and were positively and significantly correlated with Z + ZR contents in endosperm and with the rate of endosperm cell division. Also roots are the major source of cytokinins for grains (Carlson *et al.*, 1987; Bano *et al.*, 1993).

2.6. Anoxia induced metabolic changes

Under oxygen deprivation, mitochondrial electron transport chain (ETC) is suppressed and hence, the synthesis of ATP is inhibited. Cells overcome energy shortage by switching to anaerobic glycolytic ATP production, and the availability of sugars as respirable substrates becomes extremely important. However, roots have been shown to suffer from sugar starvation under anoxia, because of inhibition of phloem transport, where the unloading step is affected (Saglio, 1985).

Mobilisation of starch is also affected under anoxia. The anoxia intolerant wheat seeds fail to degrade starch of the endosperm under anoxia, while in the tolerant rice α -amylases, responsible for starch breakdown, are induced under anaerobiosis (Perata *et al.*, 1992). In general, anoxia causes a significant decrease in ATP levels especially in the anoxia-intolerant species but also in the tolerant species (Chirkova *et al.*, 1984; Crawford, 1992).

The development of hypoxia in soils presents a range of challenges for plants. Roots normally require oxygen for optimal production of ATP from sugars. Under aerobic (drained) conditions, glucose in roots is oxidised to 6 mol of CO₂ and 6 mol of H₂O, and upto 38 mol of ATP. However, under anaerobic (waterlogged) conditions, glucose is oxidised to produce 2 mol of ethanol and 2 mol of ATP. Thus the transfer of roots from drained to waterlogged conditions can decrease ATP production by 95 per cent. This has important consequence for the metabolism of plants growing in waterlogged soils, as ATP is the fuel for nearly all cellular process (Barrett- Lennard, 2003). In maize root tips, ATP concentration drops steeply during the initial minutes of anoxia and then stabilizes at a low level (Drew, 1992).

Waterlogging (hypoxia) has a range of effects on plants. Firstly, it rapidly decreases the growth, initially of roots, and subsequently of shoots (Barrett-Lennard, 1986; Drew, 1983), and it increases the senescence of roots, beginning at the tips (Barrett-Lennard *et al.*, 1988; Huck, 1970; Webb and Armstrong, 1983). Secondly, it affects processes association with solute movement across membranes, such as the uptake of inorganic nutrients (Buwalda *et al.*, 1988; Trought and Drew, 1980). Thirdly, it can decrease stomatal conductance and/or leaf water potential (Bradford and Hasiao, 1982; Else *et al.*, 2001; Huang *et al.*, 1995; Jackson and Hall, 1987; Kridemann and Sands, 1984; Moezel *et al.*, 1989).

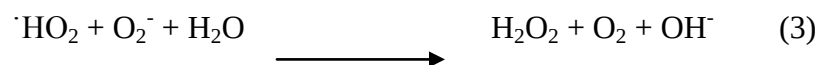
Programmed cell death also takes place in the cortex of adventitious roots to form aerenchyma. In maize this process is ethylene and hypoxia induced (Drew *et al.*, 2000) and in some rice varieties, ethylene also has a stimulatory effect on aerenchyma formation (Kawai *et al.*, 1998).

Ethylene has been shown to accumulate in submerged rice, the capacity of the natural ethylene precursor ACC to induce death of epidermal cell was studied by Mergemann and Sauter (2000).

2.7. Chemistry of active oxygen species

Lamb and Dixon (1997) reported that dioxygen in its ground state is relatively unreactive, partial reduction gives rise to “active oxygen species”, including the superoxide anion (O_2^-), hydrogen peroxide (H_2O_2), and the hydroxyl radical ($\cdot OH$). O_2^- is a byproduct of mitochondrial electron transport, photosynthesis, and flavin dehydrogenase reactions, and can then be converted to other active oxygen species, of which $\cdot OH$ is the most reactive. Much attention has been given to the mechanisms used to remove these toxic products, particularly under conditions of physical stress *e.g.*, high temperature and submergence, which lead to increased production of active oxygen species (Scandalios, 1993).

The first reaction in the partial reduction of dioxygen is addition of a single electron to form $O_2^{\cdot -}$. This can be protonated at low pH ($pK_a = 4.8$) to yield the perhydroxyl radical ($\cdot HO_2$) (equation 1), and $O_2^{\cdot -}$ and HO_2 undergo spontaneous dismutation to produce H_2O_2 (equation 2 and 3).



Equation 3 represents the major route for $O_2^{\cdot -}$ decay at cellular pH. Because of the equilibrium in equation 1, spontaneous radical dismutation will decrease as cellular pH

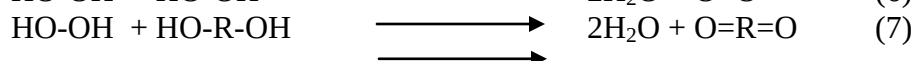
increases. Metal containing superoxide dismutase enzymes catalyze a highly efficient conversion (upto 10^{10} times faster than the spontaneous rate) of O_2^-/HO_2 to H_2O_2 (Lamb and Dixon, 1997).

H_2O_2 is stable and less reactive than O_2^- . However, in the presence of reduced transition metals such as Fe^{2+} , which may be free or complexed to chelating agent or proteins, H_2O_2 dependent formation of $\cdot OH$ can occur, and O_2^- can act as the initial reducing agent for the metal (equation 4 and 5).



$\cdot OH$ is a very strong oxidant and can initiate radical chain reactions with a range of organic molecules. This can lead to lipid peroxidation, enzyme inactivation, and nucleic acid degradation (Mittler, 2002).

H_2O_2 is removed by catalase or various peroxidases including ascorbate and glutathione peroxidases. The general equations for catalase and peroxidase reactions (equation 6 and 7) are similar because the catalase reaction can be viewed as a peroxidative reaction with H_2O_2 as both substrate and acceptor. In equation 7, the R group is often aromatic, in which case a diphenol is converted to a diquinone, a reaction important in lignin polymerization (Lamb and Dixon, 1997).



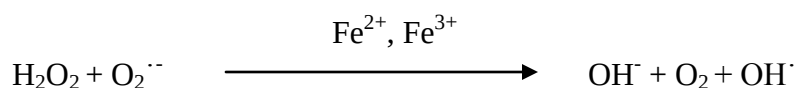
Peroxidase can also catalyze the formation of both O_2^- and H_2O_2 by a complex reaction in which NADH is oxidized using trace amounts of H_2O_2 first produced by non-enzymatic breakdown of NADH. The NAD^+ radical formed then reduces O_2 to O_2^- , some of which dismutates to H_2O_2 and O_2 (Hahlbrock *et al.*, 1995). This reaction is stimulated by monophenols and Mn^{2+} and may be a mechanism for generation of extracellular H_2O_2 for lignin polymerization (Halliwell, 1978).

2.8. Effect of submergence on reactive oxygen species production

Metabolism of the reactive oxygen species (ROS) generated during aerobic metabolism is an important corollary to anoxia tolerance. One protective system involves superoxide dismutase (SOD), converting superoxide radicals ($O_2^{\cdot -}$) to hydrogen peroxide (H_2O_2), which is then reduced to water by peroxidases or catalases (Drew, 1997).

Superoxide dismutase (SODs) are metalloproteins that catalyze the dismutation of superoxide radicals to hydrogen peroxides and oxygen. In plants, environmental adversity often leads to the increased generation of reactive oxygen species, and consequently, SOD has been proposed to be important in plant stress tolerance (Tsang *et al.*, 1991).

Superoxide radicals ($O_2^{\cdot -}$) are toxic byproducts of oxidative metabolism (Fridovich, 1986). Their toxicity has been attributed to their interaction with hydrogen peroxide to form highly reactive hydroxyl radicals ($OH^{\cdot}$) through the reaction:



Superoxide dismutase inhibitor blocks H_2O_2 generation, while causing a dramatic accumulation of $O_2^{\cdot -}$. Thus, $O_2^{\cdot -}$ generation at the external surface is followed by rapid enzyme catalyzed dismutation to H_2O_2 , and accumulation of significant levels of $O_2^{\cdot -}$ in some systems *e.g.*, rice cells (Levine *et al.*, 1994; Tenhaken *et al.*, 1995), likely reflects differences in the relative rates of $O_2^{\cdot -}$ generation and dismutation.

High reactivity of $OH^{\cdot}$ radicals (the main cause of cellular damage under oxidative stress), it is difficult to control their concentration enzymatically. Living organisms avoid the presence of this radical by controlling the upstream reaction of superoxide dismutation via SOD. SOD dismutates $O_2^{\cdot -}$ to H_2O_2 (Drew, 1992; Noctor and Foyer, 1998), therefore converting one harmful oxidant to a less harmful one. This has been shown in an experiment with corn leaves, where 7d flooding treatment resulted in a

significant increase in TBARS content, membrane permeability and the production of superoxide anion radical and hydrogen peroxide (Yan *et al.*, 1996). Similar results on SOD activity have been obtained for wheat and rice under anoxia (Chirkova *et al.*, 1998).

Catalase converts H_2O_2 to water and molecular oxygen (Drew, 1992; Noctor and Foyer, 1998).

Peroxidases scavenge H_2O_2 by reducing it to H_2O in the presence of reductant. They are found throughout the cell and they have higher affinity to H_2O_2 than catalase. In plant cells, the most important reducing substrate for peroxidase is ascorbate (Drew, 1992; Noctor and Foyer, 1998). The activity of peroxidase is related to maintenance of cell membrane integrity through its involvement in detoxifying H_2O_2 to water (Levitt, 1980). Peroxidase influences plant growth through lignin synthesis (Siegel, 1953), oxidative coupling reactions involving phenolics that are esterified to cell wall polysaccharides (Fry, 1986), formation of isodityrosine bridges that are believed to crosslink structural protein molecules (Chuan Chi Lin and Ching Huei Kao, 2001). Plant peroxidases have been extensively studied and many of their functions have been described *e.g.*, scavenging of peroxide participation in lignification, hormonal signaling and plant defense (Hiraga *et al.*, 2001).

In rice, a role of cell wall peroxidase has been established in controlling anoxia and ethylene, induced growth of coleoptiles (Lee and Lin, 1995; 1996b) and abscisic acid, methyl jasmonate and cadmium inhibited growth of roots (Chen and Kao, 1995; Lee and Lin 1996a; Tsai *et al.*, 1997).

Peroxidases were usually considered as antioxidants that protect cells against damaging effects of hydrogen peroxide. However, peroxidases can also operate as oxidants when they oxidize the bivalent heme iron to trivalent state or transfer the electron from reducing agents, such as NADH, to oxygen (Lebedeva and Ugarova, 1997; Chen and Schopfer, 1999). Such peroxidase activity results in the superoxide and

hydrogen peroxide production (Minibaeva and Gordon, 2003). Peroxidases have been implicated in the regulation of plant cell elongation, phenol oxidation, polysaccharide cross linking, IAA oxidation, cross linking of extension monomers, oxidation of hydroxy-cinnamyl alcohols into free radical intermediates and wound healing (Vidhyasekaran, 1997). Braedley *et al.* (1992) reported that increased peroxidase activity has been correlated with resistance in many species including barley, cucurbits, cotton, tobacco, wheat and rice. These enzymes are involved in the polymerization of proteins and lignin or suberin precursor into plant cell wall thus constructing a physical barrier that could prevent pathogen penetration of cell walls or movement through vessels.

Ascorbate peroxidase activity showed its maximum on 25th day after tasseling in maize, then it get decreased as observed by Prochazkova *et al.* (2001).

Prochazkova *et al.* (2001) reported that increased oxidative stress as indicated by increase in H₂O₂ content with plant age results in increased lipid degradation or lipid peroxidation as reflected in increase in TBARS (thiobarbituric acid reacting substances) content which is further manifested in decline in chlorophyll and carotenoids contents. The antioxidant enzymes such as superoxide dismutase, peroxidase, catalase activities increased in the young flag-leaf initially upto 15-20 days after tasseling, however, there after the activities of all the antioxidant enzymes decreased. SOD, ascorbate peroxidase and catalase might be contributing towards delayed senescence of Deccan 103 maize.

In rice, continued stress led to plasmolysis and finally to disintegration of the plasma membrane after 7 days of anoxia (Blokhina *et al.*, 2001). Endogenous H₂O₂ level was observed to be lower and catalase activity was higher in dark-treated detached rice leaves than in light treated leaves (Lin and Kao, 1998). Willekens *et al.* (1997) clearly demonstrated that catalase can effectively remove H₂O₂.

2.9. Effect of *Pseudomonas* on plant growth and development

Free living soil bacteria that are beneficial to plants are often referred to as plant growth-promoting rhizobacteria or PGPR (Kloepper *et al.*, 1989). PGPR can affect plant growth either indirectly or directly (Glick, 1995). The indirect promotion of plant growth occurs when PGPR lessen or prevent the deleterious effects of one or more phytopathogenic organisms. The direct promotion of plant growth by PGPR for the most part entails either providing the plant with a compound that is synthesized by the bacterium or facilitating the uptake of certain nutrients from the environment. There are several ways in which different PGPR may directly facilitate the proliferation of their plant hosts (Glick *et al.*, 1998). PGPR can fix atmospheric nitrogen and supply it to plants; they can synthesize low molecular weight siderophores which can solubilize and sequester iron from the soil, and then provide it to plant cells; they can synthesize several different phytohormones, notably indoleacetic acid (IAA), cytokinins which can act to enhance various stages of plant growth; they may facilitate the solubilization of minerals such as phosphorus from the soil which then become more readily available for plant growth; and they may synthesize some enzymes that modulate plant growth and development by influencing the levels of plant hormones (Glick *et al.*, 1994a,b; 1995; Xie *et al.*, 1996; Patten and Glick, 1996; Penrose and Glick, 1997). Moreover, a particular PGPR may affect plant growth and development by using any one, or more, of these mechanisms.

Among the plant hormones whose concentrations are most likely to be altered by the addition of a PGPR such as *Pseudomonas putida* GR12-2, are ethylene and the auxin, IAA (Glick *et al.*, 1994a,b;1995; Xie *et al.*, 1996; Patten and Glick, 1996). For example, a large number of soil bacteria, including both PGPR and pathogens, synthesize and secrete IAA (Patten and Glick, 1996). In addition, it has previously been suggested that

PGPR can effectively lower plant ethylene levels by sequestering the ethylene precursor 1-aminocyclopropane-1-carboxylate (ACC) from the plant and then hydrolyzing it through the action of the enzyme ACC deaminase (Glick *et al.*, 1994a,b; 1995; Hall *et al.*, 1996).

Glick (1995) reported that PGPR, such as *Pseudomonas putida* GR12-2, that contain the enzyme ACC deaminase are bound to the seed coat of a developing seedling, they may act as a mechanism for insuring that the ethylene level does not become elevated to the point where root growth is impaired. This bacterially facilitated stimulation of root elongation could enhance the survival of some seedlings, especially during the first days after the seeds are planted.

Pseudomonas sp. that was able to utilize ACC as a sole source of nitrogen while also displayed PGPR activity (Glick *et al.*, 1995). Yoshikawa *et al.* (1993) suggested that the secretion of succinic and lactic acids *per se* by a PGPR strain of *Pseudomonas putida* may act to directly stimulate root growth in asparagus seedlings.

2.9.1. Strategies to increase plant growth promoting rhizobacteria effectiveness

The interest in PGPR is based on both the desire to unravel a complex and fascinating biological system and the potential to utilize these organisms to increase the yield of crop plants. In the first instance, strains shown to possess specific desirable traits have been selected, tested, and then used as a component of agricultural practice, although so far to a limited extent. As more and better strains are developed and shown to be effective, the use of PGPR in agriculture will increase (Glick, 1995).

One strategy that plants use to limit root colonization by phytopathogens is production of active oxygen species such as the hydroxyl radical, the superoxide anion, and hydrogen peroxide (Doke, 1983; Klotz *et al.*, 1989; Sutherland, 1991). Plant roots may also respond to colonization by PGPR by producing active oxygen species (Katsuwon and Anderson, 1989; 1990). Phytopathogens that contain higher levels of the enzymes that reduce the amount of active oxygen species, i.e., superoxide dismutase,

catalase and peroxidase, have been shown to be more effective to pathogen (Klotz and Hutcheson, 1992). It is therefore reasonable to expect that increasing the levels of one or more of these enzymes by the genetic manipulation of a PGPR might increase the colonizing ability and hence the effectiveness of that PGPR strain.

The ability of some PGPR to hydrolyze ACC may provide these strains with a competitive advantage over other microorganisms in the rhizosphere, although not in the rest of the soil, because they can use ACC as a source of nitrogen (Jacobson, 1993; Jacobson *et al.*, 1994; Glick *et al.*, 1994a,b).

In some instances it may be possible to utilize the ability of PGPR to colonize the roots of crop plants to deliver various biological insecticides to the plants. The roots of many plants are attacked by insects, because of their underground location, would normally make insecticides based on *Bacillus thuringiensis* useless as biocontrol agent. However, in one case the insecticidal toxic gene from *Bacillus thuringiensis* subsp. *kurstaki* was introduced into a PGPR strain (*Pseudomonas fluorescens* that was originally isolated from corn roots) so that after reintroduction into the soil, the engineered bacterium synthesized and released the insecticidal toxic into the rhizosphere and conferred protection against root attacking insects (Obukowicz *et al.*, 1986a,b).

In addition, some PGPR contain the enzyme ACC deaminase (Shah *et al.*, 1997; Glick *et al.*, 1998; Shah *et al.*, 1998) which can cleave the plant ethylene precursor ACC, and lower the level of ethylene in a developing or stressed plant (Burd *et al.*, 2000) and submerged plants (Grichko and Glick, 2001b). Wang *et al.* (2000) tested six PGPR strains, the two ACC deaminase positive *Pseudomonas* CHAO/ACC and CHA96/ACC were the most effective, and increased the mean root length by 11.1% - 21.4%, respectively, as compared with their wild-type strains (CHAO and CHA) in canola.

Grichko and Glick (2001a) reported that decreasing ethylene production by suppressing the expression of some of the enzymes of the Yang cycle. However, since the activity of many of these enzymes affects processes other than ethylene synthesis, there may be some advantages to utilizing the microbial enzyme ACC deaminase, which cleaves ACC to ammonia and α -ketobutyric acid (Li *et al.* 2000; Honma and Shimomura, 1978), to establish a sink for ACC. This can be achieved either through the interaction of ACC deaminase containing PGPR with plant roots. ACC deaminase can significantly decrease ACC levels in plants, especially plants subjected to flooding/submergence stress, thereby decreasing amount of stress ethylene and the subsequent damage to the plant that might occur as a consequence of that stress ethylene (Grichko and Glick, 2001b,c; Penrose and Glick, 2001).

Grichko and Glick (2001b) demonstrated that bacteria expressing ACC deaminase can stimulate normal plant growth, the effect of these bacteria on flooded plants was assessed. Compared to untreated control plants, flooded tomato plants grown from seeds that were inoculated with PGPR appeared to be taller and greener. Moreover, bacteria with ACC deaminase activity noticeably stimulated the development of both adventitious roots and stem aerenchyma in flooded tomato plants compared to non-bacterized flooded tomato plants. Leaf chlorophyll content decreased in all types of flooded plants compared to control plants. However, the concentrations of total chlorophyll and of both chlorophyll *a* and *b* were significantly higher in flooded plants that are treated with ACC deaminase containing bacteria (*Pseudomonas*) compared to flooded non-bacterized plants.

Rhizobacteria, attached to the surface of the seeds or roots, can take up some of this ACC and hydrolyze it by the activity of ACC deaminase. The amount of ACC outside the root is thus reduced. To maintain the equilibrium between internal and

external ACC levels, more ACC is exuded from seeds or roots, resulting in a reduction in the amount of ACC available for oxidation to ethylene inside the cell (Ma *et al.*, 2002).

Plant root colonization by PGPR was associated with peroxidase activity (Albert and Anderson, 1987). Seed treatment and seedling root dipping of PGPR strains induced early and enhanced levels of peroxidase in rice plants (Nayar, 1996). The strains PF1 and FP7 (*Pseudomonas fluorescens*) are the best inducers of plant chitinase and peroxidases, which are the most important components of the induced systemic resistance (Nandakumar *et al.*, 2001b). Fluorescent Pseudomonads increased the plant growth of rice and cotton by 27 and 40%, respectively, when the bacteria were applied to the seed (Sakthivel *et al.*, 1986).

The plant grown from the seeds treated with both fluorescent and non-fluorescent bacterial isolates grew faster and was taller and greener than untreated control. Seeds treated with fluorescent pseudomonads resulted in increased number of tillers and grain yield in addition to control of sheath blight disease in rice (Mew and Rosales, 1986).

Rajacommare (2000) indicated that the talc-based formulation of *Pseudomonas* strains either as individually or as chitinase mixture significantly suppressed the sheath blight and leaf folder incidence in rice. *Pseudomonas* combination treatments leaf folder adult population under field condition was significantly lower compare to control.

Rajacommare (2000) reported that enhanced plant height, increased tiller number per hill and higher peroxidase content in the *P. fluorescens* treated plants. The number of grains and weight of the grains was higher in the bacterized plants. The grain yield was significantly greater than the untreated control when bacterized with individual strains PF1 and FP7.

Sakthivel and Gnananmanickam (1987) reported that *P. fluorescens* treated rice plants were taller and had more tillers. The bacterized cv. IR 20 plants were 11% taller and had 27% more tillers than did non-bacterized plants. There was an increase in the number of grains per tiller, 1000 grain weight, and grain yield for the bacterized rice plants.

Peroxidase is a key enzyme in the biosynthesis of lignin (Bruce and West, 1989). Increased activity of cell wall bound peroxidases has been elicited in different plants such as rice (Reimers *et al.*, 1992), cucumber (Chen *et al.*, 2000), rice (Reimers *et al.*, 1992), tomato (Mohan *et al.*, 1993) and tobacco (Ahl Goy *et al.*, 1992) due to bacterial inoculation.

Nandakumar *et al.* (2001a) compared three plant growth promoting rhizobacterial strains (*P. fluorescens*), PF1, FP7 and PB2, individual and combinations. Mixture of PGPR strains promoted plant growth in terms of increased plant height, number of tillers and ultimately grain yield of rice. The average increase in yield for single strains was 17.7% and 25.9% in case of mixture. The mixture consisting of PF1 plus FP7 was the most effective in reducing the disease and in promoting plant growth and grain yield of rice.

The Pseudomonads are aggressive and competitive root colonizers (Anderson *et al.*, 1988). Protection from activated oxygen species may include the production by the bacteria of enzymes such as catalase, which degrades H₂O₂, and SOD, which dismutates O₂⁻ (Beaman *et al.*, 1985; Mandell, 1975; Winqvist *et al.*, 1984).

2.10. Effect of salicylic acid on plant growth and development

Salicylic acid is new plant hormone belongs to an extraordinary group of plant phenolics usually defined as substances that possess an aromatic ring bearing a hydroxyl group or its functional derivative. Being plant phenolics, SA and other phenolics are not treated simply as secondary metabolites of minor importance or waste products, but these compounds play as essential role in plant growth and development. Phenolics are essential for the biosynthesis of lignin, an important structural component of plant cell wall (Raskin, 1992). Furthermore, phenolics, more notable phytoalexins (Hahlbrock and Scheel, 1989), have been associated with the chemicals defense of plants against microbes and insect (Metraux and Raskin, 1992).

2.10.1. Effect of salicylic acid on reactive oxygen species production

Presently, it is proven that SA is a second messenger in the systemic signal network of plant cells (Alvarez *et al.*, 1998). One of the ways for H₂O₂ accumulation is the inhibition of catalase activity (this enzyme detoxifies hydrogen peroxidase) (Durner and Klessing, 1996). SA also stimulated the superoxide production and activated peroxidase (Minibaeva and Gordon, 2003). SA might function as a weak detergent and change the electric charge of the cell surface, facilitating secretion of soluble peroxidase isoforms into the apoplast (Minibaeva and Gordon, 2003).

2.10.2. Effect of exogenous salicylic acid

SA inhibits ethylene biosynthesis in pear cell suspension culture by blocking the conversion of ACC to ethylene (Leslie and Romani, 1986). Huang *et al.* (1993) reported that salicylic acid effectively inhibited ethylene production within 2h of its application in rice plants.

The flower inducing effects of SA were first indicated in an organogenic tobacco tissue culture supplemented with kinetic and IAA (Lee and Skoog, 1965).

SA induces flowering by acting as a chelating agent (Oota, 1975), because the free o-hydroxyl group confers metal chelating activity on benzoic acids. The iron chelating properties of SA could, however, explain the inhibitory effect of SA on the ethylene forming enzyme (ACC), because iron is an essential cofactor for the conversion of ACC to ethylene (Bouzayen *et al.*, 1991).

Rainsford (1984) have suggested some salicylic acid activities, like ability to scavenge free radicals.

Macri *et al.* (1986) reported that ATPase activity of the tonoplast enriched fraction was increased by 10 mM SA in pea plants.

Salicylic acid inhibition of the ethylene production was reported by Martinez *et al.* (2001).

Salicylic acid had promotive effect on individual free amino acid, chlorophyll content and prevention of protein degradation in wheat (Jagadish Rane *et al.*, 1995).

Salicylic acid had a specific elevating effect on the level of nitrate reductase activity was reported by Kalpana (1997) in rice.

Maibangsa *et al.* (2000) observed that foliar application of salicylic acid @ 100 ppm at panicle initiation and flowering stage to overcome low irradiance stress in rice. Highest photosynthetic pigments viz., total chlorophyll, chlorophyll *a* and *b* in the salicylic acid treated plants. Spraying salicylic acid increases the Rubisco content and photosynthetic rate with higher nitrate reductase activity resulted in increased biochemical efficiency with increased assimilation and biomass accumulation compared to control plants.

Maibangsa *et al.* (2000) reported that foliar spray of SA 100 ppm increased the number of productive tillers, number of spikelet, test weight, total dry matter production, grain yield and harvest index compared to control plants in rice under low irradiance condition.

Dinesh (1999) reported that foliar application of salicylic acid 100 ppm significantly increase the chlorophyll *a/b* ratio, yield components, plant NPK uptake and benefit cost ratio of *Thaladi* season rice.

2.11. Effect of soil aeration through rotary weeder

Mechanical weed control through the use of rotary weeder or other implements helps in minimizing weed competition, besides, improving soil aeration (Misra and Sahoo, 1971; Shad, 1986). Soil aeration and root pruning (Shad, 1986; Dinesh Chandra and Manna, 1990) as effected by conoweeder would have provided conductive

environment for the uptake of nutrients which contributed for increased yield. Knowlton (1997) reported that the population of aerobic microorganisms increases upon frequent disturbance of the soil by stirring. The effect of mechanical weeding on better soil aeration have also suggested by Uphoff (1999). Repeated use of rotary hoe with its wheels aerated the top horizon of the soil leads to better development of the rice ecosystem (Randriamiharison, 2002).

Uphoff (2001) emphasized that early and frequent weeding is essential for rice when fields are not covered with standing water. Senthilkumar (2002) observed that the higher rice grain yield in the use of mechanical weeder and continued stirring of soil for 5 times, through prolonged active leaves (LAI) and productive tillers. Sudha Lakshmi (2002) reported that grain yield was higher directed seeding during dry and wet seasons under no-weeding practice. Vijayakumar (2003) reported that rotary weeding practice was found optimum to achieve higher production, productivity and economic returns of rice. In his view, using a rotary hoe that churns up the surface soil, removes weeds and provides additional soil aeration compared to hand weeding or herbicides.

At this moment, rice research in world is focused on water scarcity and waterlogging. Drought, a well studied area and water logging an unexplored area with huge scientific truth and complications. In waterlogging research, the focal points were varietal screening for crop improvement, increasing the root activity and cytokinin content. Drainage the part and participle of waterlogging, another fact of this problem that also can't be ruled out. The recently adopted technique, system of rice intensification (SRI) also paves way for our concepts and facts. The younger seedlings, square planting, mechanical weeding through rotary weeder, alternate wetting and drying of soil and use of green manures were its components. The split application of NPK and real time N management followed through LCC and SPAD techniques are also crucial under waterlogging situation. Under continuous submergence, chemicals and biologicals may

sustain the root activity by increased root cytokinin synthesis. This is new area in rice research, chemical or biologicals, may also check the pest and diseases incidence. The above lacunas were kept in mind and work hypothesis were formulated as varietal screening with better root activity. The screened varieties *i.e.*, tolerance and susceptible varieties were studied *in vivo* and target oriented environment. The increase in root activity through soil disturbance with rotary weeder, foliar spray of salicylic acid and application of pseudomonas addressed as solutions to the lacuna through physiological mechanisms. But, present study did not attend to the hormonal imbalance, such as cytokinin production, the leaf ABA and plant ethylene concentration, which influences the plant aging, leaf and root senescence. However, some hypothesis was derived on the basis of ROS production with root senescence. The source and sink relationship is altered by hormonal balance resulting in reduced grain yield. The above facts and fictions were tried in present study, with some strategies to increase the root activity and productivity of rice under continuous submergence situation.

CHAPTER III

MATERIALS AND METHODS

Field experiments were conducted in the wetland farms of Agricultural College and Research Institute, Tamil Nadu Agricultural University, Coimbatore. The investigation consists of two sets of experiment viz. the preliminary experiment for screening of varieties and second the main experiments to study the effect of genotypes, hormones and field management on root activity and productivity of lowland double rice ecosystem. The details of the materials employed and methods followed during course of the investigation are described in this Chapter.

3.1. Materials

The preliminary experiment was laid out in the 'M₈' field and the main experiments in 'M₂' and 'K₉' fields of Wetlands of Tamil Nadu Agricultural University Farm, Coimbatore situated in North Western agro-climatic zone of Tamil Nadu at 11° North latitude and 77° East longitude at an altitude of 426.72 m above MSL.

3.1.1. Climate and Weather

The normal weather conditions of Coimbatore (mean of 50 years) are as follows. The mean annual rainfall was 674.2mm in 45.8 rainy days. The rainfall was distribution pattern was 209.4mm (16.6 rainy days) in south-west monsoon, 305.4 mm (18.7 rainy days) in north-east monsoon, 23.2mm (1.3 rainy days) in winter season and 136.2 mm (9.2 rainy days) in summer season. The annual mean maximum and minimum temperatures were 31.5 (29.4–35.2)°C and 21.0 (17.9–23.8)°C, respectively. The Relative humidity was 84.9 per cent (07.22hrs) and 49.1 per cent (14.22hrs) and the mean solar radiation was 389.7Cal cm⁻² d⁻¹.

The weather conditions that prevailed during the experimental period are furnished in Table 1a and 1b. The Cumulative rainfall, minimum and maximum temperatures are depicted in Fig. 1a and 1b. The amount of rainfall received during the main experiment cropping periods were 214.8mm and 364.0mm, distributed over 13 and 20 rainy days during December-May (2002-2003) and August-February (2003-2004), respectively. The mean maximum temperatures for the same period were 33.2°C and 31.3°C and the minimum temperatures were 21.1°C and 20.4°C, respectively. The recorded solar radiation during the cropping periods was 429.7Cal cm⁻² d⁻¹ and 401.3Cal cm⁻² d⁻¹, respectively.

3.1.2. Soil Characteristics

The soils of the experimental fields were moderately drained, deep clay loam, taxonomically classified as typic *haplustalf*. The soil was neutral in reaction (pH 8.44 to 8.62) with an EC of 0.387 to 0.411 dS m⁻¹ at 25°C. The soil was medium in available nitrogen (319.20 to 352.80 kg ha⁻¹), medium in phosphorus (12.58 to 13.20 kg ha⁻¹) and high in available potassium (716.00 to 720.00 kg ha⁻¹). The physio-chemical properties of the experimental sites are presented in Table 2.

3.1.3. Crop and Varieties

The rice varieties used were CO43, CO45, CO47, ADT36, ADT38, ADT39, ADT40, ADT43, ASD20, TRY1, White Ponni, Ponmani, Bhavani, CORH2 in the preliminary experiment (varietal screening for root activity). From this CORH2 and ADT38 were advanced to the main field experiment. Varietal descriptions of the cultivars used under the study were given in the Table 3.

3.2. Methods

3.2.1. Preliminary field experiment (Varietal screening for root activity)

Effect of drainage on the performance of varieties, rice root activity, growth and yield.

The experiment was laid out in a split plot design with three replications. The layout of the experiment is given in Fig. 2. The details of the treatments are given below.

