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**Sathya Ramalingam**

# Genetic and Molecular analysis of yield and physiological traits in three line hybrids in rice (Oryza sativa L.) under aerobic condition

Genetic studies on physiological and morphological traits of three line hybrids

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**AGRICULTURAL COLLEGE AND RESEARCH INSTITUTE**
**TAMIL NADU AGRICULTURAL UNIVERSITY**
**MADURAI - 625 104**

**2012**

# Genetic and Molecular analysis of yield and physiological traits in three line hybrids in rice (*Oryza sativa* L.) under aerobic condition


**R. SATHYA, M.Sc., (Ag.)**
**I.D. No. 08-810-101**


***Thesis submitted in partial fulfilment of the requirements for the degree of DOCTOR OF PHILOSOPHY*** **(AGRICULTURE)** ***IN PLANT BREEDING AND GENETICS to the Tamil Nadu Agricultural University, Coimbatore.***


**DEPARTMENT OF PLANT BREEDING AND GENETICS**
**AGRICULTURAL COLLEGE AND RESEARCH INSTITUTE**
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**2012**

# CERTIFICATE

This is to certify that the thesis entitled "**Genetic and Molecular analysis of yield and physiological traits in three line hybrids in rice (*Oryza sativa* L.) under aerobic condition"** submitted in partial fulfilment of the requirements for the award of degree **DOCTOR OF PHILOSOPHY (AGRICULTURE) IN PLANT BREEDING AND GENETICS** to the Tamil Nadu Agricultural University, Coimbatore is a bonafide record of research work carried out by **Miss. R. Sathya** under my supervision and guidance and that no part of the thesis has been submitted for the award of any other 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: Madurai **(S. JEBARAJ )**
Date : (Chairman)

**APPROVED BY**

**CHAIRMAN (S. JEBARAJ)**

**MEMBERS (C. VANNIARAJAN)**

**(S. MOHAN)**

**(V. GANESHARAJA)**

**EXTERNAL EXAM**

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**(R. SATHYA)**

## LIST OF SYMBOLS AND ABBREVATIONS

| | | |
|---|---|---|
| % | : | Per cent |
| $\sigma^2 A$ | : | Additive genetic variance |
| $\sigma^2 D$ | : | Dominance genetic variance |
| ° C | : | Degree Centigrade |
| CD | : | Critical Difference |
| cm | : | Centimeters |
| et al., | : | And others |
| $F_1$ | : | First filial generation |
| Fig. | : | Figure |
| g | : | Gram (s) |
| GCA/gca | : | General combining ability variance/effects |
| GCV | : | Genotypic coefficient of variation |
| h | : | Hours |
| ha | : | Hectare |
| kg | : | Kilogram |
| M | : | Molarity |
| mg $g^{-1}$ | : | Milligram per gram |
| mM | : | Millimolar |
| N | : | Normality |
| Nm | : | Nanometer |
| SCA/sca | : | Specific combining ability variance/effects |
| PCV | : | Phenotypic coefficient of variation |
| PIC | : | Polymorphic information content |
| RM | : | Rice microsatellite markers |
| SE | : | Standard Error |
| viz., | : | Namely |
| i.e. | : | That is |
| μl | : | Microlitre |

# ABSTRACT

GENETIC AND MOLECULAR ANALYSIS OF YIELD AND PHYSIOLOGICAL TRAITS IN THREE LINE HYBRIDS IN RICE (Oryza sativa L.) UNDER AEROBIC CONDITION

By
R.SATHYA

*Degree* : **DOCTOR OF PHILOSOPHY (AGRICULTURE) IN PLANT BREEDING AND GENETICS**

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*2012*

An investigation in rice (*Oryza sativa* L.) was carried out subjecting six 'lines' and 15 'testers' crossed in a Line x Tester mating design to estimate gene action, combining ability and heterosis for yield and drought tolerant traits under aerobic condition. The 21 parents were also surveyed using SSR markers.

From the Line x Tester analysis, the hybrids exhibited significant variation among themselves for all the characters studied under aerobic condition. The study of gene action for drought tolerance and yield component traits revealed that all the traits exhibited dominant gene action which was predominant. Therefore, to harness the dominant gene effects, either heterosis breeding or selection at later generations would be an appropriate breeding methodology.

