

**MORPHO-PHYSIOLOGICAL AND BIOCHEMICAL
CHARACTERIZATION OF A RECOMBINANT
INBRED LINE POPULATION OF RICE (*Oryza sativa* L.)
UNDER DIRECT-SEEDED AEROBIC CONDITIONS**

Dissertation

**Submitted to the Punjab Agricultural University
in partial fulfillment of the requirements
for the degree of**

DOCTOR OF PHILOSOPHY

in

**BOTANY
(Minor Subject: Biotechnology)**

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L-2010-BS-54-D**

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2014

CERTIFICATE I

This is to certify that the thesis/dissertation entitled, “**Morpho-physiological and biochemical characterization of a recombinant inbred line population of rice (*Oryza sativa* L.) under direct-seeded aerobic conditions**” submitted for the degree of **PhD**, in the subject of **Botany** (Minor subject: **Biotechnology**) of the Punjab Agricultural University, Ludhiana, is a bonafide research work carried out by **Amandeep Kaur Cheema (L-2010-BS-54-D)** under my supervision and that no part of this dissertation has been submitted for any other degree.

The assistance and help received during the course of investigation have been fully acknowledged.

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CERTIFICATE II

This is to certify that the thesis entitled, “**Morpho-physiological and biochemical characterization of a recombinant inbred line population of rice (*Oryza sativa* L.) under direct-seeded aerobic conditions**” submitted by **Amandeep Kaur Cheema (L-2010-BS-54-D)** to the Punjab Agricultural University, Ludhiana, in partial fulfillment of the requirements for the degree of **PhD**, in the subject of **Botany** (Minor subject: **Biotechnology**) has been approved by the Student's Advisory Committee along with Head of the Department after an oral examination on the same.

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ABSTRACT

Direct seeding of rice (*Oryza sativa* L.) is a resource conservation technology but at the cost of reduction in yield. In the present study, recombinant inbred lines (RILs) obtained from a cross between PR 120 x UPLRi 7 were sown as direct-seeded aerobic and conventional transplanted crops respectively for two seasons. Various morpho-physiological, biochemical and yield related traits were studied under the two conditions. In general, plant height, dry matter, crop growth rate, relative growth rate, leaf area and chlorophyll content were lower under direct-seeded aerobic conditions than under conventional transplanted conditions. Plant height and crop growth rate showed a positive correlation with grain yield and had a direct effect on grain yield. Dry matter accumulation did not show any significant correlation but had an indirect effect on grain yield. Relative growth rate, leaf area and chlorophyll content did not show any correlation or effect on grain yield. All the yield contributing traits viz., above ground biomass, total number of tillers per 0.5m row, number of fertile tillers per panicle per 0.5m row, spikelets per panicle, grain filling percentage, grain yield per 0.5m row, harvest index, 1000 grain weight were lower and sterile grain per panicle were higher in direct-seeded aerobic condition. Above ground biomass and harvest index showed correlation with yield and had a direct effect on grain yield under both direct-seeded aerobic and conventional transplanted conditions. In general, higher sugar, starch and proline content were detected in leaves of direct-seeded aerobic crop. Out of twenty RILs under study, Ae-RIL-B-158, showed highest proline and sugar contents. Interestingly, this RIL showed least reduction in yield when sown under direct seeded-aerobic condition as against conventional transplanted condition suggesting this RIL may be more tolerant to drought stress as it accumulated highest proline and sugars under direct-seeded aerobic condition. The development of aerenchyma was comparatively more in crop raised under conventional transplanted conditions than under direct-seeded aerobic conditions. UPLRi7 (parent) showed maximum aerenchyma under direct-seeded aerobic conditions while PR120 (parent) showed maximum aerenchyma formation under conventional transplanted conditions. Under both the sowing conditions, two high-yielding RILs (Ae-RIL-B-42 and Ae-RIL-B-44) had higher aerenchyma than the two low-yielding RILs (Ae-RIL-B-7 and Ae-RIL-B-117). These characters could be used as criteria for selecting RILs for incorporating into breeding programmes for yield enhancement.