Main plot treatments

- I₁ – Allow aeration (Restoration of irrigation, after disappearance of previously impounded irrigation water at the beginning of formation of hairline cracks)
- I₂ – Continuous submergence (5±2 cm of standing water) (Restoration 5 cm standing water well before disappearance of previously impounded irrigation water)

Sub plots treatments (Varieties and Hybrid)

Group I (Long and medium duration) (More than 135 days duration)

V₁ – CO43

V₂ – CO45

V₃ – ADT38

V₄ – ADT40

V₅ - TRY1

V₆ – WHITE PONNI

V₇ – PONMANI

V₈ – BHAVANI

Group II (Short duration varieties) (Upto 135 days duration)

V₉ – CO47

V₁₀ – ADT36

V₁₁ – ADT39

V₁₂ – ADT43

V₁₃ – ASD20

V₁₄ – CORH2

Two cultivars one from more tolerant and another from more susceptible to continuous submergence grouped based on preliminary experiment were selected for advancing to the main experiment.

3.2.2. Main experiment

Effect of varieties, hormones and field management on root activity and productivity of puddled lowland rice ecosystem.

The experiment was conducted in a 2 x 3 x 2 Factorial Randomized Block Design (FRBD) with three replications. The layout of the experiment is given in Fig. 3 and the details of the treatments are given below

Factor A (Variety / Hybrid)

V₁ – More tolerance to continuous submergence (CORH2)

V₂ – More susceptible to continuous submergence (ADT38)

Factor B (PGRs)

H₀ – Control

H₁ – Plant growth promoting rhizobacteria (PGPR)

H₂ – Foliar application of salicylic acid @ 100ppm

Factor C (Field management)

F₁- Soil aeration through rotary weeder

F₂- Continuous submergence (Existing practice)

3.2.3. Sowing and planting

The rice seedlings were raised in wet nursery. The seedlings were pulled out from the nursery along with roots and transplanted as single seedling per hill uniformly at 2.5 cm deep in the main field. Thin film of standing water was maintained while planting. The dates of sowing in nursery, transplanting and harvest for each experiment were given in Table 4.

A recommended fertilizer dose of 150:50:50 kg N: P₂O₅: K₂O ha⁻¹ was applied to the main field. Nitrogen and potassium were applied as urea and muriate of potash in four equal splits at basal, active tillering, panicle initiation and heading stages. The entire quantity of phosphorus as single super phosphate along with ZnSO₄ (25 kg ha⁻¹) were applied basally before planting. All the other crop production practices were followed as per the recommended package of practices (CPG, 1999).

3.2.4. Soil disturbance with rotary weeder

The rotary weeder was operated in between the crop rows in one direction in the F₁ treatments for five times at 10 days interval in the main experiment starting from 30 DAT. The operation was carried out by keeping a thin film of water in the plots.

3.2.5. Water management

In the preliminary screening experiment, continuous submergence (I_2) was maintained at 5 ± 2 cm water level while in the other treatment (I_1), irrigation was done immediately after the disappearance of ponded water and formation of hairline cracks. In main field experiment, water level was maintained at a level of 5 ± 2 cm standing water in all the plots. Irrigation was suspended seven days before expected harvest.

3.2.6. Foliar application of salicylic acid

Foliar application of salicylic acid @ 100 ppm was done to the respective treatments at active tillering, panicle initiation and heading stages of rice crop.

3.2.7. PGPR – Plant Growth Promoting Rhizobacteria

The PGPR was applied to the rice in the following methods:

3.2.7.1. Seed treatment

Rice seeds were treated with *Pseudomonas fluorescens* PF₁ formulation @ 10g per kg of seeds and soaked the seeds in water for over night. The excess water was decanted and the seeds were allowed for sprouting by keeping the seeds in dark for 24 hrs before sowing.

3.2.7.2. Seedling root dipping

Pseudomonas formulation was applied @ 2.5 kg to the stagnated water in an area of 25 sq. m. The roots of the seedlings after pulling out were dipped in it for a brief period of 30 minutes before transplanting.

3.2.7.3. Soil application

Pseudomonas formulation along with 50 kg of well decomposed FYM was applied @ of 2.5 kg ha^{-1} during 30, 45, 60 and 75 DAT.

3.2.8. Plant protection

Adequate prophylactic plant protection measures were taken for both nursery and main field as per the recommended package of practices (CPG, 1999).

3.2.9. Harvesting and thrashing

Staggered harvesting of individual varieties was done based on maturity. Border rows all around the plots and the sample rows were harvested first and a net plot area were harvested and threshed separately. The grain yield was estimated at 14 per cent moisture and the straw yield was recorded after sun drying.

3.3. Biometric observation

For taking various biometric observations following techniques were used

3.3.1. Plant sampling

Plant samples with roots intact, were collected at important growth stages from the sampling row to assess biomass. Fresh samples were used for enzyme estimation studies. Care was taken that no loose or dead leaf material was lost from the plants during sampling. The plants were uprooted carefully with roots intact and the soil adhering to the roots was washed over a piece of plastic wire mesh under running tap water to avoid loss of roots.

3.3.2. Sample size

Sample size consisted of five hills per plot. Samples representing the average hill size (in tiller number) were selected from sampling area avoiding border rows. This kind of restricted sampling as well as maintaining random sampling procedure was followed to get relatively high precision and accuracy.

3.3.3. Growth components

The following growth characters were recorded at active tillering, panicle initiation, heading and maturity stages.

3.3.3.1. Plant height

The plant height was measured from the base of the plant to tip of the leaf or flag leaf in all sampled plants and the average was worked out to express in cm.

3.3.3.2. Total dry matter production

The plant samples collected along with roots were initially sun dried and then oven dried for 48 hours at 70 °C. The weight of the dried samples were recorded and expressed as kg ha⁻¹.

3.3.3.3. Tiller density

Tiller density was recorded by counting the number of tillers in 20 hills per plot and the mean value was used to compute the tiller density per m².

3.3.3.4. Leaf area index

Leaf area index (LAI) was calculated by taking length and breadth of fully expanded third leaf from the top of the tiller and the LAI was arrived by using the following formula as suggested by Palaniswamy and Gomez (1974).

$$LAI = \frac{L * W * K * \text{Number of leaves hill}^{-1}}{\text{Groundarea occupied hill}^{-1}}$$

Where,

L = Leaf length W = Leaf width K = Constant factor (0.73)

LAI was recorded at active tillering, panicle initiation, heading and maturity stages.

3.3.4. Yield and Yield components

3.3.4.1. Productive tillers

The panicle bearing tillers were counted from the five hill samples obtained before harvest and was expressed as productive tillers hill⁻¹.

3.3.4.2. Total number of spikelets, filled grains and illfilled grains

The panicles obtained from single hill were threshed, separated and counted for filled and illfilled grains to express as number per hill.

3.3.4.3. Sterility percentage

The sterility percentage was computed using the following formula

$$\text{Sterility percentage} = \left(\frac{\text{Illfilled grains hill}^{-1}}{(\text{Illfilled grains hill}^{-1} + \text{Filled grains hill}^{-1})} \right) \times 100$$

3.3.4.4. Test weight

One thousand filled grains were taken at harvest from each plot and weighed at 14 per cent moisture to express as test weight in grams.

3.3.4.5. Harvest index

The harvest index was calculated by using the following formula

$$\text{Harvest Index} = \frac{\text{Economic yield (Grain yield)}}{\text{Biological yield (Grain yield + Straw yield)}}$$

3.4. Observations on root

3.4.1. Root volume

The roots scooped along with soil to a depth of 45 cm and whole plant were washed carefully in running water and then washed with distilled water. The roots were detached from their nodal bases and the excess moisture on the surface of the roots was removed wiping with filter paper. Then the volume of the roots were measured by volume displacement method and expressed as cc hill⁻¹.

3.4.2. Root length

Ten randomly selected rootlets were weighed and their length was measured and totaled from the roots drawn for the 'root volume' measurement. The total length was calculated by using the weight of the total roots at the same moisture level as follows:

$$\text{Total root length (cm per hill)} = \left(\frac{\text{Weight of the total roots (g)}}{\text{Weight of the sample root (g)}} \right) \times (\text{length of sample root (cm)})$$

3.4.3. Root activity as observed through colour of the roots

Based on the colour of the roots, the roots were differentiated and graded as active, moderately active and less active as suggested by Chen (1983). The roots having white colour are considered as active while, brown and black colour were determined as moderately active and less active roots, respectively. The proportion of different coloured roots was visually scored at different stages viz., active tillering, panicle initiation, heading and maturity stages immediately upon uprooted the hill and washing in the field itself.

3.5. Biochemical analysis

3.5.1. Leaf chlorophyll

Chlorophyll 'a', chlorophyll 'b' and total chlorophyll contents were estimated following the method suggested by Yoshida *et al.* (1971) and expressed as mg g⁻¹ fresh weight of leaf. Chlorophyll was extracted in 80% acetone and their optical density readings were read out at 663 nm, 645 nm and 652 nm in a spectrophotometer. The amount of chlorophyll present was calculated using the following formula:

$$\text{Chlorophyll 'a' (mg per g tissue)} = \frac{12.7(\text{OD value at 663nm}) - 2.69(\text{OD value at 645nm})}{1000 \times W} \times V$$

$$\text{Chlorophyll 'b' (mg per g tissue)} = \frac{22.9(\text{OD value at 645nm}) - 4.68(\text{OD value at 663nm})}{1000 \times W} \times V$$

$$\text{Total chlorophyll (mg per g tissue)} = \frac{\text{OD value at 652nm} \times 1000 \times V}{34.5 \times 1000}$$

Where,

OD – Absorbance at specific wavelength

V – Final volume of chlorophyll extract in 80% acetone

W – Fresh weight of tissue extracted

3.5.2. Peroxidase

One gram sample was extracted in 5ml of 0.1M phosphate buffer pH 7 at 4°C. The homogenate was centrifuged at 15,000 rpm for 30 min for enzyme extraction. Aliquot of one ml extract was added at zero time (without lapse of time) to each tube containing 3ml of 0.1M phosphate buffer (pH 7), 0.5ml of 0.05N hydrogen peroxide and 0.5ml of 1.0 per cent aqueous solution of pyrogallol. The optical density was followed continuously for 3 min at 430nm using spectrophotometer. The result was expressed as change in optical density per gram for a min (Putter, 1974).

3.5.3. Superoxide dismutase

Superoxide dismutase (SOD) activity was determined by using nitro blue tetrazolium (NBT) salt as described by Beau-Champ and Fridovich (1971) and expressed in enzyme units (EU) of fresh weight of leaf sample. The reagents using in the enzyme assay are given in Table 5.

The absorbance was measured at 560 nm. The SOD activity was measured using the following equations

$$\text{Absorbance of reference blank} = X$$

$$\text{Absorbance of sample} = Y$$

$$\frac{X-Y}{X} \times 100 = Z\% \text{ inhibition}$$

$$50\text{per cent inhibition} = \frac{Z}{50} = A \text{ units}$$

i.e., 50 µl enzyme extract yielded A unit

∴ 1000 µl yield $A/50 \times 1000 = B$ unit g^{-1} (EU)

3.5.4. Root ATPase

The enzyme was assayed by estimating the inorganic phosphate released from ATP. The assay mixture (2 ml) contained 100 mM Tris-HCl buffer, pH 7.5, 5 mM ATP, 40 mM KCl and 80 mM NaCl. After incubation for 20 min at 35°C the reaction was stopped by adding 1 ml of 10 per cent trichloroacetic acid and the samples were cleared by centrifugation at 10,000 rpm for 10 min. The following control sets were run (i) zero time control, (ii) boiled enzyme extract and (iii) without ATP – to check endogenous phosphate, non-enzymatic ATP hydrolysis and unspecific phosphatase activity. The released inorganic phosphate was determined by the method of Ames (1966).

3.5.5. Catalase

Plant samples (1.0g) were macerated with 10ml of 0.1M phosphate buffer pH 7.0 in a prechilled mortar and pestle. Centrifuged at 15,000 rpm for 30 min at 4°C. The supernatant was used as enzyme source. Pipette out 3ml of phosphate buffer, 2ml of H₂O₂ and 1ml of enzyme extract into a test tube. The activity was arrested after 5 minutes by adding 10ml of 0.7N H₂SO₄ and titrated with 0.025N potassium permanganate, to find out the residual H₂O₂ until a faint purple colour persists for atleast 15 sec. Prepare the blank by adding the enzyme extract, 3ml of buffer, 2ml of H₂O₂ and 1ml of H₂SO₄ at zero time and was also titrated against potassium permanganate. The difference in titre value gives mg of hydrogen peroxide destroyed by catalase. Using the factor of one ml 0.025N KMnO₄ = 0.425 mg H₂O₂, the activity of the enzyme was expressed as mg H₂O₂ $g^{-1} h^{-1}$ (Chance and Machly, 1955).

3.5.6. Soluble protein

Soluble protein content of leaf was estimated as per the method of Lowry *et al.* (1951) and expressed as mg g^{-1} .

3.5.7. Root CEC

The CEC of root was estimated by using the method suggested by Crooke (1964). A known quantity of dry root samples was placed in a beaker and moistened with few drops of distilled water to prevent floating during the next stage. 200 ml of 0.01 N hydrochloric acid was added and stirred intermittently for five minutes. The root materials was allowed to settle and acid was quickly decanted through Whatman No.1 filter paper. The sample was washed free of chloride with distilled water. Then the filter paper was pierced collecting the root material in a beaker by washing with 200 ml of 1 M potassium chloride (pH 7.0). The pH of the suspension was determined and enough 0.01 N KOH was added to the suspension to restore to pH 7.0 to maintain the pH during the arbitrary five minutes titration time. From the volume of 0.01 N KOH consumed to restore to pH 7.0, root CEC was calculated and expressed as $me\ 100^{-1}$ g of dry roots.

3.6. Chemical analysis

3.6.1. Soil analysis

Initial soil samples of the experimental fields were collected from 0-15 cm depth and analysed for physical and chemical characters. The samples were shade dried, powdered, sieved through 2mm sieve and then used for analysis. The methods employed and the analytical results obtained are tabulated in the Table 2.

3.6.2. Soil redox potential

The redox potential was measured by the platinum electrode method. In this method, when a platinum electrode is introduced in the system, it registered the electron potential of the system. The voltage recorded in the pH meter is known as the redox potential (Eh) (Hesse, 1971).

3.6.3. Water analysis

3.6.3.1. Dissolved oxygen

Dissolved oxygen content of water samples was estimated as per the method of Anon (1965) and expressed as mg L⁻¹.

3.8. Statistical analysis

The data on various characters and analysis studied during the course of investigation were statistically analyzed as suggested by Gomez and Gomez (1984). Whenever the treatment differences were found significant by the 'F' test, critical differences were constructed at 5 per cent probability level and the values were furnished in the respective table. The treatment differences that were non-significant at 5 per cent were denoted as "NS".

3.9. Economic analysis

The cost of cultivation was worked out for all the treatment studied. Gross return, net return ha⁻¹ and benefit cost ratio, were also calculated.

Table 2. The physio-chemical properties of the experimental fields

Particulars	M ₈	M ₂	K ₉
A. Mechanical analysis (Piper, 1966)			
Clay (%)	44.0	45.1	32.5
Silt (%)	19.7	18.4	22.4
Fine sand (%)	21.5	21.3	27.0
Coarse sand (%)	14.7	15.0	18.0
Texture	Clay loam	Clay loam	Clay loam
B. Chemical analysis			
pH (1:2.5 water suspension) (Piper, 1966)	8.62	8.60	8.44
EC (dS m ⁻¹) (Piper, 1966)	0.387	0.411	0.398
Organic carbon (%) (Walkley and Black, 1934)	0.64	0.64	0.63
Available N (kg ha ⁻¹) (Subbiah and Asijah, 1956)	319.20 (Medium)	324.80 (Medium)	352.80 (Medium)
Available P ₂ O ₅ (kg ha ⁻¹) (Olsen <i>et al.</i> , 1954)	12.94 (Medium)	12.58 (Medium)	13.20 (Medium)
Available K ₂ O (kg ha ⁻¹) (Stanford and English, 1949)	718.00 (High)	716.00 (High)	720.00 (High)

Table 3. Varietal description

Varieties	Parentage	Duration (Days)	Grain yield (kg ha ⁻¹)	Test weight (g)	Habit	Rice colour	Grain type	Panicle
CO43	Dasal X IR20	135-140	5200	20.00	Erect	White	Medium slender	Long dropping
CO45	Rathu Heenathi/ IR3403- 267-1	135-140	5800	24.90	Erect	White	Long lender	Long and dense
CO47	IR50 / CO43	110-115	5832	----	Semi dwarf	White	Medium slender	Long dropping
ADT36	Triveni X IR20	110	4000	20.60	Erect	White	Medium	Long compact
ADT38	IR1529-680-3-2 /IR4432- 52-6-4 /IR7963-30-2	130-135	6200	21.00	Semi dwarf, erect	White	Long slender	Long moderately dense
ADT39	IR8 / IR20	120-125	5000	18.00	Semi dwarf	White	Medium slender	Medium moderately dense
ADT40	RPW 6-13 / Sona	145-150	4690	25.20	Semi dwarf, erect	White	Short bold	Well exerted

Table 3. Contd...