Based on the per se performance of lines and testers, the following parents i.e., IR79128A ($L_1$), IR79156A ($L_2$), COMS14A ($L_5$), COMS24A ($L_6$), IR 80286-22-3-6-1R ($T_3$) and IR7925A-428-2-1-1R ($T_4$) were adjudged as the best parents and crosses involving them would be expected to throw desirable segregants for both yield and drought tolerant traits under aerobic condition.

Based on the gca effects, the parents IR79128A ($L_1$), IR70369A ($L_4$), IR79156A ($L_2$), BI-33 ($T_{15}$), IR79582-21-2-2-1R ($T_5$), KMP-105 ($T_{11}$), $T_1$ (IR 69726-29-1-2-2R) and MAS - 946-1 ($T_9$) were the best general combiners and the crosses involving them would result in the identification of superior segregants with favourable genes for both drought and yield.

Out of 21 parents evaluated based on per se and gca effects, three ‘lines’ viz., IR79128A ($L_1$), IR79156A ($L_2$) and IR70369A ($L_4$) and three ‘testers’ viz., IR7925A-428-2-1-1R ($T_{11}$), KMP -148 ($T_{12}$) and BI-33 ($T_{15}$) were identified as the best genotypes which will be utilized in further breeding programmes as parents for improvement of yield and drought tolerance under aerobic conditions.

The cross combination IR70369A / MAS -26 ($L_4$ x $T_{10}$) was identified as the best for recombination breeding to get desirable segregants for yield and drought tolerant traits under aerobic conditions. The cross combinations viz., IR70369A / IR 7925A-428-2-1-1R ($L_4$ x $T_4$) and IR70369A / KMP-105 ($L_4$ x $T_{11}$) had high per se, sca effects and standard heterosis for drought tolerant and yield traits under aerobic conditions. They may be exploited for getting heterotic segregants. Hence, IR70369A is suggested for conversion to cytoplasmic male sterility with suitable male sterile source. The parents MAS -26, IR 7925A-428-2-1-1R and KMP-105 are recommended for testing their restorability with suitable CMS source.

Correlation studies showed that the productive tillers per plant, panicle length, spikelet fertility, harvest index, proline content, SPAD chlorophyll meter reading, chlorophyll stability index, relative water content and dry root weight have to be given priority during selection to increase grain yield under aerobic conditions as they were significantly and positively correlated with yield and inter correlated among themselves.

Path analysis indicated that panicle length, filled grains per panicle, productive tillers per plant, 100 grain weight and harvest index had high indirect effects on grain yield. Hence, these are the major yield contributing characters and have to be given importance in selection under aerobic conditions as they had high indirect effects through proline content.

The parental survey indicated that out of 26 SSR markers, seven markers were found to be highly polymorphic. Based on the PIC values, the polymorphism observed in seven SSR markers (RM206, RM278, RM324, RM279, RM303, RM334 and RM281) among the rice cultivars in the present study demonstrated the effectiveness of this method in determining genetic variation. The PIC values for these seven markers were > 0.50.

Genetic similarity values among the 21 rice genotypes used led to the construction of dendrogram. At 73 per cent level of similarity, UPGMA cluster diagram showed VIII groups with additional clusters within each group. The clustering pattern revealed that the genotypes within each cluster had superior performances for one or more traits. The genotypes within each cluster may have more similarity and hence cannot be used in the improvement of traits whereas more diversity occurs between clusters. Hence, the genotypes of one cluster may be crossed with the genotypes of another cluster. The genotypes IR 79128A, IR79156A, IR 7925A-428-2-1-1R, IR 69726-29-1-2-2R, IR 79582-21-2-2-1R, IR 80402-88-3-1-3R, KMP-149, KMP-148, BR-2655 and BI-33 belonging to any one of the VIII clusters exhibited superior performances for different traits. These parents are highly suitable for introgression of important traits which contribute yield improvement in aerobic rice breeding.

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# CHAPTER I

# INTRODUCTION

Rice (*Oryza sativa* L.), a member of poaceae family, is one of the world's most important food crops, feeding more than half of the world's population. It is the most diversified crop due to its adaptation to wide range of geographical and climatic regimes. According to estimates from the United States Department of Agriculture, the average world rice productivity in 1960 was 1.84 tonnes per hectare and in 2009 it was at 3.59 tonnes per hectare with a production of 452 million tonnes whereas the rice area is projected to increase by almost one million hectare from 154.4 million hectares in 2007-08 to 155.3 million hectares in 2008-09. The world population, particularly in the rice consuming countries is increasing at a faster rate. By the year 2025, about 756 million tonnes of paddy, which is 70 per cent, more than the current production, will be needed to meet the growing demand (Tuong and Bowman, 2002). Crop improvement in rice depends on the magnitude of genetic variability and the extent to which the desirable genes are heritable.