Keywords: Direct-seeded aerobic rice, conventional transplanted rice, morpho-physiological, biochemical, yield and yield contributing parameters, aerenchyma formation.

Signature of Major Advisor

Signature of the Student

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ਸਾਰ ਅੰਸ਼

ਝੋਨੇ ਦੀ ਸਿੱਧੀ-ਬਿਜਾਈ ਇੱਕ ਸਾਧਨ-ਬਚਾਉ ਤਕਨੀਕ ਹੈ ਪਰ ਇਸ ਨਾਲ ਪੈਦਾਵਾਰ ਵਿੱਚ ਘਾਟ ਹੁੰਦੀ ਹੈ। ਮਜ਼੍ਹੂਦਾ ਅਧਿਐਨ ਦੌਰਾਨ ਪੀ ਆਰ 120 x ਯੂ ਪੀ ਐਲ ਆਰ ਆਈ 7 (PR 120 x UPLRi 7) ਦੇ ਕਰੌਸ ਨਾਲ ਪੈਦਾ ਕੀਤੀਆਂ ਰੀਕੰਮਬੀਨੈਂਟ ਇੰਨਬ੍ਰੈਡ ਲਾਈਨ (ਰਿਲਜ਼) (RILs) ਨੂੰ ਸਿੱਧੇ ਅਤੇ ਰਿਵਾਇਤੀ ਬਿਜਾਈ ਦੇ ਢੰਗ ਨਾਲ ਦੋ ਸਾਲਾਂ ਲਈ ਬੀਜਿਆ ਗਿਆ। ਵੱਖ-ਵੱਖ ਮੌਰਫੋ-ਫਿਜ਼ਿਓਲੋਜੀਕਲ, ਬਾਇਓਕੈਮੀਕਲ ਅਤੇ ਪੈਦਾਵਾਰ ਸਬੰਧੀ ਗੁਣਾਂ ਦਾ ਅਧਿਐਨ ਕੀਤਾ ਗਿਆ। ਆਮ ਤੌਰ ਤੇ ਸਿੱਧੀ-ਬਿਜਾਈ ਵਿੱਚ ਪੌਦੇ ਦੀ ਉਚਾਈ, ਡ੍ਰਾਈ ਮੈਟਰ (dry matter), ਕਰਾਪ ਗਰੋਥ ਰੇਟ (crop growth rate), ਰੇਲਾਟਿਵ ਗਰੋਥ ਰੇਟ (relative growth rate), ਪੱਤਿਆਂ ਦਾ ਖੇਤਰਫਲ (leaf area) ਅਤੇ ਕਲੋਰੋਫਿਲ (chlorophyll content) ਆਦਿ ਰਵਾਇਤੀ ਬਿਜਾਈ ਨਾਲੋਂ ਘੱਟ ਸਨ। ਪੌਦੇ ਦੀ ਉਚਾਈ ਅਤੇ ਕਰਾਪ ਗਰੋਥ ਰੇਟ ਦਾ ਅਨਾਜ ਪੈਦਾਵਾਰ ਨਾਲ ਸਬੰਧ ਸੀ ਅਤੇ ਇਹ ਅਨਾਜ ਪੈਦਾਵਾਰ ਤੇ ਸਿੱਧਾ ਅਸਰ ਪਾਉਂਦੇ ਹਨ। ਅਨਾਜ ਪੈਦਾਵਾਰ ਦਾ ਡ੍ਰਾਈ ਮੈਟਰ ਐਕੁਮੁਲੇਸ਼ਨ ਨਾਲ ਕੋਈ ਵੀ ਮਹੱਤਵਪੂਰਨ ਸਬੰਧ ਨਹੀਂ ਸੀ ਪਰ ਇਸਦਾ ਅਸਰ ਅਸਿੱਧੇ ਤੌਰ ਤੇ ਅਨਾਜ ਪੈਦਾਵਾਰ ਤੇ ਪਿਆ। ਰੇਲਾਟਿਵ ਗਰੋਥ ਰੇਟ, ਪੱਤਿਆਂ ਦਾ ਖੇਤਰਫਲ ਅਤੇ ਕਲੋਰੋਫਿਲ ਦਾ ਕੋਈ ਵੀ ਸਬੰਧ ਅਨਾਜ ਪੈਦਾਵਾਰ ਨਾਲ ਨਹੀਂ ਸੀ। ਸਿੱਧੀ-ਬਿਜਾਈ ਵਿੱਚ ਪੈਦਾਵਾਰ ਨਾਲ ਸਬੰਧਿਤ ਗੁਣ ਜਿਵੇਂ ਕਿ ਜ਼ਮੀਨ ਤੋਂ ਉਪਰਲਾ ਬਾਇਓਮਾਸ, ਕੁੱਲ ਬਣੇ ਪ੍ਰਤੀ 0.5 ਮੀਟਰ ਕਤਾਰ, ਹਾਰਵੇਸਟ ਇੰਡੈਕਸ, 1000 ਦਾਣਿਆ ਦਾ ਭਾਰ, ਉਪਜਾਊ ਬੂਝੇ ਪ੍ਰਤੀ 0.5 ਮੀਟਰ ਕਤਾਰ, ਸਪਾਇਕਲੇਟ ਪ੍ਰਤੀ ਸਿੱਟਾ, ਅਨਾਜ ਭਰਾਈ ਪ੍ਰਤੀਸ਼ਤਤਾ ਰਵਾਇਤੀ ਬਿਜਾਈ ਨਾਲੋਂ ਘੱਟ ਅਤੇ ਨਿਰਜੀਵ ਦਾਣੇ ਪ੍ਰਤੀ ਸਿੱਟਾ ਵੱਧ ਸਨ। ਦੋਨੋਂ ਬਿਜਾਈ ਦੇ ਤਰੀਕਿਆਂ ਵਿੱਚ ਜ਼ਮੀਨ ਤੋਂ ਉਪਰਲੇ ਬਾਇਓਮਾਸ ਅਤੇ ਹਾਰਵੇਸਟ ਇੰਡੈਕਸ ਦਾ ਬੀਜ ਪੈਦਾਵਾਰ ਨਾਲ ਸਬੰਧ ਸੀ ਅਤੇ ਇਹ ਪੈਦਾਵਾਰ ਤੇ ਸਿੱਧਾ ਅਸਰ ਪਾਉਂਦੇ ਹਨ। ਆਮ ਤੌਰ ਤੇ ਸਿੱਧੀ-ਬਿਜਾਈ ਵਿੱਚ ਕੁੱਲ ਘੁਲਣਸ਼ੀਲ ਖੰਡ (total soluble sugar), ਕੁੱਲ ਘੁਲਣਸ਼ੀਲ ਸਟਾਰਚ (total soluble starch) ਅਤੇ ਪ੍ਰੋਲੀਨ (proline content) ਮਾਤਰਾ ਜ਼ਿਆਦਾ ਹੁੰਦੇ ਹਨ। ਦੋਹਾਂ ਬਿਜਾਈ ਦੇ ਤਰੀਕਿਆਂ ਦੌਰਾਨ ਅਧਿਐਨ ਕੀਤੀਆਂ ਦੀ ਰਿਲਜ਼ ਵਿੱਚੋਂ Ae-RIL-B-158 ਵਿੱਚ ਇਹ ਮਾਤਰਾਵਾਂ ਸਭ ਤੋਂ ਵੱਧ ਸਨ। ਦਿਲਚਸਪੀ ਇਹ ਹੈ ਕਿ Ae-RIL-B-158 ਸਭ ਤੋਂ ਘੱਟ ਪੈਦਾਵਾਰ-ਘਾਟਾਉ ਨੂੰ ਦਰਸਾਉਂਦੀ ਹੈ ਜਦੋਂ ਇਸਦੀ ਤੁਲਨਾ ਰਵਾਇਤੀ ਬਿਜਾਈ ਦੇ ਤਰੀਕੇ ਨਾਲ ਕੀਤੀ ਗਈ। ਐਰਿਮਕਾਇਮਾ ਟੀਸ਼ੂ (aerenchyma tissue) ਸਿੱਧੀ-ਬਿਜਾਈ ਦੇ ਤਰੀਕੇ ਦੀ ਤੁਲਨਾ ਵਿੱਚ ਰਵਾਇਤੀ ਬਿਜਾਈ ਦੀ ਤਕਨੀਕ ਵਿੱਚ ਵੱਧ ਵਿਕਸਿਤ ਹੁੰਦਾ ਹੈ। ਸਿੱਧੀ-ਬਿਜਾਈ ਵਿੱਚ ਯੂ ਪੀ ਐਲ ਆਰ ਆਈ 7 (UPLRi 7) ਅਤੇ ਰਵਾਇਤੀ ਬਿਜਾਈ ਤਕਨੀਕ ਵਿੱਚ ਪੀ ਆਰ 120 (PR 120) ਸਭ ਤੋਂ ਵੱਧ ਐਰਿਮਕਾਇਮਾ ਟੀਸ਼ੂ ਵਿਕਸਿਤ ਸੀ। ਦੋਹਾਂ ਹੀ ਤਕਨੀਕਾਂ ਵਿੱਚ ਵੱਧ-ਪੈਦਾਵਾਰ ਵਾਲੀਆਂ ਰਿਲਜ਼ ਵਿੱਚ ਵੱਧ ਅਤੇ ਘੱਟ-ਪੈਦਾਵਾਰ ਵਾਲੀਆਂ ਰਿਲਜ਼ ਵਿੱਚ ਘੱਟ ਐਰਿਮਕਾਇਮਾ ਟੀਸ਼ੂ ਵਿਕਸਿਤ ਪਾਇਆ ਗਿਆ। ਇਹਨਾਂ ਗੁਣਾਂ ਨੂੰ ਬ੍ਰੀਡਿੰਗ ਪ੍ਰੋਗਰਾਮ ਵਿੱਚ ਸ਼ਾਮਲ ਕਰਕੇ ਪੈਦਾਵਾਰ ਵਧਾਉਣ ਦੇ ਤਰੀਕਿਆਂ ਵਿੱਚ ਰਿਲਜ਼ ਦੀ ਚੋਣ ਕਰਨ ਲਈ ਵਰਤਿਆ ਜਾ ਸਕਦਾ ਹੈ।