Varieties	Parentage	Duration (Days)	Grain yield (kg ha ⁻¹)	Test weight (g)	Habit	Rice colour	Grain type	Panicle
ADT43	IR50 / Improved Pooni	110	----	15.50	Semi dwarf	White	Medium slender	Moderately long, Intermediate type, dropping
ASD20	IR18348/ IR25863/ IR58	110	----	22.08	Erect	White	Long slender	Medium compact
TRY1	IR578-172-2-2/ SR-1-2B-1	135-140	5255	24.00	Erect	White	Medium	Long moderately compact
White Ponni	Taichung 65/2 Mayang Ebos-80	135-140	4500	16.40	Medium tall	White	Medium slender	Long dropping
Ponmani	Pankaj X Jagananth	155-160	5300	23.50	Erect	White	Medium slender	Long dropping
Bhavani	Peta X BPI76	130-135	5000	21.50	Medium tall	White	Long slender	Long compact
CORH2	IR58025/ IR66R	115	----	23.80	Semi dwarf	White	Medium	Compact

Table 4. Experiment details

Sl. No.	Particulars	Preliminary screening experiment	Main experiment I	Main experiment II
1.	Season	<i>Navarai</i> 2002-2003	<i>Samba</i> 2003	<i>Thaladi</i> 2003-2004
2.	Date of sowing	13.12.2002	01.08.2003	06.10.2003
3.	Date of transplanting	08.01.2003 20.05.2003	02.09.2003	07.11.2003
4.	Date of harvest	(Long duration varieties) 16.04.2003 (Medium duration varieties) 06.04.2003 (Short duration varieties)	19.12.2003 (CORH2) 19.12.2003 (ADT38)	01.03.2004 (CORH2) 01.03.2004 (ADT38)
5.	Spacing (cm)*	20 X 10	20 X 10	25 X 10
6.	Gross plot size (m ²)	2.0 X 1.5	5.0 X 4.0	5.0 X 4.0
7.	Net plot size (m ²)	-	4.4 X 2.0	4.4 X 2.0
8.	Recommended Fertilizers			
	N (kg ha ⁻¹)	150	150	150
	P ₂ O ₅ (kg ha ⁻¹)	50	50	50
	K ₂ O (kg ha ⁻¹)	50	50	50
	ZnSO ₄ (kg ha ⁻¹)	25	25	25

* based on experience gained from experiment I in operating rotary weeder the spacing of experiment II was altered.

Table 5. SOD Reagents

Sl. No.	Stock	Working solution	Total volume
1.	Riboflavin 200 μ M (100X) 3.8 mg/50ml	2 μ M	30 μ L
2.	Buffer 250 mM (5X) KH_2PO_4 3.402g/100ml	50 mM	600 μ L
3.	Methionine 130 mM (10X) 0.9698 g/50ml	13 mM	300 μ L
4.	EDTA monosodium salt 10 mM (100X) 0.3722 mg/5ml	0.1 mM	30 μ L
5.	NBT 7500 μ M (100X) 4.08 mg/5ml	75 μ M	30 μ L
6.	Enzyme extract in phosphate buffer (pH 7.8)	-	50 μ L
7.	Distilled water		
	i. For sample	-	1.96
	ii. Blank (NBT – enzyme extract)	2.04	-
	iii. Reference blank (Enzyme)	-	2.01

CHAPTER IV

RESULTS

Preliminary and main field experiments were conducted at wetland farm of Tamil Nadu Agricultural University during *Navarai* 2002 – 2003, *Samba* 2003 and *Thaladi* 2003 -2004. The preliminary study was to find out the effect of drainage on the performance of varieties, root activity and yield of puddled lowland rice. The objectives of main field experiments were to find out the effect of genotypes, hormones and field management on root activity and productivity of puddle lowland rice ecosystem. The results obtained from these experiments are presented in this chapter.

4.1. Preliminary field experiment (*Navarai* 2002 – 2003)

A total of 14 varieties including a hybrid were, grouped as more than 135d duration and up to 135d duration varieties. These were screened for their ability to withstand continuous submergence under puddled lowland rice ecosystem.

4.1.1. Growth components

4.1.1.1. Plant height

The data on plant height of different rice varieties recorded at active tillering (AT), panicle initiation (PI), heading (H) and maturity (M) stages are presented in Table 6.

There were differences in plant height due to varieties but not due to aeration treatments. Allowing aeration as compared to continuous submergence had relatively tall plants. Among the varieties, more than 135d duration had relatively taller plants. During heading stage, White Ponni (V₆) was the tallest and ASD20 (V₁₃) was the shortest.

4.1.1.2. Number of leaves (Table 7)

In general green leaf production increased with the growth of the crop up to heading stage. Provision of aeration (I₁) did influence the production of green leaves at PI but not sustained till maturity stage though there was some numerical advantage.

Varietal difference on leaves per hill was significant among the varieties. Varieties with less than 135d duration varieties had relatively higher number of leaves at maturity.

4.1.1.3. Leaf area index (LAI) (Table 8)

LAI increased up to heading and registered a maximum value of 9.29 and declined to 5.86 at maturity. Allowing aeration as compared to continuous submergence recorded higher value of LAI at AT and PI stages. During H and M stages, the LAI remained unaffected by the field management practices. The performance of genotypes on LAI varied in relation to crop stages. At AT stage ADT36 (V₁₀) registered significantly higher LAI of 1.07 followed by CORH2 (V₁₄) (0.91). During PI and H stage, CO45 (V₂) registered significantly higher LAI of 4.98 and 13.00, respectively. However, at the M stage ADT39 (V₁₁) registered higher LAI of 8.54. Field management (I) X genotype (V) interaction was found to be significant during early stages of rice (AT and PI), while at later stages viz., H and M, interaction was found to be non-significant.

4.1.1.4. Total photosynthetic area (Table 9)

Total photosynthetic area increased up to H stage and showed a sharp decline towards maturity. Among the field management studies, provision of aeration, through irrigation management (I₁) significantly increased the total photosynthetic area as compared to continuous submergence (I₂) at AT and H stages of crop growth. Among the genotypes studied, the genotype behaviour varied with crop stages. Similar to that of LAI, the total photosynthetic area was also found to be higher with ADT36 (V₁₀), CO45 (V₂) and ADT39 (V₁₁) during AT, PI, H and M stages, respectively.

4.1.1.5. Number of tillers

The data on number of tillers per hill are presented in Table 10.

Tiller production also increased up to heading. Number of tillers showed a differential behaviour among genotypes with respect of stages. Among the field

management, the difference between managements was not significant. However, at PI stage I₁ treatment significantly increased the number of tillers per hill as compared to I₂. In respect of genotypes, at AT stages ADT36 (V₁₀) produced more number of tillers and the least number was recorded by CO45 (V₂). During PI stage, ADT38 (V₇) produced higher number of tillers followed by Ponmani (V₇). At H stage, ADT38 (V₃) produced more number of tillers per hill followed by CO43 (V₁). At M stage Ponmani (V₇) registered significantly higher number of tillers as compared to other genotypes.

The interaction impact was not significant at all the growth stages.

4.1.1.6. Shoot dry matter production (DMP)

The data on shoot DAP per hill recorded at AT, PI, H and M are presented in Table 11.

The shoot DMP was consistently higher at all the growth stages in the plots that were given with aeration (I₁). At the early stage of crop growth (AT), CORH2 (V₁₄) recorded significantly higher shoot DMP. During PI stage, TRY1 (V₅) produced more shoot DMP of 10.08 g per hill followed by ADT38 (V₃) (9.25). At H stage, ADT40 (V₄) registered higher shoot DMP. During M stage of crop Ponmani (V₇) recorded higher shoot DMP followed by ADT40 (V₄). Field management and genotypes interaction was found to be significant at PI, H and M stages. TRY1 (V₅) during PI and ADT40 (V₄) during H and M stages among other varieties when provided with aeration rather than without aeration (submergence) recorded higher shoot DMP.

4.1.1.7. Root dry matter production (DMP) (Table 12)

There was steady increase in the weight of root biomass till H stage. Afterwards it declined at M stage. Provision of aeration (I₁) favoured the root growth showing higher root DMP than the continuous submergence (I₂) at AT, PI and H stages of crop growth. However, at M stage, I₁ did influence root DMP. The higher root DMP was recorded by ADT36 (V₁₀) followed by CO47 (V₉) and ADT39 (V₁₁) at

AT and PI stages, respectively. Ponmani (V₇) produced significantly higher root DMP at H and M stages followed by White Ponni (V₆).

Interaction effect was found to be significant at AT, H and M stages. ADT36 (V₁₀) during AT, and Ponmani (V₇) during H and M stages when provided with aeration recorded higher root DMP.

4.1.1.8. Total dry matter production (TDMP)

The data on TDMP recorded at AT, PI, H and M stages are presented in Table 13.

TDMP was significantly reduced under continuous submergence situation and the reduction was more at heading (30.25%) than at M stage (23.71%). TRY1 (V₅) recorded significantly higher TDMP followed by ADT36 (V₁₀) at PI stage. During H and M stages Ponmani (V₇) produced significantly higher TDMP, which was on par with ADT40 (V₄).

The impact of interaction between field management and genotypes during early stage of crop growth (AT) was not significantly influenced for TDMP. However, during the other crop growth stages, the interaction effect was found to be significant. ADT43 (V₁₂) during PI, White Ponni (V₆) and Ponmani (V₇) during heading and ADT40 (V₄) and Ponmani (V₇) during maturity stages all under aerated soil condition registered increased TDMP then when compared to their respective other treatments.

4.1.1.9. Root volume (Table 14)

In general, the root volume tends to increase up to heading stage while thereafter reduced considerably. Significant influence by allowing aeration (I₁) on root volume was observed at AT, PI and M stages of crop growth. Root volume was significantly reduced under continuous submergence condition and the reduction was higher at AT (27.08%) than at M (27.45%) stages. At AT stage, ADT36 (V₁₀) and Bhavani (V₈) recorded equal and higher root volume, while CO43 (V₁) relatively

recorded lower root volume of 1.55 cc per hill. During H stage, White Ponni (V₆) recorded significantly higher root volume followed by Ponmani (V₇) and ADT40 (V₄). At M stage, CORH2 (V₁₄) retained more root volume of 18.34cc per hill followed by Ponmani (V₇). The lowest root volume was recorded in ASD20 (V₁₃) and ADT38 (V₃).

The interaction effect was significant at AT, H and M stages. At peak growth stages (H), White Ponni (V₆) recorded higher root volume of 57.33 cc per hill under allowing aeration treatment (I₁), while the lowest root volume of 17.33 cc per hill was recorded in CO47 (V₉) with continuous submergence. At M stage, CORH2 (V₁₄) produced significantly more root volume under allowing aeration treatment (I₁).

4.1.1.10. Total root length (Table 15)

The total root length was increasing up to heading stage with sharp decline during M stage of crop growth. The provision of aeration (I₁) by irrigation schedule significantly increased the total root length at PI, H and M stages. At early stage of crop growth (AT) the field management did not influence the total root length. Among the genotypes tested, CO43 (V₁) during PI, Ponmani (V₇) during H and ADT40 (V₄) during M stages recorded significantly higher total root length per hill.

The interaction between field management and varieties tested were not significant during all the stages.

4.1.1.11. Root CEC

The data on root CEC recorded at AT, PI, H and M stages are presented in Table 16.

Root CEC was significantly higher under allowing aeration (I₁) situation and the difference between field managements was more at M (28.51 per cent). At early stages (AT and PI) the impact of allowing aeration (I₁) was non realized. During AT stage, the root CEC was significantly influenced by genotypes. Among the genotypes

studied, TRY1 (V₅) recorded higher root CEC of 16.80 me/100 g dry roots followed by ADT38 (V₃) genotype at AT stage. During PI stage, the CORH2 (V₁₄) registered significantly higher root CEC.

The interaction effect of field management and genotypes did not vary at all the stages of crop growth.

4.1.2. Yield components

4.2.2.1. Number of productive tillers

The data on mean productive tillers per hill recorded for each treatment at harvest stage are presented in Table 17.

The number of productive tillers per hill was not altered due to the two field management strategies followed whereas, genotypes differed largely on this parameter. Among the genotypes studied, Ponmani (V₇) produced significantly more (12.43) productive tillers followed by ASD20 (V₁₃) (11.17). The least number of productive tillers per hill was recorded in ADT38 (V₃) (8.30) and Bhavani (V₈) (7.67).

The interaction effect was not influenced between the treatments.

4.1.2.2. Test weight (Table 17)

The test weight was not altered significantly due to field management practice. Genotypes differed as per their genetic potential. The genotype, TRY1 (V₅) registered higher test grain weight (25.60g) followed by ADT40 (V₄) (23.92g) and CORH2 (V₁₄) (23.18g). The grain weight of ADT43 (V₁₂) was the lowest (16.45g).

The interaction between field management and genotypes was not seen.

4.1.2.3. Panicle length

The mean data on panicle length recorded at harvest stage are presented in Table 17.

Provision of aeration did not influence the panicle length. Among genotypes studied, CO45 (V₂) recorded significantly higher panicle length of 25.05cm followed by TRY1 (V₅) (23.68cm). The shortest panicle length was recorded in CO47 (V₉) (18.41cm).

The interaction between treatments did not found to be significant.

4.1.2.4. Number of filled, ill filled spikelets and sterility percentage (Table 18)

The variation in the number of filled and ill filled spikelets hill⁻¹ was found to be significant between the field management practices and the genotypes tested. However, the sterility percentage variation could only be seen between field management practices.

The soil aeration through irrigation regime (I₁) had significant influence to produce more number of filled spikelets and thus reduced the number of illfilled spikelets hill⁻¹. Similarly soil aeration treatment recorded lower sterility percentage. Among the 14 genotypes tested, CORH2 (V₁₄), CO47 (V₈) and ADT43 (V₁₂) had recorded higher number of filled spikelets per hill.

The genotypes (V₁ to V₈) which had more than 135d of duration had significantly less number of illfilled spikelets when compared to those genotypes with field duration of less than 135d (V₉ to V₁₄). Within the lower duration group ADT36, ADT43 and ASD20 had lower number of ill filled spikelets per hill. The genotypes, did not differ among them in their sterility percentage and ranged from 29.61 (White Ponni – V₆) to 41.01 (CO43 – V₁). The interactions were found to non significant.

4.1.2.5. Grain yield (Table 19)

Grain yield varied to genotypes and within duration groups. Field management of soil aeration through irrigation schedule had 6175 kg ha⁻¹ compared to 5728 kg ha⁻¹

in continuous standing water. Among the genotypes tested White Ponni (V₆), Bhavani (V₈), CORH2 (V₁₄), ADT40 (V₄) and TRY1 (V₅) had produced significantly at par and higher grain yield than those of other genotypes. The other genotypes were significantly at par and produced lower grain yield. The lowest grain yield was recorded with ASD20 (V₁₃).

The interaction between field management and genotypes were non significant.

4.1.2.6. Straw yield (Table 19)

The straw yield variation was also found to be significant within genotypes rather than the field managements studied. Bhavani (V₈), CORH2 (V₁₄), White Ponni (V₆) and TRY1 (V₅) were found to be on par and higher in regarding straw yield. The other genotypes except ADT40 (V₄) were at par and less in their straw yield.

The interaction effect was non significant.

4.1.2.7. Harvest index (HI) (Table 19)

Both the genotypes and field managements had not influenced the HI significantly and the HI ranged from 0.38 to 0.43.

4.1.3. Redox potential and dissolved oxygen (Table 20 and 21; Fig.3a)

Provision of allow aeration plots (I₁) moderately improved the redox potential of puddled lowland soil as compared to continuous submergence (I₂). Under this situation, redox potential was recorded +90 to -140mV and +135.9 to -160.5mV, group I and group II fields, respectively. The soil aeration recorded higher dissolved O₂ in the soil solution as compared to continuous submergence.

4.1.4. Correlation regression analysis (Table 22)

The degree of association of grain yield to various independent characters where analysed through simple correlation regression studies. TDMP at the time maturity had positive correlation with the grain yield. Root characters like root biomass, root volume, root length, root CEC were found positively correlated with

grain yield. Similarly grain yield was influenced positively by number of filled grains per hill. Sterility percentage was related very much with grain production.