Rice is the staple food for over 70 per cent of Asians, the majority of whom are living below the poverty line. More than 90 per cent of the world's rice is produced and consumed in Asia (Barker *et al.,* 1999) and rice production must be increased by an estimated 56 per cent over the next 30 years to keep up with population growth and income-induced demand for food in most Asian countries where about 75 per cent of total rice production comes from irrigated lowlands (Maclean *et al.,* 2002).

India has the largest area under rice crop (about 45 million ha) and ranks second in production next to China with a production of 84.5 million tonnes in an area of 5.60 million hectares whereas, Tamil Nadu ranks 12$^{th}$ in rice production and second in productivity and grown in an area of 2.6 million hectare with a production of 8.19 million tonnes and productivity of 3.2 tonnes per hectare during 2009-2010. Rice contributes 43 per cent of total food grain production and 46 per cent is irrigated; 35 per cent is rainfed medium and low land; 12 per cent in sunderban rainfed upland and the remaining three per cent falls under deep water cultivation. Almost 25 per cent of the world's rice is grown under rainfed lowlands and frequently affected by uneven rainfall distribution. Another 13 per cent of the rice area under cultivation is always subjected to water stress during the growing season.(Bouman *et al*., 2007).

However, even though rice is an important food source for many millions of people, it is also the single largest user of water, requiring two to three times more water input (rain, irrigation) per unit of grain produced than the major cereal crops, such as wheat and maize.

More irrigated land is devoted to rice than to any other crop. With the growing population, increased urbanization and environmental degradation, the supply of fresh water for all human activities is depleting and the situation is getting rapidly worse. For example, it has been estimated that by 2025, 15 million ha of irrigated rice will suffer 'physical water scarcity', and most of the 22 million ha of irrigated dry season rice grown in South and Southeast Asia will suffer 'economic water scarcity' (Tuong and Bouman, 2002). Most of the world's rice production comes from irrigated and rainfed lowland rice fields. Therefore, the development of new rice cultivation techniques and cultivars are required to reduce water consumption in rice production systems.

Various field techniques to save irrigation water have been explored. They include direct seeding, keeping the soil saturated and alternate wetting and drying system (AWD) in lowland fields. Bouman and Tuong (2001) reported that, compared with continuously flooded conditions, small yield reductions (0 to 6 per cent) occurred under saturated conditions, but larger reductions (10 to 40 per cent) occurred under AWD, when soil water potential (SWP) during dry phase reached values between −10 and −40 kPa. Therefore, in order to sustain and to increase the rice production to meet the future demands with limited water supplies, there is a need to genetically alter the basic water requirements of rice through breeding techniques (Vijayakumar *et al*., 2006). Aerobic rice is one such option to decrease water requirements in rice production.

A new water-saving technology is called aerobic rice system (Bouman 2001; Bouman *et al*., 2005). In aerobic rice system, fields remain unsaturated throughout the growing season, as in wheat or maize cultivation. Water can be supplied by surface irrigation (e.g. flush or furrow irrigation) or by sprinklers, but in both cases, the goal is to keep the soil wet but not flooded or saturated. Using this technology, farmers can actually reduce the irrigation water requirement upto 50 per cent and can obtain yields of 4.5 to 6.5 t/ha (Naoki Matsuo *et al*., 2010). This new concept of "Aerobic Rice" combines the characteristics of both upland and high yielding lowland varieties with less water requirement and high response to inputs. Traditional upland rice varieties are grown this way, but they have been selected to give stable but low yields in adverse environments where water availability is very low. On the other hand, high-yielding lowland rice grown under aerobic conditions shows greater potential to save water, but at a severe yield penalty. The distinguishing future of aerobic production system is that crops are direct seeded in free draining; non puddled soils where no standing water is maintained in the field and roots grow mainly in aerobic environment (Atlin *et al*., 2005). Maintaining the production and reducing the water use by rice, is a complex trait (Lafitte and Bennet*,* 2002). Since aerobic rice is targeted at water-short areas, socio-economic comparisons must include water-short lowland rice and other upland crops. The development of high-yielding aerobic rice is still in its infancy and germplasm still need to be improved and appropriate management technologies developed. New varieties that are high yielding and responsive to inputs in aerobic conditions must be developed if the concept of growing rice like an irrigated upland crop is to be successful