ਸ਼ਬਦ ਕੁੰਜੀ: ਝੋਨੇ ਦੀ ਸਿੱਧੀ-ਬਿਜਾਈ, ਝੋਨੇ ਦੀ ਰਵਾਇਤੀ ਬਿਜਾਈ, ਮੌਰਫੋ-ਫਿਜ਼ਿਓਲੋਜੀਕਲ, ਬਾਇਓਕੈਮੀਕਲ, ਅਨਾਜ ਪੈਦਾਵਾਰ ਅਤੇ ਅਨਾਜ ਪੈਦਾਵਾਰ ਸਬੰਧੀ ਗੁਣ ਅਤੇ ਐਰਿਮਕਾਇਮਾ ਟੀਸ਼ੂ।

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Chapter-I

INTRODUCTION

Rice is one of the most important staple food crops in the world. In India, rice is grown in an area of 441 m ha with production of 157.98m tonns. In Punjab, it is grown in an area of 2821 thousand ha with annual production of 15813thousand tonns (Anon 2012). There are three principal methods for establishing rice crop, viz, i) transplanting, which involves replanting rice seedlings grown in nurseries into puddled soils; ii) dry seeding, where seeds are sown (broadcast, drilled or dibbled) on unsaturated soils and iii) wet seeding, where pre-germinated seeds are sown in saturated puddled soils. The conventional procedure of raising rice crop involves growing rice seedlings in a nursery bed and later transplanting them into main field. In this method, field preparation consists of soaking, ploughing and puddling after harvesting the previous crop. This procedure is water consumptive, labour intensive and additionally may accelerate mineralization of organic matter, reduce soil fertility and deteriorate chemical and physical properties of soil (Papendick *et al* 1997). It also forms a plough pan that restricts percolation of water causing temporary water logging and restricts root penetration and growth of succeeding crops (Gill *et al* 2006). Therefore, there is an urgent need to adopt alternative systems of rice cultivation that requires less water and is less deleterious to physical and ecological traits of soils.