4.2. Main field experiments

4.2.1. Growth components

4.2.1.1. Plant height (Table 23)

Among the two genotypes tested, CORH2 *i.e.*, more tolerant to continuous submergence recorded the highest plant height when compared to the other variety (ADT38) in *Samba* season. The similar trend was also noticed in the *Thaladi* season. The two PGRs *viz.*, Pseudomonas and salicylic acid resulted in comparatively taller plants when compared to control in both the seasons. However, salicylic acid treatment during PI stages of *Thaladi* produced significantly taller plants. In general the plant height remains higher in soil aerated treatment compared to the existing practice.

Interaction among variables was not observed.

4.2.1.2. Number of green leaves (Table 24)

Green leaf production increased with the growth of crop up to heading stage in both *Samba* and *Thaladi* season but the green leaf production was comparatively higher in *Thaladi* season. The hybrid, CORH2 produced significantly more number of green leaves compared to ADT38. The same trend was observed in *Thaladi* season. Pseudomonas and salicylic acid recorded significantly more number of green leaves compared to control during later growth stages of *Thaladi* rice. Lack of aeration (F₂-Existing practice) resulted in numerically less number of leaves compared to provision of aeration through rotary weeder at all the four stages of crop growth in both seasons.

Interactions were non significant at all the four stages of observation made.

4.2.1.3. Number of tillers (Table 25)

The number of tillers m^{-2} of the genotypes tested varied significantly between them at all the stages during both the seasons. CORH2 which is tolerant to the continuous submergence recorded more number of tillers m^{-2} in all the stages.

The PGRs application brought a significant increase in the number of tillers m^{-2} when compared to control particularly during *Thaladi* than at *Samba*. Within the PGRs, salicylic acid application increased the number of tillers m^{-2} at all the stages excepting active tillering stage.

Leaving the soil under continuous submergence or aerating frequently through rotary weeder did not influence the tiller number m^{-2} during all the stages of *Samba* and early stages of *Thaladi*. However, soil aeration had increased significantly the tiller number of crops at heading and maturity stages of *Thaladi* season.

Interaction effects were not significant at all the four stages of observation made.

4.2.1.4. Root volume (Table 26)

The root volume increased up to heading and then declined towards maturity stage. CORH2 the hybrid recorded significantly higher root volume at all the stages of crop growth both in *Samba* and *Thaladi* seasons compared to ADT38.

The root volume did not change within the PGRs during *Samba* season. However, during *Thaladi*, pseudomonas at the early stages (AT) and salicylic acid during mid stages (PI and H) registered an increased root volume over these respective treatments.

The field management treatment had registered a significant impact during panicle initiation and heading stages than at other stages in both the seasons. Aerating the soil rather than continuous submergence recorded significantly higher root volume in both the seasons at the above said stages.

4.2.1.5. Total root length (Table 27)

Total root length showed an increasing trend up to heading stage and thereafter decreased towards maturity. The total root length was significantly longer with

CORH2 (V_1) than ADT38 (V_2) at all the stages of crop growth during both the seasons.

Among the PGRs treatment studied, lengthier root was registered in salicylic acid (H_2) followed by pseudomonas (H_1) at heading stage of *Thaladi* season. The total root length increased with the provision of soil aeration but the increase was non significant during active tillering and maturity of both the seasons. At panicle initiation and heading stages, soil aeration treatment recorded significantly higher total root length in *Thaladi* and *Samba* seasons, respectively.

4.2.1.6. Shoot dry matter production (DMP) (Table 28)

Shoot biomass was relatively higher in *Thaladi* than *Samba* season. It steadily increased till heading and declined at harvest. The shoot DMP was significantly higher in CORH2 (V_1) when compared to ADT38 (V_2) at all the stages of observation during both the seasons.

Pseudomonas application registered an increased shoot DMP at the vegetative and maturity stage of *Samba* season than the other treatments. The mid stages of crop growth (PI and H) of *Samba* season did not produce significant variation among PGRs and in that salicylic acid recorded higher shoot DMP.

The field management treatments were unable to establish a significant variation in shoot DMP of the crop at all the stages during both the season except PI and M stages of *Thaladi*.

4.2.1.7. Root dry matter production (DMP) (Table 29)

Root DMP increased up to H stage and thereafter progressively decreased during both the seasons. The root growth of *Thaladi* rice was faster and attained the

maximum weight quite earlier than *Samba* season crop. Among the two genotypes CORH2 registered significantly higher root biomass at all the stages. In respect of PGRs studied, the difference between treatments was significant during heading and maturity stages of *Samba*. However, in *Thaladi* season all the stages of crop growth exhibited significant variation in root biomass. Among the two PGR treatments F₂ (salicylic acid) recorded significantly higher root biomass followed by pseudomonas (F₁) application during Panicle initiation, heading and maturity stages. Field management even though did not produce significant variation, provision of soil aeration (F₁) favoured the root growth showing numerically higher weight than the practice of continuous submergence (F₂).

4.2.1.8. Total dry matter production (TDMP) (Table 30)

In general there was steady increase in TDMP from AT to M stages. Among the two genotypes, CORH2 registered significantly higher TDMP at all the stages of observation in both the seasons. The TDMP was significantly higher by PGRs treatments as compared to control, in all the stages of crop growth. Salicylic acid (H₂) and pseudomonas recorded on par TDMP, especially at heading and maturity stages in both the seasons. Provision of soil aeration (F₁) did not influence the TDMP in *Samba* season but in *Thaladi* season it favoured higher TDMP at PI, H and M stages of crop growth.

Total dry matter accumulation did not vary with the interaction of variables.

4.2.1.9. Leaf area index (LAI) (Table 31)

LAI increased up to heading stage and thereafter declined till M stage. CORH2 recorded significantly higher LAI as compared to ADT38 at all the stages in both the crop seasons. In respect of PGRs treatment the LAI was significantly higher in pseudomonas (H₁) application during early stage (AT) of crop growth in *Samba* crop, while it was on par with the salicylic acid treatment (H₂) at all stages in *Thaladi* season crop. During *Samba* season, both salicylic acid and pseudomonas treated

plants recorded significantly higher and on par LAI as compared to control, during panicle initiation, heading and maturity stages.

The field management practices followed had exhibited a remarkable variation in LAI during heading stage of both the seasons. Soil aeration imposed through rotary weeder had clearly recorded higher LAI during all the stages particularly more so in heading stage.

Interaction among variables was not observed.

4.2.1.10. Total photosynthetic area (TPA)

The data on total photosynthetic area per hill at AT, PI, H and M stages are given in Table 32.

TPA also followed trend of LAI. Hybrid CORH2 recorded significantly higher TPA at all the stages of crop growth in both the seasons. Among the PGRs, salicylic acid spray (H_2) had registered significantly higher values of TPA at panicle initiation stage, while it was on par with the pseudomonas application (H_1) at later stages of heading and maturity in both the seasons of study. Provision of soil disturbance (F_1) as compared to continuous submergence (F_2) had produced significantly higher value of TPA at panicle initiation, heading and maturity stages of crop growth particularly in *Thaladi* season.

4.2.1.11. Root activity (Table 33 and 34)

The percentage of white, brown and black roots was found to be insignificant during active tillering and panicle initiation stages between genotypes, PGRs and field management variables of both the seasons. However, the variation among the genotypes, PGRs and field management practices was seen during heading stage during both the seasons. The dead root or black roots was found to be more in ADT38, without PGR application and continuous submergence treatments during both the seasons. The PGRs application had controlled the percentage of black roots up to heading stage, whereas during maturity it was found on par with control. But,

aerating the soil rather than continuous submergence had kept the black root percentage under control from active tillering till maturity during both the seasons.

4.2.1.12. SPAD values (Table 35)

In all the stage viz., PI, H and M stages of *Samba* and *Thaladi* CORH2 (V₁) hybrid recorded increased SPAD values than the other genotype ADT38 (V₂). But within seasons the SPAD value variation at all stages was inconspicuous. The PGRs even did not produce a significant variation than control until PI in both the seasons but during heading and maturity there was significant variation. Similar results were seen between field management practices, where the soil aeration influenced the SPAD value at H and M stages.

4.2.1.13. LCC values (Table 36)

The LCC values recorded during PI, H and M stages of the two genotypes tested exhibited significant variation. In all these stages during both the seasons CORH2 (V₁) recorded higher LCC values as that of SPAD values. The PGRs application had influenced the LCC values significantly at later stages (heading and maturity). Similarly the field management practices had significant variation during maturity stage of both the seasons.

4.2.2. Biochemical study

4.2.2.1. Chlorophyll 'a' content

The data on chlorophyll 'a' content recorded at PI, H and M stages are presented in Table 37.

From PI to H stage there was steady increase in chlorophyll 'a' content and then decreased in maturity stage irrespective of the variables studied. In respect of genotypes, significantly higher chlorophyll 'a' content was recorded with CORH2 (V₁) the hybrid at PI, H and M stages, as compared to ADT38 (V₂) during both the seasons. Among the PGRs treatments studied, significantly higher chlorophyll 'a' content was registered for the foliar spray of salicylic acid, and it was on par with the *Pseudomonas* application at H stage of *Thaladi*, M stage of *Samba* and *Thaladi*

seasons. Provision of aeration by rotary weeder (F₁) significantly increased the chlorophyll 'a' content at H and M stages in *Samba* and *Thaladi* season.

4.2.2.2. Chlorophyll 'b' content (Table 38)

The chlorophyll 'b' content recorded along with 'a' in the leaves was increasing as the growth progressed up to heading and then the decreased. Among the two genotypes studied, V₁ (CORH2) had registered significantly higher values of chlorophyll 'b' content at all the stages of *Samba* and *Thaladi* seasons. Among the PGRs, higher chlorophyll 'b' content was registered under foliar spray of salicylic acid (H₂) during *Thaladi* season. However, it was on par with pseudomonas application (H₁) in maturity stage of *Samba*. Existing practice (F₂) of continuous submergence condition had noted with significantly reduced chlorophyll 'b' content at H and M stage of *Samba* crop and M stage of *Thaladi* crop.

4.2.2.3. Total chlorophyll content (Table 39)

Total chlorophyll content of the leaves also increased up to H stage and then decreased. Cultivar with more tolerance to continuous submergence, viz., hybrid (CORH2,) produced significantly higher total chlorophyll content as compared to susceptible variety, ADT38 at all the stages of crop growth during *Samba* and *Thaladi* seasons. The PGRs did not influence the total chlorophyll content during all the stages in both the seasons except during heading stage of *Thaladi*. The chlorophyll content during that stage was registered with control treatment was the lowest. Soil aeration treatment (F₁) facilitated better maintenance of the total chlorophyll content in the leaves as revealed by significantly higher total chlorophyll content at H to M stages compared to existing practice (F₂) of continuous submergence, during both the seasons of crop growth.

4.2.2.4. Root peroxidase content (Tables 40 and 41)

Root peroxidase production reached the peak at heading stage and then declined in both the seasons of study. Among the two genotypes studied, higher root

peroxidase content was recorded with hybrid (CORH2) at PI, H and M stages of crop growth

during both the seasons. The effect of PGRs treatment significantly increased the root peroxidase activity as compared to control at all the stages of growth during both the seasons. Pseudomonas application (H_1) registered higher root peroxidase at heading stage, however it was on par with salicylic acid during panicle initiation in both the seasons. During maturity stage foliar spray of salicylic acid (H_2) recorded significantly higher root peroxidase activity followed by pseudomonas application (H_1) in *Samba* and *Thaladi* seasons. Soil aeration by mechanical disturbance to the soil with rotary weeder (F_1) significantly increased the root peroxidase content at all the stages of crop growth except PI as compared to existing practice (F_2) of continuous submergence during *Samba* and *Thaladi* seasons.

Genotypes and PGRs had interaction effect and produced more root peroxidase content at all the stages of crop growth during both the seasons, except initial stage (PI) of *Samba* crop. CORH2 with pseudomonas (V_1H_1) interaction significantly registered higher root peroxidase activity followed by V_1H_2 (CORH2 with salicylic acid) at PI and H stage in *Samba* and *Thaladi* seasons. At M stage, CORH2 and salicylic acid (V_1H_2) interaction significantly produced higher root peroxidase content during both the seasons.

4.2.2.5. Leaf peroxidase content (Tables 42 and 43)

The hybrid CORH2 (V_1) with more tolerance to continuous submergence recorded significantly higher leaf peroxidase content as compared to susceptible variety ADT38 (V_2) at all the stages of crop growth in *Samba* and *Thaladi* season. Similarly PGRs treatments also significantly increased the leaf peroxidase content compared to control. Pseudomonas application (H_1) registered more leaf peroxidase content followed by salicylic acid foliar spray (H_2) in both the genotypes at PI, H and M stages of both the seasons. In respect of field management, significantly higher leaf peroxidase content was seen in the soil aeration by mechanical disturbance to the soil

(F₁) at all the stages of crop growth of both the seasons, except PI stage of *Samba* season.

Genotypes with PGRs and field management interaction significantly varied with the leaf peroxidase content during heading and maturity stages in both the season. Both the genotypes (CORH2 and ADT38) with *Pseudomonas* and soil aeration interaction significantly produced higher leaf peroxidase content than other treatment combination in both the seasons

4.2.2.6. Root catalase (Tables 44 and 45)

The effect of genotypes, PGRs and field management treatments on root catalase content varied in relation to crop stages and seasons. The root catalase content was significantly higher in the CORH2 in the PI, H and M stages as compared to ADT38 during *Samba* and *Thaladi* seasons. Among the PGRs treatments studied, significantly higher root catalase content was recorded under foliar spray of salicylic acid (H₂) followed by *pseudomonas* application (H₁) at all the stages of crop growth in both the seasons. Provision of soil aeration (F₁) significantly increased the root catalase content as compared to existing practice (F₂) at PI, H and M stages in *Samba* and *Thaladi* seasons.

The interactions were found significant during panicle initiation and heading stages but not, at the later stages of crop growth in both the seasons.

4.2.2.7. Root superoxide dismutase (SOD)

The data on root SOD content recorded at PI, H and M stages are presented in Table 46.

There was increase in the root SOD content up to H stage and decreased at maturity. CORH2 (V₁) hybrid registered significantly higher root SOD content as compared to ADT38 (V₂) at all the stages of growth during *Samba* and *Thaladi* seasons. In respect of PGRs treatments, significantly higher root SOD content was

registered by the foliar spray of salicylic acid (H₂) at all the stages of crop growth during *Samba* and *Thaladi* seasons. Among the two field managements studied, soil aeration (F₁) significantly increased the root SOD content as compared to existing practice (F₂) at PI, H and M stages in the both the seasons, except at H stage of *Thaladi* season.

4.2.2.8. Leaf superoxide dismutase (SOD) (Tables 47)

In general, there was increase in leaf SOD content from PI to H stages and there after sharp decline at M stage. Varietal differences were not seen for leaf SOD except at later stage of crop growth, maturity in *Samba*. In *Thaladi* season CORH2 (V₁) hybrid had significantly higher leaf SOD content as compared to ADT38 (V₂) at all the stages of crop growth. Higher leaf SOD content was registered under foliar spray of salicylic acid (H₂) followed by pseudomonas application (H₁) at all the stages of crop growth in both the seasons compared to no foliar spray. Among the field management studies, soil aeration (F₁) significantly increased the leaf SOD content at PI, H and M stages during *Samba* and *Thaladi* seasons.

4.2.2.9. Root ATPase (Tables 48 and 49)

As the crop approached towards maturity, the ATPase content of the roots had a decreasing trend. There was significant variation due to genotypes. CORH2 (V₁) recorded significantly higher root ATPase content in all the stages of crop growth during *Samba* and *Thaladi* seasons, except later stage (M) of *Thaladi* crop. Foliar spray of salicylic acid (H₂) significantly increased the root ATPase content at PI, H and M stages of *Samba* and *Thaladi* seasons. Provision of soil aeration by mechanical rotary weeder (F₁) significantly increased root ATPase content as compared to the existing practice (F₂) of continuous submergence at all the stages of *Samba* and *Thaladi* seasons, except maturity stage of *Thaladi* season crop.

The interaction among variables was noticed only during heading stage of *Thaladi* season. But the variety versus PGRs, variety versus field management and all the possible interactions were noticed during PI, H and M stages, respectively during *samba* season. In general CORH2 (V₁) hybrid either with pseudomonas or aeration the soil or its combination had resulted in equal impact in recoding root ATPase at PI, H and M stages.

4.2.2.10. Root CEC

The data on root CEC content recorded at PI, H and M stages are presented in Table 50.