Many studies of aerobic rice systems have focused mainly on comparing agronomic traits such as shoot growth, yield and yield components of aerobic rice with those observed under flooded paddy conditions (Bouman *et al.,* 2005; Yang *et al.,* 2005; Peng *et al.,*. 2006). This may be because the concept of aerobic rice is quite new and the difference in soil water conditions between aerobic rice system and temporary water stress conditions is not yet appreciated. Furthermore, there are no studies which have compared the agronomical, morphological and physiological traits between the two situations.

The success of plant breeding programme depends to a greater extent on the knowledge of the genetic architecture of the population and selection of appropriate breeding method for the improvement of traits of interest. It is essential to estimate the various types of gene action for the selection of appropriate breeding procedure to improve the quantitative and qualitative characters (Banumathy *et al.*, 2003). Understanding the target environment is critical for the success of drought tolerance research. Plants possess several morphological and physiological adaptations to overcome the deleterious effects of water stress. Drought tolerance is quantitatively inherited with a complex physiological reaction; thus its genetic basis has received limited attention and development of drought tolerant varieties has been slow (Nadarajan and Muthuramu, 2005). Therefore, it is essential to understand the effects of the prevailing drought stress in the target environment on both yield and drought tolerant traits in order to undertake the genetic improvement of aerobic rice in this region. Most of the traits are quantitative in nature; hence it is necessary to know the inheritance of these traits. Genetic information about the combining ability of parents and hybrids and nature of gene action involved in the inheritance of a trait would be of immense value to plant breeders in the choice of parents and to identify potential crosses of practical use.

Significant yield advantage gained through the adoption and spread of hybrid rice technology had helped China to add about 350 million tonnes of extra rice to its food basket during 1976-1998 and enabled it to divert some of their rice areas to other commercial crops (Anon, 1998). Hybrid rice technology had also shown increased yield, farmer profitability and better adaptability to stress environments such as water scarce and aerobic conditions. Development of rice hybrids with high yield potential for aerobic conditions would be one of the exciting researches to be carried out to overcome the existing water crisis in India. Breeding strategies based on selection of hybrids require expected level of heterosis as well as the specific combining ability.

In breeding high yielding varieties of crop plants, the breeders often face with the problems of selecting parents and crosses. Combining ability analysis is one of the powerful tools available to estimate the combining ability effects and aids in selecting the desirable parents and crosses for the exploitation of heterosis. The Line x Tester analysis provides information about general combining ability (*gca*) of parents and specific combining ability (*sca*) effects of crosses and is helpful in estimating various types of gene actions. Zhang *et al.* (2002) studied the heterosis and combining ability of hybrid rice. The genetic improvement of rice for aerobic environments has not been understood well and major efforts in this front are lacking.

Therefore, the present investigation was carried out to identify best combining parents and hybrids suitable for aerobic cultivation. Keeping the above points in consideration, the present investigation has been formulated with the following objectives;

1. To study the genetics, including physiological, morphological and molecular characteristics of drought tolerance, yield and yield components involving aerobic cultivars

2. Comparison of hybrids with the promising checks under non puddled condition

3. To assess the *gca* of parents and *sca* of hybrids

4. To estimate the heterosis for physiological, yield and yield component traits

5. To study the interrelationship between drought tolerant traits under aerobic condition and to partition the total effects into direct and indirect effects

6. To identify best hybrids for optimum yield coupled with drought tolerant traits and

7. To assess the polymorphism of the parents through molecular markers.

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# CHAPTER II

# REVIEW OF LITERATURE

Rice with the widest adaptation is being cultivated in almost all the types of soils as well as climatic conditions. However, about half of the rice area in the world and 56 per cent of rice in India, do not have sufficient moisture during its growth phase mainly due to inadequate rainfall and less water efficient irrigation system which ultimately cause enormous loss in crop yield (Anbumalarmathi and Nadarajan, 2008).