A fundamental approach to overcome these concerns is to grow rice crop like an irrigated upland crop. Direct seeding involves establishing rice crop from seeds sown in the field rather than by transplanting seedlings from the nursery. Direct seeding which includes dry and wet seeding methods is becoming more popular with rice farmers because it requires less labour and time than conventional transplanting (Tuong *et al* 2000). Under irrigated conditions, farmers commonly practice wet seeding, using pre-germinated seeds. Dry seeding is usually adopted in areas where water is scarce or its supply is unpredictable, such as in rainfed areas (Chin and Mortimer 2002). Direct-seeding methods have several advantages as such crop are faster and easier to plant, are less labour intensive, consume less water (Bhushan *et al* 2007), are conducive to mechanisation (Khade *et al* 1993), have shorter crop duration (Farooq *et al* 2006 a,b), mature 7–10 days earlier and have less methane emissions (Balasubramanian and Hill 2002) than the transplanted crop. It is a resource conservation technology as it has been found to save 35-57% water (Singh *et al* 2002). Further, direct seeded crop does not experience growth delay due to transplant injury. Direct seeding also offers the option to resolve edaphic conflicts between rice and the subsequent non-rice crop and enhance sustainability of succeeding winter crops, particularly early sown wheat (Farooq *et al* 2008).

Rice plants grown under both direct seeded and transplanted systems are sensitive to water stress. Direct-seeded also known as aerobic rice has a great potential for saving water but at the cost of severe reduction in yield. A substantially lower grain yield has been reported in aerobic rice as compared with flooded lowland rice (Wei *et al* 2011). As dry seeded rice are grown on marginal soil moisture, any brief episode of drought is deleterious for plants raised by direct seeding. In rice, the effect of drought varies with the variety, degree and duration of stress and its coincidence with different growth stages (Dwivedi *et al* 2012). The susceptibility of rice crop to water stress is more pronounced at reproductive stage and causes greater reduction in grain yield when stress coincides with the irreversible reproductive process (Cruz and O'Toole 1984). Less water availability at reproductive stage is found to be a reason for low yield of aerobic rice (Bouman *et al* 2002). Time to anthesis reduces when panicle water potential decreases, resulting in large scale panicle sterility. Further, rice cultivation in aerobic conditions may lead to unknown challenges with respect to productivity, weed infestation, availability of nitrogen, micronutrients and pest and disease incidence (Singh *et al* 2002).

A key component of success in aerobic rice system is selection of appropriate cultivars (Wang *et al* 2002). Compared with lowland rice breeding, the aerobic rice breeding programme is small and the genetic base is very narrow. Only a few successful aerobic rice cultivars with high-yield potential and broad biotic and abiotic stress tolerance are commercially grown. A group of temperate aerobic rice cultivars, called Han Dao, has been developed by the breeders from China Agricultural University and are being commercially grown by farmers in northern China since the early 1990s (Yang *et al* 2002). In 2001, IRRI started a breeding program to develop tropical aerobic rice cultivars for the Asian tropics (Bouman 2001) and some improved tropical upland rice cultivars (such as Apo) that performed well under aerobic conditions were identified (George *et al* 2002; Lafitte *et al* 2002).

To achieve high yields under aerobic conditions, aerobic rice cultivars should combine the drought-tolerance characteristics of upland cultivars with the high-yielding characteristics of lowland cultivars (Lafitte *et al* 2002). Yield in crop depends upon three processes viz. i) the interception of radiation, ii) the transformation of intercepted radiation into biomass and iii) partitioning of biomass into grain (harvest index). The amount of intercepted radiation depends on the development of leaf surface area and total duration of crop in the field (Bouman *et al* 2006). There are conflicting reports in literature regarding radiation use efficiency *vis a vis* transplanted and direct seeded rice. In an experiment conducted at various sites in China, in general, under direct seeded conditions, there was decreasing radiation use efficiency (RUE) with decreasing water input (Bouman *et al* 2006) while experiments from IRRI, Manila have shown that direct seeded rice exhibited higher crop growth

rates and tillering ability during vegetative stages than transplanted rice even when planting density and geometry were equal (Dingkuhn *et al* 1990). Differences in growth kinetics were caused by physiological shock induced by transplanting procedure.