Among the genotypes studied, the hybrid CORH2 (V₁) which was selected due to its higher resistance to submergence registered higher root CEC at all the stages of crop growth during *Samba* and *Thaladi* seasons. But it was on par with ADT38 (V₂) at PI and H during *Samba* and *Thaladi* seasons, respectively. PGRs treatments significantly increased the root CEC at PI, H and M stages of *Samba* and *Thaladi* seasons, except H stage of *Thaladi* season. Provision of soil aeration to puddled lowland rice through mechanical disturbance by rotary weeder (F₁) registered significantly higher root CEC as compared to the continuous submergence (F₂) at all the stages of crop during both the seasons.

4.2.3. Pest incidences

4.2.3.1. Leaf folder infestation (Tables 51 and 52)

Result from both the seasons indicated that the CORH2 (V₁) recorded higher leaf folder infestation as compared to ADT38 (V₂). Among the plant growth regulators studied, pseudomonas application (H₁) and foliar spray of salicylic acid (H₂) significantly suppressed the leaf folder infestation compared to control at all the stages of crop growth in both the seasons. Provision of soil aeration (F₁) registered significantly higher leaf folder infestation as compared to existing practice (F₂) at PI, H and M stages of *Thaladi* season. In *Samba* both the field management practices did

not vary in the percentage of leaf folder infestation except at maturity stage, where, continuous submergence recorded higher infestation.

Genotypes and PGRs interaction significantly suppressed the leaf folder infestation. ADT38 with pseudomonas application (V_2H_1) considerably decreased the infestation at PI and H stages in *Samba* season. Similarly, in *Thaladi* season the ADT38 with pseudomonas application (V_2H_1) kept the incidence under check at PI and M stages. Also, genotypes with existing practice (F_2) had interaction during maturity stage of *Thaladi* season. Provision of soil aeration with PGRs significantly suppressed the leaf folder infestation at M stage of *Samba* season.

4.2.3.2. Disease incidence

The per cent leaf spot incidence during panicle initiation and heading stages was provided in Table 53.

The genotypic response in controlling the disease incidence was found more in ADT38 during both the seasons. But, its impact was clear during heading stage of *Samba* season. PGRs application especially pseudomonas application had kept disease under control effectively. Among the field management, continuous submergence during *Samba* season had checked the disease incidence effectively than the soil aeration practiced.

4.2.4. Yield components

4.2.4.1. Productive tillers (Tables 54 and 55)

In general the number of productive tillers in the *Samba* season was lower than *Thaladi* season. Among the genotypes, CORH2 (V_1) recorded higher productive tillers than ADT38 (V_2) during *Samba* and *Thaladi* seasons. Both the PGR treatments were on par and recorded significantly higher productive tillers as compared to control in both the seasons. Soil aeration (F_1) did promote the panicle bearing tillers more effectively in the *Thaladi* season, but not during *Samba* season over the continuous submergence.

All the interactions were non significant during both seasons of investigation.

4.2.4.2. Panicle length

The mean data on panicle length is presented in Tables 54 and 55.

The effect of all the variables (genotypes, PGRs and field management) and their interactions remained non significant in both the seasons of study, except in *Thaladi* season where CORH2 (V_1) and soil aeration treatment (F_1) could alter the panicle length as compared to their respective other treatment.

4.2.4.3. Panicle weight (Tables 54 and 55)

The mean panicle weight showed advantage to the hybrid, CORH2 (V_1), compared to the variety ADT38 (V_2). PGRs application and soil aeration also had influence on panicle weight. Foliar application of salicylic acid and soil aeration through mechanical stirring by rotary weeder did significant improvement in panicle weight. The variety versus PGR and PGR versus field management interaction was significant in *Samba* season. Both the varieties invariably recorded significantly higher panicle weight when applied with *Pseudomonas* or salicylic acid. Similarly, the expression of PGRs was significantly more in aerated soil treated through mechanical rotary weeder than continuous submergence in *Samba*.

4.2.4.4. Test weight (Tables 54 and 55)

The variation in test weight was significant between the varieties in *Samba* and within varieties and PGRs in *Thaladi* season, respectively. Among the two genotypes, CORH2 (V_1) produced significantly higher test weight as compared to ADT38 (V_2) during both the seasons. The two PGRs viz., *Pseudomonas* or salicylic acid applied had on par and higher test weight as compared to control (H_0). Test weight was not altered due to soil aeration ensured by rotary weeder.

The interactions were absent.

4.2.2.5. No. of spikelets, filled, illfilled and sterility percentage (Table 56 and 57)

Hybrid (CORH2-V₁) produced higher number of spikelets per unit area compared to variety (ADT38-V₂). Field management of soil aeration and foliar application of salicylic acid were all had interaction with variety, CORH2 and produced the highest number of spikelets per unit area.

Number of filled grains per unit area was seen influenced by variety, foliar spray and field management practices. Aerating the soil through mechanical disturbance by rotary weeder, along with salicylic acid foliar application, facilitated the spikelets to be filled more conveniently, irrespective of variety but with more benefit to CORH2.

Sterility percentage ranged from 20.9 to 37.9 and 19.1 to 33.5% during *Samba* and *Thaladi* season, respectively. CORH2 (V₁), soil aeration with rotary weeder and salicylic acid spray altered significantly and lowered the sterility percentage in both the seasons.

4.2.5. Grain yield (Tables 58 and 59)

The hybrid CORH2 which has more tolerance to continuous submergence produced significantly higher grain yield than the variety ADT38. The tolerant variety enhanced the grain yield by 19.9 and 15.3% over susceptible variety during *Samba* and *Thaladi* seasons, respectively. Increase in grain yield due to the application of PGRs treatments was significant. The PGRs viz., pseudomonas and salicylic acid improved the grain yield by 11.5 to 13.7 and 17.9 to 24.2% over control during *Samba* and *Thaladi* seasons, respectively. Among the PGRs tested, foliar spray of salicylic acid (H₂) registered more grain yield. The soil aeration (F₁) treatment did significant improvement in the grain yield during *Thaladi* season than in *Samba* season. There was grain yield advantage of 7.7% over continuous submergence (F₂ – existing practice).

Interaction effects were not significant. However, the hybrid (CORH2) with foliar application of salicylic acid and providing soil aeration through rotary weeder ($V_1H_2F_1$) recorded higher grain yield of 6944 and 8955 kg ha⁻¹ during *Samba* and *Thaladi* seasons, respectively. The lowest grain yield was recorded with the variety (ADT38) with no PGRs and existing practice of continuous submergence ($V_2H_0F_2$) in both the seasons.

4.2.6. Straw yield

The data on straw yield recorded at harvest are presented in Tables 58 and 59.

Hybrid (CORH2 – V_1) produced higher straw yield as compared to the variety ADT38 in *Samba* and *Thaladi* seasons. Among the PGRs, foliar spray of salicylic acid (H_2) registered higher straw yield followed by pseudomonas application (H_1). Soil aeration (F_1) favoured the straw yield when compared to existing practice (F_2) of continuous submergence.

However, all the variables and interactions were non significant during the *Samba* and *Thaladi* seasons.

4.2.5. Harvest index (HI) (Tables 58 and 59)

The harvest index for the existing practices of continuous submergence with no foliar application (F_2H_0), showed identical mark between the seasons (*Samba* and *Thaladi*) studied but with a slightly low index during *Thaladi* (0.36) compared to *Samba* (0.37) for hybrid and no variation for variety. But the field management practice of aeration of the soil by rotary weeder coupled with salicylic acid foliar application aimed to convert the source to sink enhanced the index. The enhancement was more spectacular in *Thaladi* (0.44) than in *Samba* (0.41) to F_1H_2 .

4.2.6. Economics (Table 60)

Gross and net returns were higher with provision of aeration in both the seasons. Hybrid CORH2 recorded higher benefit cost ratio as compared to variety ADT38. Gross return, net return and benefit cost ratio were higher in *Thaladi* compared to *Samba*. Both the genotypes viz., CORH2 and ADT38 under H_2F_1 (foliar

application of salicylic acid and soil aeration through rotary weeder) treatment combination recorded higher benefit cost ratio as compared to other treatment combinations. For the hybrid salicylic acid and soil aeration through rotary weeder added the gross, net incomes and also the B:C ratio. Whereas, when the variety with susceptible nature to submergence is considered then the soil aeration alone is sufficient to get better B:C ratio.

CHAPTER V

DISCUSSION

The puddled lowland rice production in India, vast areas under rice crop, being subjected to the vagaries and vicissitudes of weather. Thus, during the monsoon seasons several million hectares become waterlogged and yield under such conditions is very poor depending upon the duration and depth of water stagnation. Though the changes in structure and chemistry of the soil brought out by waterlogging are fairly known, the physiological changes in the crop leading to lower yield are little understood. The present investigation was undertaken as i) preliminary experiment - to screen the genotypes through waterlogging and drainage on root activity and as ii) main field experiment - to assess the integrated effect of genotypes (tolerant and susceptible to continuous submergence), plant growth regulating substances (biological and chemical) and field management strategies (aerated through rotary weeder and continuous submergence) in achieving higher productivity of puddled lowland rice.

The result of the preliminary and main field experiments conducted during *Navarai* 2002-2003, *Samba* 2003 and *Thaladi* 2003 – 2004 at wetland farm, Tamil Nadu Agricultural University, Coimbatore on “Root activity and productivity of puddled lowland rice as influenced by cultivars, soil aeration and plant growth promoting substances” are critically examined and discussed hereunder.

5.1. Weather and Crop

5.1.1. *Navarai* (2002-2003) and rice

The weather prevailed during this cropping season was very favourable for the growth and yield of rice. In *Navarai* season, the mean maximum temperature and minimum temperature was 33.2°C and 21.1°C, respectively (Fig. 1a). The recorded average solar radiation during the *Navarai* season was 429.7Cal cm⁻² day⁻¹ (Fig. 1b). The amount of rainfall received during the cropping period was 214.8 mm in 13 rainy

days. As rice plant requires optimum temperature of 13 - 31°C, the temperature prevailed during *Navarai* 2003 season may have favoured positively the physiological process involved in grain production. As reported by Yoshida (1981) the growth rate increases almost linear with increasing temperature and solar radiation from the base minimum towards optimum. The grain yield of the *Navarai* crop ranged between 4739 and 7705 kg ha⁻¹.

5.1.2. Samba and Thaladi season and rice

The maximum temperature ranged from 28.4 to 34.1°C during *Samba* 2003, while it was from 28.4 to 35.0°C for *Thaladi* 2003 – 2004. There was an increasing trend of maximum temperature from early stage (seedlings) to heading stage and thereafter a slight decrease towards maturity stage in *Samba* 2003. However, in *Thaladi* 2003–2004 the maximum temperature was increasing from vegetative to reproductive. Similar trend was seen in minimum temperature also. The amount of rainfall received during this crop growth period was 354 and 256.5mm. Mean solar radiation was 377.4 and 411.1Cal cm⁻² day⁻¹ during *Samba* 2003 and *Thaladi* 2003-2004, respectively. The results obtained from the investigation revealed that the crop growth, yield and yield parameters were relatively better in *Thaladi* compared to *Samba* irrespective of the variables studied. The average grain yield of the *Samba* crop was 5914 kg ha⁻¹ whereas in *Thaladi* it was 7578 kg ha⁻¹. The reason for overall low yield in *Samba* may be due to lower number of leaves, TDMP, higher leaf folder infestation, lower productive tillers, panicle weight, number of filled grains, higher sterility percentage and lower harvest index compared to *Thaladi* 2003-2004. Higher root activity was observed in the *Thaladi* 2003-2004 compared to *Samba* 2003 and thus resulted in higher shoot DMP, root DMP and TDMP. This increase in dry matter may also be attributed to higher solar radiation prevailed during *Thaladi* 2003-2004, more specially during reproductive. Higher solar radiation during reproductive phase resulted in higher productivity. During *Samba* 2003, sterility percentage was higher compared to *Thaladi* 2003-2004. The rainfall received during maturity phase of *Samba* might have

affected the reduction of harvest index during *Samba* 2003 than in *Thaladi* season crop.

Apart from this, several physio-chemical factors are also responsible in deciding the root activity and productivity of rice ecosystem. Hence, the present investigation involves screening of rice genotypes (tolerant and susceptible to continuous submergence) and to improve their productivity through various management strategies.

5.2. Impact of field management on the performance of rice varieties

Plant height, an indicator of varietal character, differed with varieties and field management practices. The number of elongated internodes and the sum of the length of elongated internodes accounts for a larger fraction of plant height (Yoshida, 1981). The plant height was not significantly altered by the field management practiced here. However, within field management, allow aeration (I_1) recorded comparatively higher plant height. Increase in plant height under aerated field condition was earlier reported by Mohan (1995). The plant height under aerated situation in rice culture of about 100 cm may be desirable for lowland condition (IRRI, 1975). The result of this experiment seems to agree with the above hypothesis. The LAI is determined by the number of tillers, number of green leaves per hill and average leaf size (Rai and Murty, 1979). LAI was significantly reduced under waterlogged situation and the reduction was more at active tillering than during panicle initiation stage (Fig 4). The LAI determines the total photosynthesizing area available to the plant and quantum of source that would be translocated to sink. Presence of functional leaves and their index (LAI) were found increasing all along the vegetative phase. After flowering they steadily decreased as the maturity approached, as observed by Ramasamy (1992). Yoshida (1981) reported that leaf weight decreased at later stages of crop growth due to translocation as metabolites

like protein, sugars and starch to the upper leaves or to the reproductive organs depending upon the growth period. He also pointed out that faster leaf senescence may be due to unfavourable weather or soil conditions and reduced green leaf proportion. Higher number of senescent leaves in continuous submergence plots of the present study might be due to unfavourable soil condition as mentioned by Yoshida (1981). CO45 (V₂) and ADT43 (V₁₂) produced higher LAI at peak growth stage (heading). ADT38 (V₃) produced higher number of tillers hill⁻¹. TRY1 (V₅) produced lower number of tillers hill⁻¹. Contrastingly these two genotypes had a lower LAI. ADT39 (V₁₁) retained more LAI at maturity stage. With regards to tillering, higher tillering ability was noticed under aerated soil situation. At panicle initiation the number of tillers per hill under aerated soil ensured through irrigation schedule significantly increased compared to continuous submergence.

Dry matter production of a crop reflects its efficiency to utilize the available resources such as solar radiation, moisture, nutrients and other niches of the existing environmental conditions. It is the product of the influence of the growth characters like plant height, number of tillers, LAI and efficiencies of the crop to capture available resources. Positive growth rate for shoot DMP and TDMP in both are field managements and genotypes was observed in the study till maturity. But the root DMP steadily increased up to heading and thereafter declined at maturity stage due to senescence and degradation of roots (Fig. 4). Cheng (1983) observed a initial slow growth rate of dry weight and significantly vigorous, sturdy culm in the later part of the growth period. Higher root DMP and TDMP was observed in soil aerated field condition starting from active tillering to maturity stage than continuous submergence plots. Ramasamy *et al.* (1997) also observed higher TDMP under aerated soil environment. At maturity stage, Ponmani (V₇) produced significantly higher shoot and total DMP due to higher growth rate and longer duration, followed by ADT40 (V₄). In ADT43 (V₁₂) the shoot DMP reduction was minimal under different field managements, especially at maturity stage. But, in White Ponni (V₆) the shoot DMP

reduction was higher compared to other genotypes may be due to degeneration of incompetetive tillers. Root DMP at heading in Ponmani (V₇) had significantly higher value followed by White Ponni (V₆) under allow aerated plots.

In general, root volume and root length were found increasing up to heading and then decreased towards maturity (Fig 5.). Aeration of plots (I₁) had enhanced root volume and root length in all the genotypes, may be due to better root atmosphere of aerated soil condition and enhanced percolation of water in the soil (not measured in this experiment). Among the varieties, ADT40 (V₆) and Ponmani (V₇) had higher root volume followed by hybrid CORH2 (V₁₄), especially at heading stage. The hybrid CORH2 (V₁₄) retained more root volume at maturity stage under both aerated and continuous submergence situation due to hybrid vigour a character, which is favourable for efficient translocation and continued photosynthesis till maturity. The varieties of ASD20 (V₁₃) and ADT38 (V₃) failed to retain the root volume at maturity stage due to susceptible nature, under submerged ecosystem through accelerated root senescence. The higher root volume and root length recorded under aerated soil condition in Ponmani (V₇) were may be due to the occurrence of moderate redox potential in aerated plots. Sekhon *et al.* (1988) reported that positive soil redox potential increases the root density under submerged soil situation.