In India upland rice is grown traditionally in aerobic soils under rainfed conditions with minimal inputs and thus produces very low yields (Atlin and Lafitte, 2002). Food security of this continent depends heavily on rice production from conventional transplanted system, which is under threat as decreasing freshwater availability may lead to water scarcity in 15 million ha of Asia' s irrigated rice by 2025. The per capita availability of water in most of the basins in India, rice growing regions in particular, also predicted to decline below water scarcity line by 2025. Hence, it is imperative to develop alternate rice production systems, which will save water, while maintaining the productivity. Growing rice under aerobic conditions as in the case of other crops will reduce the water requirement by atleast 30 per cent (Sheeba *et al.,* 2005).

The slogan 'Rice is Life' is more appropriate for India as this crop plays a vital role in our National food security and is a means of livelihood for millions of rural household (Misra *et al.,*, 2004). Therefore, in order to sustain and to increase the rice production to meet the future demands with limited water supplies, there is a need to alter genetically the basic water requirements of rice through breeding techniques (Vijayakumar *et al.,* 2006).

The challenge is to develop novel technologies and production systems that will allow rice production to be maintained or increased in the face of declining water availability. Aerobic rice is an emerging agronomical production system that uses less water than conventional flooded rice (Tuong *et al*., 2005). The aerobic rice system uses rice varieties capable of responding well to reduce water inputs in non-puddled and non-saturated soils (Bouman and Tuong, 2001; Atlin *et al*., 2006; Peng *et al*., 2006; Luo, 2010). The crop can be either rainfed or irrigated, depending on rainfall distribution, soil type and subsurface hydrology. Thus, there is some overlapping in the definitions of traditional upland rice and aerobic rice (Bouman *et al*., 2007). Rainfed rice in fertile uplands using high-yielding varieties and ample rainfall can be regarded as aerobic rice because the specific requirement is high production under aerobic soil conditions, whereas non-irrigated rice with lower yield expectations should be regarded as upland rice.

## 2.1. DROUGHT AND DROUGHT TOLERANCE IN RICE

Among the abiotic stresses, drought is a serious limiting factor that reduces rice production and yield stability in rainfed ecosystems. Conventional breeding for drought tolerance is slow in attaining progress due to poor understanding of genetic control of drought tolerance.

A large portion of the world's poor farm is rainfed system where the water supply is unpredictable and drought is common. In Asia, about 50 per cent of the rice land is rainfed and, although rice yields in irrigated systems have doubled and tripled over the past 30 years, only modest gains have occurred in rainfed rice ecosystems. In part, this is because of the difficulty in improving rice varieties for environments that are heterogenous and variable and in part because there has been little effort to breed rice for drought tolerance (Anon, 2003).

A phenomenal enhancement in productivity of rice, wheat and maize has been accomplished and has been well documented as green revolution across the world. In complete contrast to this scenario, the increase in productivity of crops in drought prone habitat has been meager, especially in rice, a crop grown under diverse moisture stress (Shashidhar, 2008).

When rice populations are subjected to drying soil conditions, genotypes are very clearly separated into those that wilt and dry readily and those that maintain a measure of turgor and viability as stress continues (De Datta *et al*., 1988). Furthermore, genotypes differ in their recovery upon rehydration and the level of genotypic recovery is closely related to its hydration status prior to recovery (Malabuyoc *et al*., 1985). Drought tolerance in terms of these responses is most likely dependent mainly on one or more of the following components:

- Moderate water use through reduced leaf area and shorter growth duration

- The ability of the roots to exploit deep soil moisture to provide for evapotranspirational demand

- The capacity for osmotic adjustment which allows to retain turgor and protect meristems from extreme dessication and

- The control over non-stomatal water loss from leaves.

Published results (Turner, 1986; Yu *et al*., 1995) indicated that traditional upland cultivars generally tend to excel in root growth and soil moisture extraction capacity while lacking in osmotic adjustment. These cultivars usually develop severe leaf hydration and leaf rolling as soon as soil moisture is depleted. When plant water deficit develops, they tend to conserve moisture and leaf water status by stomatal closure. Stomatal closure in these cultivars may be induced by either lack of osmotic adjustment or by a hormonal root signal (Davies *et al*., 2002). On the other hand, low land improved cultivars tend to lack root depth, but they generally excel in osmotic adjustment. Such cultivars retain turgidity and leaf gas exchange to lower leaf water potential than the former cultivars. However, without sufficient deep root development, they are bound to severely desiccate once the top soil is dried.