Despite acknowledged drought susceptibility of aerobic rice, yield potential and water productivity is less reported (Xue *et al* 2008). Most experiments have shown that yield gets consistently reduced with increased duration of drought (Bouman and Tuong 2001). Rajkumar and Ibrahim (2013) have reported that the number of panicles were significantly lower in plants, which were exposed to aerobic condition at vegetative stage than the plants under flooding. Number of productive tillers per plant is associated with higher productivity (Joshi *et al* 2004). Rice breeding over last decade has increased water productivity by increasing yield together with reducing crop growth duration, and hence reducing seasonal transpiration (Tuong 1999). Grain yield is characterized by: a) the amount of biomass produced by photosynthesis and b) the amount of biomass partitioned to grains, usually expressed as harvest index. Most of the increases in rice yield in the last decades were achieved by improvement in harvest index. Developing short-duration varieties has been an effective strategy for minimizing yield loss from terminal drought, as early maturity helps the crop to avoid the period of stress (Kumar and Abbo 2001). However, yield is generally correlated with longer crop duration under favorable growing conditions, and any reduction of crop duration below optimum would adversely affect yield (Turner *et al* 2001).

Aerobic systems are likely to require cultivars that have been selected from early generations under high-input aerobic management to produce genotypes that combine moderate tolerance of moisture stress with high harvest index and lodging resistance. The rice gene pool can be best utilized for development of promising or superior varieties, if exhaustive characterization of the various germplasm collections that constitute the rice gene pool is fully characterized to identify useful genetic diversity. The crosses between the parents with maximum genetic divergence are generally the most responsive approach for genetic improvement. Cultivars that perform well under aerobic management usually contain germplasm from both traditional upland and elite irrigated parents, but some cultivars without elite-irrigated high-yielding variety parentage, and some developed for irrigated systems also display high yields in aerobic systems (Atlin and Lafitte 2003). Physiological basis of yield gap between aerobic and flooded rice has not been studied extensively.

In the present study, recombinant inbred lines obtained from a cross between PR 120 x UPLRi 7 were used to obtain correlation between physiological traits and yielding ability under direct seeded aerobic conditions. PR 120 is semi dwarf variety while UPLRi 7 is upland rice variety. The F₈ generation of this cross produced by School of Agricultural Biotechnology, PAU was used in our studies. Physiological and biochemical traits were correlated with yield and yield components

under both direct-seeded aerobic and conventional transplanted sowing conditions. Irrigation management strategies under direct-seeded aerobic condition can be developed to reverse the yield decline only after the causes of yield decline are identified. Keeping in view the above facts, the present study was planned with following objectives:-

- To study the morpho-physiological traits in a recombinant inbred line population of rice under direct-seeded aerobic conditions.
- To correlate different physiological and biochemical traits with yield and yield components under direct-seeded aerobic conditions.

References:

- Anonymous (2012) Package of Practices for kharif crops of Punjab, Punjab Agricultural University, Ludhiana. Pp 1-17.
- Atlin G N and Lafitte H R (2003) Developing and testing rice varieties for water-saving systems in the tropics. In Water-Rice Production. In: Bouman B A M, Hengsdijk H, Hardy B, Bindraban P S, Tuong T P and Ladha J K, (eds.) *Proceedings of a Thematic Workshop on Water-Wise Rice Production, at IRRI Headquarters in Los Banos, Philippines*. pp 8-11 International Rice Research Institute, Los Banos, Philippines.
- Balasubramanian V and Hill J E (2002) Direct seeding of rice in Asia: emerging issues and strategic research needs for the 21st century. In: Pandey S, Mortimer M, Wade L, Tuong T P, Lopez K, Hardy B (eds) *Direct seeding: research strategies and opportunities*. pp 15–39. Los Banos, Philippines: International Rice Research Institute,
- Bhushan L, Ladha J K, Gupta R K, Singh S, Tirol-Padre A, Saharawat Y S, Gathala M and Pathak H (2007) Saving of water and labor in a rice–wheat system with no-tillage and direct seeding technologies. *Agron J* **99**: 1288–96.
- Bouman B A M, Yang X, Wang H, Wang Z, Zhao J and Chen B (2006) Performance of aerobic rice varieties under irrigated conditions in North China. *Field Crops Res* **97**: 53–65.
- Bouman B A M (2001) Water-efficient management strategies in rice production. *Int Rice Res Notes* **16**:17–22.
- Bouman B A M and Tuong T P (2001) Field water management to save water and increase its productivity in irrigated lowland rice. *Agric Water Manag* **49**:11–30.
- Bouman B A M, Xiaoguang Y, Huaqui W, Zhiming W, Junfang Z, Changgui W and Bin C (2002) Aerobic rice (Han Dao): A new way growing rice in water short areas. In: *Proceedings of 12th International Soil conservation Organization Conference*. pp 175-81. Beijing, China.
- Chin D V and Mortimer M (2002) Weed management in direct-seeded rice in Southern Vietnam. In: Pandey S, Mortimer M, Wade L, Tuong T P, Lopez K, Hardy B (eds) *Direct seeding: research strategies and opportunities*. pp 349–56. Los Banos, Philippines: International Rice Research Institute.

- Dingkuhn M , Schnier H F , De Datta S K , Wijangco E and Doeffling K (1990) Diurnal and developmental changes in canopy gas exchange in relation to growth in transplanted and direct seeded flooded rice. *Aust J Plant Physiol* **17**:119–34.
- Dwivedi D K , Kumar A , Mishra V K and Dwivedi S (2012) Phenotypic correlation and path coefficient analysis in rice (*Oryza sativa* L.) introgression lines under drought and controlled conditions. *Inter J of Curr Res* **4**: 7-12.
- Farooq M , Basra S M A , Tabassum R and Afzal I (2006b) Enhancing the performance of direct seeded fine rice by seed priming. *Plant Prod Sci* **9**: 446–56.
- Farooq M , Basra S M A and Asad S A (2008) Comparison of conventional puddling and dry tillage in rice–wheat system. *Paddy Water Environ* **6**: 397–404.
- Farooq M , Basra S M A and Wahid A (2006a) Priming of field-sown rice seed enhances germination, seedling establishment, allometry and yield. *Plant Growth Regul* **49**: 285–94.
- George T, Magbanua R, Garrity D P, Tubaña BS and Quiton J (2002) Rapid yield loss of rice cropped successively in aerobic soil. *Agron J* **94**:981–89
- Gill M S, Kumar P and Kumar A (2006) Growth and yield of direct-seeded rice (*Oryza sativa*) as influenced by seeding technique and seed rate under irrigated conditions. *Indian J Agron* **51**: 283–87.
- Khade V N , Patil B D , Khanvilkar S A and Chavan L S (1993) Effect of seeding rates and level of N on yield of direct-seeded (Rahu) summer rice in Konkan. *J Maharash Agric Univ* **18**: 32–35.
- Kumar J and Abbo S (2001) Genetics of flowering time in chickpea and its bearing on productivity in the semi-arid environments. *Adv Agron* **72**: 107-38.
- Lafitte H R and Bennett J (2002) Requirements for aerobic rice : physiological and molecular considerations. In: Bouman B A M, Hengsdijk H, Hardy B, Bindraban P S, Twong J P and Ladha J K (eds) *Water Wise Rice Production*. pp.259-71. Proceedings of the International Workshop on Water-wise Rice Production, IRRI, Los Banos, Philippines.
- Papendick R I and Parr J F (1997) No-till farming: The way of the future for sustainable dryland agriculture. *Ann Arid Zone* **36**: 193–208.
- Rajkumar S and Ibrahim S M (2013) Aerobic Rice: Identification of suitable rice hybrids adaptability to aerobic condition in water-short areas. *Inter j. of Agric Sci* **3**:586-95.
- Singh A K, Choudhury B U and Bouman B A M (2002) Effects of rice establishment methods on crop performance, water use and mineral nitrogen. In: Bouman B A M, Hengsdijk H , Hardy B , Bindraban B , Toung T P and Ladha J K (eds.) *Proceedings of the International Workshop on Water-wise Rice Production*. pp. 237–46. International Rice Research Institute, Los Banos, Philippines.
- Tuong T P , Singh A K , Siopongco J D L C and Wade L J (2000) Constraints to high yield of dry-seeded rice in the rainy season of a humid tropic environment. *Plant Prod Sci* **3**: 164–72.
- Tuong T P (1999) Productive water use in rice production: Opportunities and limitations. *J Crop Prod* **2**: 241-64.