High measure of root CEC under aerated plot is also an indicator of higher root activity. The CEC of the roots under continuous submergence plots felt sharply compared to allow aeration plots as the age advanced. Jagadeesan and Rajamannar (1978) reported a root activity of 12.0 me/100g dry roots at maturity. In the continuous submergence plots the CEC slipped down to 9.19 me/100g dry roots at maturity from its heading stage of 16.01 me/100g dry roots, which confirms the development of inactive roots during maturity. Among the genotypes CORH2 (V₁₄) hybrid recorded higher root CEC at heading stage and also maintains the root CEC due to hybrid vigour and maintains active roots up to maturity stage (Fig. 6). The number of

productive tillers are in general varietal specific. Even though numerically higher tiller number was noticed in the aerated plots, the difference was not significant. The results were in consonance with that of Ramasamy (1992). The tiller in continuous submergence plots ought to have met with an anaerobic respiration and ethanol accumulation to toxic level, resulting in higher mortality as reported by Voroev and Aleshin (1979). The higher number of productive tillers in Ponmani (V₇) followed by CORH2 (V₁₄), observed during maturity may be due to continued root activity as seen these cultivars (Fig. 6). Lower number of productive tillers in ADT38 (V₃) may due to susceptible nature of the variety to continuous submergence.

The test weight variation may mainly be attributed with varietal characters. Field management practices did not alter the test weight significantly. White Ponni (V₆) recorded higher test weight.

Number of grains per panicle is a genetic character but in reality that is also decided by the amount of carbohydrates available with the tiller at the time of panicle initiation. The number of grains per panicle was significantly higher in aerated plots. Ramasamy (1992) recorded increased number of spikelets per panicle under aerated environment. ADT43 (V₁₂), CORH2 (V₁₄) and CO47 (V₉) recorded higher number of grains per panicle compared to other genotypes. Varieties CO47 (V₉) and CORH2 (V₁₄) recorded higher number of grains per panicle under aerated treatment may be a varietal character.

Number of filled grains per unit area decides the yielding ability of a variety. Filled and ill-filled grains per hill may be altered by field management practices (Fig 7).

Provision of soil aeration paved way for the conversion of spikelets in to filled grains, whereas, the same was subdued by continuously submerged field condition. Grain filling is the process of accumulation of carbohydrates and proteins in the grains. This accumulation is the function of translocation of stored carbohydrates and current

photosynthates. A maximum of 60% of the grain carbohydrate can be derived from current photosynthates (Yoshida, 1981). Green leaves, remaining after heading, flag leaf, leaf sheaths and green pigments in palea and lemma area are all contributing to this 60% (Sheela Ghosh *et al.*, 1990). Aeration treatment alone improved grain filling by 22.41%. The number of filled grains per hill was higher in CORH2 (V₁₄) than that of other varieties. Similarly, number ill-filled grains was also higher in CORH2 (V₁₄), giving a scope for further improvement. Sterility percentage was significantly reduced by aerated soil with good root activity up to maturity. These results were in accordance with the finding of Ramasamy *et al.* (1997) and Yang *et al.* (2002).

The impact of field managements practiced in this experiment on grain yield was not so distinct. Correlations for TDMP, root DMP, root volume, root length, root CEC and filled grains with grain yields were all positive for aerated plots and hence, higher grain yield under well aerated system (Fig 7). Increased grain yield by well drained field condition (Vinaya Rai and Murty, 1976) and increased percolation rate (Ahn *et al.*, 1991; Ramasamy, 1992) confirm the higher grain yield with aerated plots in the present study. The varieties exhibited a marked variation in grain yielding ability of the different field management situation. Higher grain yield recorded by White Ponni (V₆) than any other varieties was due to higher root volume and LAI, lower sterility percentage. Bhavani (V₈), ADT40 (V₄) and TRY1 (V₅) had lodging nature and thus poor yield. Field management of allow aeration treatment (I₁) considerably favoured all the varieties to record higher grain yield compared to the continuous submergence practices (I₂).

Higher yield advantage in hybrid (CORH2- V₁₄) may be attributed to root activity, root CEC, total number of grains per panicle, test weight and root volume. The results were supported by the earlier findings of Ramasamy and Pathmanaban (2003). The straw yield also followed similar trend of grain yield. The harvest index was not altered by the field management strategies. White Ponni (V₆) had higher harvest index compared with other varieties.

The varieties CORH2 (more tolerant to continuous submergence) and ADT38 (more susceptible to continuous submergence) were selected from this screening study from 14 genotypes, based on their performance under the two field management practices viz., allow aeration and continuous submergence. The grain yield difference between the two field management practices, root volume, DMP, CEC and root activity were the other indices considered for the selection. In addition lodging resistance was taken into consideration to arrive at one tolerant (CORH2) and one susceptible (ADT38) variety.

5.3. Influence of varieties on growth, root activity and yield of puddled lowland ecosystem

In the present investigation, the rice hybrid CORH2 (more tolerant to continuous submergence) and variety ADT38 (more susceptible to continuous submergence) were taken from the preliminary screening experiment conducted during *Navarai* 2003. The study was carried out in two seasons of puddled lowland ecosystem of *Samba* 2003 and *Thaladi* 2003-2004. Water management and drainage in most of the farm in traditional rice belts with canal irrigation is beyond the control. There is continuous standing water in rice fields in most part of the rice growing period. Root activity in that situation falls very sharply and the situation becomes unproductive. The main objective was to find out the strategy to sustain root activity for better production under puddled lowland ecosystem of continuous submerged soil condition. Rice growth parameters studied in the present investigations were plant height, number of green leaves per hill, number of tillers per m², shoot DMP per m², TDMP per m², LAI and total photosynthetic area.

Germination and leaf emergence was early and faster in hybrid than in variety. Rice hybrid manifested greater plant height, LAI and dry matter production. Among the two seasons, plant height was higher in *Samba* than in *Thaladi*. In general, rice

hybrid CORH2 recorded higher plant height compared to variety. Virmani *et al.* (1982) reported that F₁ rice hybrids in general possess vigour for taller plants as compared to varieties. Presence of functional leaves and their index (LAI) were found increasing all along the vegetative growth. After heading, they steadily decreased as the maturity approached. Hybrid CORH2 produced more number of functional leaves and higher LAI as compared to variety in both the seasons (Fig. 10). Yoshida (1972) reported that manifestation of greater leaf area is one of the important traits of hybrid rice. The number of green leaves per hill was more in *Thaladi* season. But *Thaladi* season rice was not able to maintain the higher number of green leaves and LAI till the maturity stage of the crop growth, which it enjoyed at the early stage of the growth. This variation was not seen with the *Samba* experiment. The number of tillers recorded was more in rice hybrid CORH2 during both the seasons, due to the hybrid vigour. During *Samba* season more number of tillers at maturity was recorded than *Thaladi* season crop. Faster development of photosynthetic area at vegetative stage in the hybrid, CORH2, is highly correlated with shoot and total dry matter production and thus the vigorous growth rate. These results were in agreement with Ponnuthurai *et al.* (1984) and Tu *et al.* (1993). Shoot DMP and TDMP were more during *Thaladi* season crop and was due to higher LAI and more number of tillers. Ramasamy (1992) and Ramasamy *et al.* (1997) reported that more TDMP in the *Thaladi* season rice crop than *Samba* season.

Increase in root biomass (Fig. 9), volume (Fig. 11), length (Fig. 8) and root activity was observed up to heading in *Samba* and *Thaladi* season. The fraction of root biomass to the TDMP was higher in the heading stage, afterward root biomass was found decreasing, as the growth advanced. Rice hybrid, CORH2, produced more root biomass, volume, length, due to better root activity observed as more number of white and brown roots up to maturity and higher root catalase, peroxidase, SOD, ATPase and CEC (Fig. 12) as compared to the rice variety, ADT38 during both the seasons. The colour change in the root system has a significant relation to root activity (Cheng, 1983). Catalase remove the accumulation of hydrogen peroxidase in the cells

which otherwise leads to toxic effect. Catalase activity in hybrid rice favours photosynthesis and transmission of assimilates to panicle (Wuhan University, 1977; Noctor and Foyer, 1998). Higher root peroxidase in the hybrid CORH2, increases the lignin synthesis; hence it is possible for postponement of root senescence, as evidenced by increased root volume, root length and root DMP. Bozso *et al.* (2002) reported peroxidases are involving in cell wall strengthening at the attachment site by promoting the cross-linking of specific proteins or lignifications. Root growth is very much dependent on the shoot growth. Tian *et al.* (1980) and Wu *et al.* (1980) reported that rice hybrid showed higher number of roots, root dry weight and higher root activity. According to Deng Hongde (1988) the roots of hybrid rice synthesizes more amino acids than the conventional varieties. The total amino acids synthesized and transported in hybrid rice during flowering and milk stage was reported to be 33.5 per cent more than varieties.

SPAD and LCC values showed increase (relative greenness) up to heading after that declined towards maturity due to aging of the crop, reduced chlorophyll content and mobilization of photosynthates from source to sink. Hybrid (CORH2) recorded more SPAD and LCC value as compared to variety (ADT38) in both the seasons of study. Kim and Lee (1994) reported that rice hybrid has more photosynthetic activity, chlorophyll content when supported with higher nitrogen application.

Yield parameters and yield were higher in rice hybrid CORH2, in both the seasons. In general, the number of productive tillers was higher in *Thaladi* season than in *Samba* season. The variations may mainly be attributed to seasonal effects. In contrast, panicle length, panicle weight and test weight were reduced in the *Thaladi* season as compared to *Samba* season. The number of filled, ill-filled and total number of grains per hill recorded were higher in the rice hybrid CORH2 as compared to variety ADT38 (Fig. 13). The sterility percentage (Fig. 14) was significantly lower in the hybrid CORH2. The high grain filling ability of rice hybrid CORH2 was found to be due to the heterosis in the activity of enzymes such as catalase, peroxidase, SOD and ATPase.

Ponnuthurai *et al.* (1984) reported increases in source activity, better partitioning of dry matter to spikelets as well pronounced factors in rice hybrids. Higher number of productive tillers, higher ratio of filled grains per hill, lower sterility percentage, and better root activity, were all contributing factors for the higher grain yield in rice hybrid CORH2 compared to variety ADT38. Both the assimilation rate per unit area and the functional photosynthetic area have contributed to higher partitioning of assimilates to spikelets, which resulted in increased harvest index of rice hybrid CORH2 (Fig. 15). Higher yield parameters, better root activity, higher solar radiation, rare occurrence of heavy downpour, were all the contributing factors for the higher grain yield in *Thaladi* season as compared to *Samba* season.

5.4. Influence of PGRs (plant growth promoting substances) on growth, root activity and yield of puddle lowland rice

Majority of the irrigated rice ecosystems are under continuous submerged condition. This situation is further complicated by poor movement of subsoil water and accumulation of toxic organic acids causing low redox condition. Prolonged submergence of rice roots makes to loose the ability to do normal physiological activity.

Under this circumstance an attempt was made to explore the possibilities of sustaining the activity through some management practices like application of PGRs (*Pseudomonas* and salicylic acid).

PGRs application increased the plant height compared to control under puddled lowland condition during *Samba* and *Thaladi*. Rajacommare (2000) and Grichko and Glick (2001b) reported that *Pseudomonas* application stimulates plant growth and resulted in taller plants. Raskin (1992) reported that salicylic acid application increases the plant height. Relatively, *Samba* crop recorded higher plant height. PGRs application increased the green leaves production and LAI from the

beginning of the crop growth and delayed the senescence of leaf up to flowering. After heading a gradual reduction in leaf production and LAI was noted till maturity. This reduction as ascribed by Yoshida (1981) was due to remobilization (redistribution) that normally occurs in cereals. More number of green leaves retained more at maturity under PGRs application treatments was due to increased activity of leaf peroxidase and leaf SOD.

Foliar application of salicylic acid significantly increased the number of tillers per m² in the *Thaladi* crop. Dinesh (1999) reported that salicylic acid increases the tiller production in *Thaladi* season rice. But in *Samba* season, PGRs application did not alter the tiller production, significantly. In the early stage of crop growth pseudomonas application increased the number of tillers. Rajacommare (2000) also observed that pseudomonas application increased the tiller number of rice plants. The growth rate of shoot DMP and TDMP of PGRs applied plots after heading was significantly higher than those of control plots. The shoot DMP was not affected by the PGRs at beginning stage of the *Samba* crop. While the application accelerated the crop growth rate in the beginning and thereby they had better advantage in terms of TDMP throughout the period. PGRs application increased the shoot DMP and TDMP due to higher LAI, chlorophyll content, root CEC and enzyme activity. The results were in consonance with that of Ramasamy and Pathmanaban (2003), Rajacommare (2000) and Maibangsa *et al.* (2000). Application of PGRs had increased the activity of the roots till maturity as it was seen from colour (Fig. 16), root biomass, length and volume of the root. In the early stage of the crop growth, it is possible for the root to maintain its whiteness due to its higher ability to oxidize and reconvert the ferrous iron present within the zone (Chen *et al.*, 1980).

The root peroxidase, root catalase, root SOD, root ATPase and root CEC were higher in the PGRs treated plants. These activities increase the root to produce cytokinin and retain more roots and postpone the senescence. Klopper *et al.* (1980a,

b) reported that PGPR application created an environment more favourable for root growth. Katsuwon and Anderson (1990) who reported that pseudomonas application increased the levels of catalase and SOD activity in the rice plants.

Salicylic acid application increased the ATPase activity (Macri *et al.*, 1986), SOD content (Rao *et al.*, 1997) and peroxidase activity (Minibaeva and Gordon, 2003). Application of PGRs increased the SPAD and LCC values, the increase may be due to higher amount of chlorophyll *a*, *b* and total chlorophyll in the treated plants. Foliar application of salicylic acid recorded the higher chlorophyll content due to salicylic acid promotive effect on free amino acid, prevention of protein degradation and protection of nitrate reductase activity (Jagadish Rane *et al.*, 1995; Kalarani *et al.*, 2002), though the SPAD and LCC values were relatively similar for both the seasons.

Application of pseudomonas and foliar application of salicylic acid significantly suppressed the leaf folder incidence during both the seasons. During *Samba* season comparatively higher leaf folder incidence was noticed than *Thaladi* season. However, the disease incidence was more during the *Thaladi* season. In the early stage of crop growth pseudomonas effectively suppressed the leaf folder than later stage. Salicylic acid treated plants reduced the leaf folder incidence at later stage than initial stage. During *Thaladi* season both pseudomonas and salicylic acid treatment effect was relatively similar. Pseudomonas application significantly reduced the disease incidence in both the seasons and it may be due to higher leaf peroxidase activity. Increased peroxidase has been observed in number of resistant interactions involving plant pathogens (Nandakumar *et al.*, 2001a). Peroxidase have been implicated in a number of physiological functions that may contribute to resistance including lignification (Walter, 1992). Accumulation of peroxidase has been correlated with induced systemic resistance (Chen *et al.*, 2000). Rajacommare (2000) reported that *Pseudomonas fluorescens* application suppressed the sheath blight and leaf folder incidence in rice due to increase in leaf peroxidase activity.

Higher productive tillers were noticed under *Thaladi* season than *Samba* season. The PGRs application significantly increased the number of productive tillers per hill. Foliar application of salicylic acid also increased the number of productive tillers due to increased ATPase activity, photosynthetic rate and higher nitrate reductase activity. Similarly, salicylic acid spray increased the panicle length, panicle weight and test weight. Maibangsa *et al.* (2000) reported that salicylic acid increases the yield parameters like productive tillers, test weight and biomass accumulation in rice plants. Application of PGRs influenced the number of grains per hill in both the seasons. Thus, the salicylic acid foliar spray significantly increased the total number of grains per hill and also filled grains per hill. Salicylic acid application at heading, when the roots were active, greatly helped the grain filling and increased the number of filled grains and reduced the sterility percentage. Dinesh (1999) also observed similar results. Higher grain yield under salicylic acid application may be attributed to increased photosynthetic area, higher number of productive tillers, higher root activity, low leaf folder incidence and higher yield parameters. Straw yield did not alter significantly due to PGRs application in both the seasons. The harvest index was higher in *Thaladi* season compared to *Samba* season. PGRs application played a crucial role in *Thaladi* season. Whereas the reason for deduced HI in *Samba* season was due to higher sterility recorded in that season.