It can be speculated that under upland situations with deep soil moisture there have been a selective advantage to deep and thick root systems, which served to maintain high leaf water status and dehydration avoidance. Under such conditions, deep roots have evolved in adapted materials. Osmotic adjustment did not evolve under such conditions because plants were usually avoiding severe water deficit. The capacity for osmotic adjustment may have evolved where leaf tissue water status was often reduced by water deficit, such as in lowland rice where deep rooting is often deterred by the subsoil compaction. These different modes of response to drought stress require validation and further research to suggest clues to desirable breeding strategies with respect to the different rice environments.

## 2.2. NEED FOR AEROBIC RICE AND ITS IMPORTANCE

Food security in Asia is challenged by increasing food demand and threatened by declining water availability. More than 75 per cent of the rice supply comes from 79 million ha of irrigated land. Thus, Asia's present and future food security depends largely on the irrigated rice production system. However, the water-use efficiency of rice is low and growing rice requires large amounts of water. In Asia, irrigated agriculture accounts for 90 per cent of total diverted freshwater and more than 50 per cent of this is used to irrigate rice. Until recently, this amount of water has been taken for granted, but now the global "water crisis" threatens the sustainability of irrigated rice production. The available amount of water for irrigation is becoming scarce (Gleick, 1993; Postel, 1997). The reasons for this are diverse and location-specific, but include decreasing quality (chemical pollution, salinization), decreasing resources (e.g., falling groundwater tables, silting of reservoirs) and increased competition from other sectors such as urban and industrial users. Because of the increasing scarcity of water, the cost of its use and resource development are increasing as well. The conventional flooding technique is very high water consuming. Brown *et al.* (1978) have indicated that 48 per cent (570 mm) of the applied irrigation water (1180 mm) is lost through evapotranspiration (ET). The remainder is lost due to runoff and infiltration. Water represents a major and necessary production cost for rice growers. Therefore, farmers and researchers alike are looking for ways to decrease water use in rice production and increase its use efficiency.

A fundamental approach to reduce water inputs in rice is to grow the crop like an irrigated upland crop such as wheat or maize. Instead of trying to reduce water input in lowland fields, the concept of having the field flooded or saturated is abandoned altogether. Upland crops are grown in nonpuddled aerobic soil without standing water. Irrigation is applied to bring the soil water content in the root zone up to field capacity after it has reached a certain lower threshold e.g., halfway between field capacity and wilting point (Borell *et al*., 1997).

The amount of irrigation water should match evaporation from the soil and transpiration by the crop. Since, it is not possible to apply irrigation water to the root zone only, some of it is lost by deep percolation and is unavailable for uptake by the crop. Typical field application efficiencies vary from 60–70 per cent using surface irrigation (e.g., flash or furrow irrigation) to more than 90 per cent using sprinkler or drip irrigation (Jha and Singh 1997).

De Datta *et al.* (1973) tried growing rice like an upland crop using furrow irrigation in the dry season of 1971 at IRRI. Using the high-yielding lowland variety IR20, total water (irrigation plus rainfall) savings were 56 per cent and irrigation water savings 78 per cent compared with growing the crop under flooded conditions. However, yield decreased from 7.9 to 3.4 t $ha^{-1}$. Upland cultivars that performed equally well under flooded and dryland irrigation were used, but their yields of around 5 t $ha^{-1}$ were much lower than those of lowland cultivars. Studies on non-flooded irrigated rice using sprinkler irrigation were conducted in the United States in Texas and Louisiana (Westcott and Vines, 1986 and McCauley, 1990). Experiments used commercial rice cultivars under lowland cultivation.

Irrigation water requirements were 20–50 per cent less than in flooded rice, depending on soil type, rainfall and water management. The highest yielding cultivars (producing 7–8 t $ha^{-1}$ under flooded conditions) however had yield reductions of 20–30 per cent compared with flooded rice. The most drought-resistant cultivars produced the same under both conditions, but their yields were much lower (5–6 t $ha^{-1}$). Under economic conditions prevalent in the US, the adoption of irrigated dryland rice (using existing cultivars) was not economically attractive. New varieties must be developed if growing rice like an irrigated upland crop is to be successful.

Lowland cultivars have been selected to give high yields under continuously flooded lowland conditions. They generally suffer a yield loss when the soil water content drops below saturation. Upland varieties have been developed to give stable though low yields in adverse environments where rainfall is low, irrigation is absent, soils are poor or toxic, weed pressure is high and farmers are too poor to supply high inputs.

Therefore, IRRI recently coined the term “aerobic rice” to refer to high-yielding rice grown in nonpuddled aerobic soil. This aerobic rice, which can be rainfed or irrigated, should be responsive to high inputs and should tolerate flooding. It has to combine characteristics of both upland and high yielding lowland varieties.

### 2.2.1. Aerobic rice breeding and its improvement

Water in irrigated rice production has been taken for granted for centuries, but the “looming water crisis” may change the way rice is produced in the future. Water-saving irrigation technologies that were investigated in the early 1970s, such as saturated soil culture and alternate wetting and drying, are receiving renewed attention from researchers. These technologies reduce water input, though mostly at the expense of some yield loss.

Traditional upland rice crops are grown in unbunded, unflooded fields, where soil conditions in the root zone remain aerobic through most of the growing season. Farmers usually treat upland rice as a subsistence crop, investing little on inputs beyond family labour. Because upland rice varieties are grown without irrigation in unsaturated soils, they are considered to be drought tolerant. However, upland rice yields under traditional systems are low, averaging one to two tonnes per ha in most rice growing regions. Intensification of management of these systems with currently available germplasm is difficult because most traditional upland rice varieties are tall, low tillering and prone to lodging when grown under conditions of favorable moisture and high soil fertility.The development of aerobic rice varieties is probably the most ambitious challenge of all (Lafitte, 2002).

However, little progress has been made in the breeding for aerobic rice, because the fundamental mechanisms of drought tolerance and yield contributing characters of aerobic rice are poorly understood. Development of high yielding aerobic rice is still in its infancy and germplasm still needs to be improved and appropriate breeding and management technologies developed. Hence, improvement of rice yield under aerobic systems will be made possible only through the incorporation of drought tolerance and yield contributing traits in breeding programme.

A number of physiological and morphological traits have been proposed to improve the performance of aerobic rice challenged by limited water and extensive input conditions. There is strong evidence that high input aerobic systems require specially bred cultivars that differ from both conventional upland varieties and elite irrigated varieties. Thus, aerobic rice varieties need to be more tolerant to drought stress, particularly at the sensitive reproductive stage, than most irrigated varieties and aerobic rice breeding programs must emphasize drought tolerance. Optimization of aerobic systems will likely require the development of a new cultivar type combining moderate drought tolerance, high rates of tillering, high harvest index and lodging resistance (Atlin, 2003).

The China Agricultural University (CAU) started its systematic aerobic rice breeding programme in the early 1980s. This programme is based on the genetic recombination of lowland and upland varieties from different eco-geographic origins. Han Dao 113 and Han Dao 58 are currently the most extensively grown aerobic rice varieties (Wang Huaqi *et al*., 2002). Yield and drought tolerance of an aerobic rice is a complex trait, expression of which depends on action and interaction of different morphological, physiological and biochemical characters. The identification of genes that are responsible for morphological and physiological traits and their locations on chromosomes have not been possible, but their inheritance pattern and nature of gene action have been reported. Polygenic inheritance of root characters is reported by Ekanayake *et al*. (1985). Though some more reports in this regard for other traits are available, further investigation is the need of the hour to have better understanding of genetic control of morphological and physiological traits contributing to drought tolerance and higher yield under aerobic conditions.

Recently, a new class of upland adapted cultivars with improved lodging resistance, harvest index and input responsiveness has been developed by breeding programmes in China, Brazil and Philippines. These varieties combine some of the yield potential-enhancing traits of lowland high-yield varieties adapted to low input systems. IRRI recently coined the term "Aerobic Rice" referred to high yielding rice grown in non-puddled aerobic soil. It is commercially grown in Brazil, China, Philippines and rice-wheat belt of India (Haryana, Punjab and Uttar Pradesh). The distinguishing feature of aerobic production system is that crops are direct seeded in free-draining, non-puddled soils where no standing water layer is maintained in the field and roots grow in a mainly aerobic environment (Bouman, 2001 and Atlin *et al.,* 2005).