5.5. Influence of mechanical rotary weeder on soil aeration and grain yield

Most of the irrigated rice ecosystems are under poorly drained field condition, either due to deltaic nature of the rice belts or due to continuous submergence, means without exposure of the soil surface to open air; both the macro and micro pores are always above saturation, of the puddled lowland ecosystem. Dawn Berkelaar (2001) reported that rice roots degenerate under flooded condition and mechanical disturbance with rotary weeder, result in more air in the soil and greater root growth in the rice plants.

The practice of soil aeration through rotary weeder did not alter the plant height, number of leaves but altered the tiller per m² in the later stage of *Thaladi* season. Perceptible difference surfaced between soil aeration and continuously submerged plots, only during later part of the crop growth due to differential leaf senescence, an inevitable process of aging. The green leaves production was numerically more under soil aeration plots, ultimately ended with increased LAI. Ramasamy (1992) reported that provision of drainage increases the functional leaf production and decreases the senescence of roots. Under soil aeration through rotary weeder operation at 10 days interval between 30–70 DAT significantly increased the TDMP due to the higher LAI, higher chlorophyll content, high root CEC in *Thaladi* season compared to *Samba*. Provision of soil aeration through rotary weeder improve the supply of O₂ and reduce the accumulation of toxic compounds in the lowland condition and increases the favourable environment for root growth and development Dawn Berkelaar (2001). The colour change in a root system is an indicator of root activity. As seen from the number of white and brown roots, the root activity slackened fast as the age of the crop advanced from tillering through ripening in continuous submergence treatment. On the contrary, with the provision of aeration, the activity of the roots was not only better but also it was maintained till ripening as it was seen from the colour, root biomass, root volume, root length and root catalase, root peroxidase activity. Ota (1970) also viewed that under favourable soil condition it will be more difficult to distinguish the old and young roots because the senescence of old roots gets delayed. This may be the reason for higher root biomass under soil aeration through rotary weeder plots after heading. On the other hand, when soil condition has been unfavourable (continuous submergence plot), senescence of the older roots occurred relatively faster and discolouration of the root took place due to loss of root activity.

Further, evidence of higher root activity under soil aeration system was seen by the parameters like CEC, catalase, peroxidase, SOD and ATPase of the roots

studies in both the seasons. The peroxidase increases the lignification in root system and reduces the root senescence. Provision of soil aeration increased ATPase due to enrichment of O₂ concentration in soil and increased the ATP production. Barrett-Lennard (2003) reported that under waterlogged situation the ATP production drastically reduced.

The number of productive tillers per hill was altered by the provision of soil aeration in *Thaladi* season, but not in *Samba* season. The tillers in continuously submerged plots ought to have met with an anaerobic respiration and ethanol accumulation to a toxic levels (Voroev and Aleshin, 1979) and increased concentration of ACC (Grichko and Glick, 2001a) resulting in higher mortality of tillers. Panicle length and test weight were not altered significantly by the field management practices. Whereas panicle weight was altered due to provision of soil aeration through rotary weeder. Provision of mechanical disturbances favoured the formation of duly filled grains, whereas continuous submergence affected it negatively. Grain filling capacity is improved through translocation and accumulation of photosynthates. Photosynthesis is a function of chlorophyll, CO₂ and water removed from soil, where water is supplied by active roots. So, the root activity after heading decides the grain filling efficiency and eventually number of filled grains per hill as recorded in soil aerated plots. Hence, the soil aerated plots significantly reduced the sterility percentage. The more number of filled grains per hill and low sterility percentage in the *Thaladi* season as compared to *Samba* season is the result of soil aeration provided through mechanical rotary weeder.

Grain yield significantly increased in the soil aeration allowed plots through rotary weeder as compared to that in continuously submerged plots during *Thaladi* season. However, in *Samba* season, provision of soil aeration did not alter very much the grain yield. Harvest index improved significantly in the *Thaladi* season. Higher grain yield in *Thaladi* season may be due to higher number of productive tillers encouraged by,

higher root activity, higher enzyme activity and led to, higher TDMP, higher number of filled grains and low sterility percentage. Ramasamy (1992) observed similar trend between aerated and continuous submergence practices. Thiagarajan *et al.* (2002) also reported that practice of rotary weeder in the lowland field increases the grain yield.

5.6. Influence of varieties, PGRs and field management on lowland rice

In general, under unfavourable soil condition, hybrid rice (CORH2) performed better than the variety (ADT38). Similarly, PGRs application and provision of aeration through rotary weeder treatment increased growth, yield and yield parameters of CORH2 as well as ADT38 genotypes. PGRs application controlled the leaf folder infestation and altered yield parameters significantly. Varieties, PGRs and field management did not alter much the productive tillers but, panicle weight was positively influenced by PGRs application in hybrid compared to ADT38 in *Samba*. Similarly provision of soil aeration increased the panicle weight significantly in CORH2 compared to ADT38. Test weight was not altered in both the seasons. The number of grains hill⁻¹ was significantly influenced by the interaction between genotypes, PGRs and field management during *Samba* but not in *Thaladi* due to seasonal variations. CORH2 with salicylic acid spray coupled with mechanical disturbance of soil significantly increased the number of filled grains hill⁻¹. Application of salicylic acid in addition to rotary weeder operation increased the grain yield of both CORH2 and ADT38, due to increased root activity, higher TDMP, higher enzyme activity, higher root CEC and higher yield parameters. The salicylic acid spray mitigated the oxidative stress and mechanical disturbance with rotary weeder improved the environment for better root activity. Harvest index was also higher in the above treatment combinations.

5.7. Influence of economics on selection of combination of management variable

Gross, net and benefit cost ratio was higher in the *Thaladi* season as compared to *Samba* season due to higher grain and straw yield in the *Thaladi* season. Similarly hybrid

CORH2 recorded higher benefit cost ratio in both the seasons. The hybrid CORH2 produced more grain yield, straw yield and relatively reduced the cost of cultivation as compared to variety. The variety ADT38 is susceptible nature to continuous submergence resulted in the lower grain yield.

The benefit cost ratio was higher when the CORH2 hybrid was coupled with provision of soil aeration through rotary weeder. Provision aeration increased the benefit cost ratio of the variety ADT38, a variety susceptible for submergence. For the hybrid and as well for the variety ADT38 salicylic acid and soil aeration through rotary weeder added the gross, net income and also the benefit cost ratio.

Gross returns, net returns and benefit-cost ratio were highest with provision of aeration through rotary weeder in both the seasons. The benefit-cost ratio was higher when the soil aeration was coupled with salicylic acid foliar spray treatment in both the genotypes, compared to other treatment combinations in both *Samba* and *Thaladi* seasons of CORH2.

CHAPTER VI

SUMMARY AND CONCLUSION

Field experiments were carried out at Tamil Nadu Agricultural University, Coimbatore to study the influence of field management through water, mechanical soil disturbances, varieties and plant growth promoting substances on root activity and productivity of puddled lowland rice ecosystem. The preliminary experiment was conducted in *Navarai* 2002-2003 with 14 varieties in a split plot design with three replications. The treatments were two irrigation management practices viz., Allow aeration - Restoration of irrigation, after disappearance of previously impounded irrigation water at the beginning of formation of hairline cracks (I_1) and Continuous submergence - Restoration 5 cm standing water well before disappearance of previously impounded irrigation water (I_2) in main plots and 14 varieties in a sub plots. The main field experiments were carried in a two seasons viz., *Samba* 2003 and *Thaladi* 2003-2004 with CORH2 and ADT38 in a 2 x 3 x 2 factorial randomized block design with three replications. The treatments imposed were two varieties viz., CORH2 (V_1) and ADT38 (V_2), Two plant growth promoting substances namely plant growth promoting rhizobacteria (H_1), foliar spray of salicylic acid (H_2) with control (H_0) and two field management practices of soil aeration through rotary weeder (F_1) and continuous submergence (Existing practice) (F_2).

The experiments were conducted for assessing growth parameters, root activity, enzyme activity periodically at different growth stages, grain yield and yield parameters at harvest and economics.

Based on the results of the preliminary experiment, a follow up experiment was carried out during *Samba* 2003 and *Thaladi* 2003-2004 in CORH2 (more tolerance to continuous submergence) and ADT38 (more susceptible to continuous submergence) with the objective of sustaining the root activity and increase the

productivity of rice under puddled lowland ecosystem. A brief summary of the results obtained and conclusions drawn from the study are presented below.

Screening of varieties

The plant height, LAI and total photosynthetic area of more than 135 days duration varieties were found to be higher than less than 135 days duration. Irrigation regimes were imposed on different varieties did not influence the plant height to a significantly.

Soil aeration through limited irrigation practices prolonged the presence of green leaves till maturity in all the varieties. The LAI was higher in aerated plots, especially before heading compared to continuous submergence plots.

The shoot DMP and TDMP were consistently higher at all the growth stages in plots that were given with aeration through irrigation practices. Shoot DMP and TDMP of Ponmani variety were found to be higher than other varieties. However, under soil aerated condition ADT40 recorded significantly higher shoot DMP and TDMP compared to other varieties.

The root DMP, root volume and root length per hill were higher in the soil aerated plots as compared to the continuously submerged plots. Root degradation in aerated plots were found to be delayed and relatively less compared to continuous submergence plots, which resulted in higher root DMP, root volume and root length at maturity. Ponmani, CORH2 and ADT40 varieties recorded significantly higher root DMP, root volume and root length, under aerated soil condition (I_1). Root DMP was higher with Ponmani and root volume was higher with CORH2.

High and continued root activity a highlight of this study was discussed in relation with higher root biomass, root volume, root length and root CEC, monitored throughout the growth. Soil aeration through irrigation management (I_1) possessed prolonged root activity in all the rice varieties.

The number of productive tillers per hill was not significantly altered due to two field management strategies. Productive tiller number was higher in Ponmani variety as compared to other varieties.

Panicle length and test weight were not influenced by field management practices. The test weight was relatively high in the variety TRY1. Variety CO45 have higher panicle length than other varieties examined.

Soil aeration through irrigation management plots had better filled grains and total number of grains per hill than the continuous submergence plots. Among the varieties studied, ADT43 and CORH2 produced higher number of spikelets and filled grains per hill, under aerated plots. Sterility percentage was less under soil aerated plots as compared to continuous submerged. The sterility was low in the variety White Ponni than other varieties.

Soil aeration through irrigation management increased the grain yield, straw yield and HI than continuous submergence. But the irrigation regimes did not influence much on the grain yield, straw yield and HI. White Ponni, Bhavani, CORH2, ADT40 and TRY1, on the average of two methods of irrigation management, recorded higher grain yield than other varieties. Bhavani and White Ponni recorded higher straw yield and HI, respectively.

Management of puddled lowland rice

The plant height was relatively higher in hybrid CORH2 during *Samba* and *Thaladi* season. Application of PGRs and soil aeration through rotary weeder treatments recorded the highest plant height.

The number of leaves per hill, LAI and total photosynthetic area was higher in the hybrid CORH2 as compared to variety, ADT38 in both the seasons. PGRs application showed significant positive effect on leaf production through out the growth period in both the season. The LAI and total photosynthetic area were higher

in provision of soil aeration through rotary weeder plots. *Samba* season crop retained more LAI even at maturity as compared to *Thaladi* season crop.

The number of tillers, shoot DMP and TDMP per m² of hybrid CORH2 were found to be higher than variety ADT38. PGRs application brought a significant increase in the number of tillers, shoot DMP and TDMP as compared to control during *Samba* and *Thaladi* season. Soil aeration through rotary weeder had significantly increased the number of tillers, shoot DMP and TDMP.

The fraction of root biomass to the TDMP was higher in initial growth period, and steadily increase up to heading. The weight of root biomass per m², root volume per hill and root length per hill were higher in CORH2 than in ADT38 during both the seasons. Salicylic acid application treatment increased the root biomass, volume and length.

The general process of root degradation under provision of soil aeration through rotary weeder was found to delay the process and relatively that was low compared to continuous submergence and resulted in higher root biomass, volume and length during heading and maturity.

The overall performance of variety, PGRs and field management system was accounted to 'root activity'. The proportion of white active roots were higher and were found to maintain throughout the growth in hybrid CORH2. Similarly salicylic acid application and provision of soil aeration through mechanical disturbance plots recorded higher proportion of white active roots.

Higher and better root activity up to maturity phase, an outcome of this investigation was discussed in relation to higher root volume, root length, root biomass, root activity tested through peroxidase, catalase, SOD, ATPase and CEC, assessed from active tillering stage to maturity stage.

SPAD and LCC values are decided by the chlorophyll content of the leaves. CORH2 recorded higher SPAD and LCC values due to higher chlorophyll content as compared to ADT38. PGRs application significantly increased the SPAD and LCC values at later stages of the crop growth at both the seasons. SPAD and LCC values were found to be influenced positively by provision of soil aeration (F1) as well as chlorophyll content of the leaves were higher in *Samba* and *Thaladi* season.

CORH2 recorded higher leaf folder infestation and disease incidence as compared to ADT38 during both the seasons. Application of salicylic acid suppressed the leaf folder infestation and disease incidence remarkably. Leaf folder infestation was more during *Samba* season while disease incidence was more during *Thaladi* season.

Hybrid CORH2 recorded higher productive tillers during *Samba* and *Thaladi* seasons. PGRs treatments viz., *Pseudomonas* and salicylic acid significantly increased the productive tillers in both the seasons. Productive tillers per hill was almost similar for the two field managements tested. In general, the number of productive tillers in *Samba* season was lower than *Thaladi* season.

CORH2 and soil aeration through rotary weeder treatment, altered the panicle length during *Thaladi* season, but not during *Samba* season.

Panicle weight was relatively high in hybrid CORH2. Foliar application of salicylic acid and soil aeration through mechanical disturbances did significant impact in panicle weight.

Hybrid CORH2 recorded higher test weight of the grains. Also, PGRs application increased the test weight than control. While field management systems did not influence much.

In general, grains per hill is decided by the carbohydrate reserve at the time of panicle initiation but their conversion as filled grains was altered by root activity.

Hybrid CORH2 had more filled grains than the variety ADT38. Application of salicylic acid at the time of heading when the roots were active, improved the filling process further more. Soil aeration through rotary weeder had better filled grains than the continuous submerged plots during both the seasons. CORH2, soil aeration through rotary weeder and salicylic acid application altered significantly and lowered the sterility percentage during Samba and Thaladi season.

Grain yield was higher in Thaladi than in Samba. The major contributors of higher yield were higher number of productive tillers per hill and higher amount of filled grains per hill.

Hybrid CORH2 recorded higher grain yield over variety ADT38 due to the hybrid vigour, better root activity and higher yield contributing character during *Samba* and *Thaladi* season.

Foliar application of salicylic acid favoured the grain yield by prolonged active root system, higher number of filled grains per hill and lowered the sterility percentage.

Grain yield was higher in soil through rotary weeder plots than continuous submerged plots in *Thaladi* season.

In general grain yield was higher in the hybrid CORH2 with foliar application of salicylic acid and provision of soil aeration through rotary weeder as compared to other treatment combination during *Samba* and *Thaladi* season.

Hybrid CORH2, salicylic acid spray and provision of soil aeration treatment recorded the higher straw yield and HI compared to other treatments.

Gross income, net income and benefit cost ratio were higher in CORH2 with salicylic acid spray and provision of soil aeration through rotary weeder in both

Samba and Thaladi seasons. The benefit cost ratio was lower in variety ADT38 with no PGRs application and existing practices of continuous submergence.

In conclusion:

1. The varieties CORH2 (more tolerance to continuous submergence) and ADT38 (more susceptible to continuous submergence) were selected from the screening experiment, which has 14 varieties, based on the performance under the two field management viz., soil aeration through water and continuous submergence.
2. The effect of hybrid CORH2 is superior in grain yield at both *Samba* and *Thaladi* season.
3. Grain yield increased in foliar application of salicylic acid @ 100ppm during active tillering, panicle initiation and heading stages mainly due to increased number of filled grains per hill and lowered sterility percentage.
4. The effect of soil aeration through rotary weeder performed at 10 days interval between 30-70 DAT on rice growth is distinct. Provision of aeration prolonged the activity of roots, which in turn promoted the production of functional leaves, slowed down the process of leaf senescence and extends growth rate even after heading. Soil aeration through rotary weeder improved grain yield in both *Samba* and *Thaladi* season.
5. Foliar application of salicylic acid and provision of soil aeration through rotary weeder is beneficial to grain yield if there is sustained root activity, otherwise the grain filling process will be reduced.
6. Benefit cost ration high with salicylic acid foliar spray during active tillering, panicle initiation and heading stages and provision of soil aeration through rotary weeder in both *Samba* and *Thaladi* season of puddle lowland rice.

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