Traditionally aerobic rice is grown in rainfed uplands with low or no inputs with declining water availability for agricultural use, aerobic rice cultivation is expected to expand into the irrigated, intensive and high productivity cropping systems (Vijayakumar *et al.,* 2006).

Aerobic rice production also constitutes a separate target environment from traditional upland rice based systems. Water inputs in aerobic rice was more than 50 per cent lower (470-650mm), water productivity 64-88 per cent higher, gross returns 28-44 per cent lower and labour use 55 per cent lower compared with lowland rice. Thus aerobic rice, which can be rainfed or irrigated, should be responsive to high inputs and should tolerate flooding. It has combined characteristics of both upland and high yielding low land varieties. Breeders have to respond to the challenge of breeding varieties that perform well under non-permanently flooded conditions.

Development of high yielding aerobic rice cultivars will considerably improve the rice production in rainfed and water scarce low land conditions. However, little progress has been made in breeding for aerobic rice; because the fundamental mechanisms of drought tolerance and yield contributing characters of aerobic rice are poorly understood. Development of high yielding aerobic rice is still in its infancy and germplasm still needs to be improved and appropriate breeding and management technologies developed. Hence, improvement of rice yield under aerobic systems will be made possible only through the incorporation of drought tolerant and yield contributing traits in breeding programme.

Atlin *et al.* (2005) reported, the rice cultivars for aerobic system need to combine high biomass production, harvest index and lodging resistance with moderate drought tolerance, particularly at the sensitive stage, because aerobic system depends on direct seeding in dry soil, without accumulation of standing water, vigorous early growth is also needed to compete with weeds and to root deeply to avoid early season drought. Recent research has shown that drought tolerance and high-spikelet fertility under reproductive stage stress in aerobic adapted germplasm are strongly associated with short duration and minimal flowering delay under stress.

Aerobic production systems based on high-yield, input responsive upland cultivars have already been developed to replace conventional irrigated lowland rice production on the water short plains of north eastern China, producing yields of 4.5 to 6.5 t/ha, with substantial water savings relative to conventional irrigated production (Bouman *et al.,* 2005).

Atlin and Lafitte (2002) reported, the yield in high input aerobic systems is currently about 30 per cent lower than conventional irrigation management and at least 100 per cent greater than yield in conventional low-input upland systems, which average to 2 t/ ha because of the lower yield of aerobic systems. Direct selection under high-input aerobic management from the earliest stages of a breeding programme is therefore likely to be required to maximize selection response. Early screening of breeding lines under high-fertility aerobic management is particularly important in selecting for lodging resistance, a key trait for aerobic cultivars.

## 2.3. GENETICS OF DROUGHT TOLERANCE AND YIELD

Yield and Drought tolerance are a complex trait, expression of which depends on action and interaction of different morphological (earliness, reduced leaf area, reduced tillering, efficient rooting system, leaf rolling and stability in yield), physiological (reduced transpiration, high water use efficiency, stomatal closure and osmotic adjustment) and biochemical (accumulation of proline, polyamine, trehalose, *etc*., increased nitrate reductase activity and increased storage of carbohydrate) characters. Very little is known about the genetic mechanisms that condition these characters. Very little is known about the genetic mechanisms that condition these characters. The genetic improvement of rice for aerobic (non-flooded) has not been understood well and major efforts on this front are lacking (Vijaykumar *et al*., 2006).

The long root and high root number are controlled by dominant alleles and thick root tip by recessive alleles (Armenta-Soto *et al*., 1983). The identification of genes that are responsible for morphological and physiological traits and their locations on chromosomes have not been possible, but their inheritance pattern and nature of gene action have been reported. Polygenic inheritance of root characters is reported by Ekanayake *et al*. (1985). However, leaf rolling has shown monogenic inheritance (Singh and Mackill, 1991).

The genetic basis is still very narrow and only a few successful aerobic rice varieties exist. Further efforts need to be directed at increasing the yield potential and looking at broad biotic (diseases, weed) and abiotic (drought, micronutrient deficiency) stress tolerances. Besides yield, grain quality should be a key focus of attention since this will determine consumer acceptability (Wang Huaqi *et al.,* 2002).

Though some more reports in this regard for other traits are available, further investigation is the need of the hour to have better understanding of genetic control of morphological and physiological traits contributing to drought tolerance and higher yield under aerobic conditions