- Turner N C, Wright G C and Saddique K H M (2001) Adaptation of grain legumes (pulses) to water-limited environments. *Adv Agron* **71**: 123-31.
- Wei F, Hongbin T, Shan L, Bouman B A M, Zhang L, Wang P, Dittert K (2011) Rate and duration of grain filling of aerobic rice HD297 and their influence on grain yield under different growing conditions. *Sci Asia* **37**: 98–104
- Xue C Y , Yang X G , Bouman B A M , Deng W , Zhang Q P , Yan W X , Zhang T Y , Rouzi A and Wang H Q (2008) Optimizing yield, water requirements, and water productivity of aerobic rice for the North China Plain. *Irrigation Sci* **26**: 459-74.
- Yang X, Wang H, Wang Z, Zhao J, Chen B, Bouman B A M (2002) Yield of aerobic rice (Han Dao) under different water regimes in northern China: opportunities and challenges. *In*: Bouman B A M, Hengsdijk H, Hardy B, Bindraban P S, Tuong T P, Ladha J K (eds) *Water-wise rice production*. pp 155–63. Proc International Workshop on Water-wise Rice Production, Los Baños, Philippines. International Rice Research Institute, Los Baños, Philippines.

Chapter-II

REVIEW OF LITERATURE

Rice is one of the most important food crops of the world and staple food for more than half of global population. Traditionally, rice is grown by transplanting three-to five-week old seedlings into puddled fields. Along with high water requirement, continuous puddling in the long run causes deterioration of soil physical properties through structural breakdown of soil aggregates. Additionally such rice crop leads to other environment damages such as emission of greenhouse gases. Puddling also forms plough pan that restricts percolation of water causing temporary water logging and restricts root penetration and growth of succeeding crops (Gill *et al* 2006). Further, rice transplanting is labour intensive operation and under changing socio-economic conditions, either workers are not available or economically not viable to employ. Therefore alternative methods of establishing rice crop that requires less labour and water without compromising on yield are required. Currently, direct seedling of rice is being encouraged. It refers to the process of establishing the crop from seeds sown in the field rather than by transplanting seedlings from nursery (Farooq *et al* 2011). Direct seedling avoids three basic operations, puddling, transplanting and maintaining standing water.

Raising direct seeded rice into non-puddled soils has been found to save 20 % (Gupta *et al* 2003) or 35–57% (Singh *et al* 2002) water. However, for rice to succeed as an aerobic crop, it should tolerate intermittent water deficits and higher soil impedance created due to aerobic conditions (Lafitte and Bennet 2002).

Seedling emergence and establishment

In transplanted rice, early growth is delayed in comparison to direct seeded aerobic rice which is attributed to an overall phenological delay due to transplanting shock (McDonald *et al* 2006). Both depth of seeding and soil moisture affect seedling emergence (Azhiri-Sigari *et al* 2005). According to Hoshikawa (1989), with deeper seeding and submergence conditions, seed germination may be delayed due to lack of oxygen in standing water. Seedlings of various ages ranging from four to twelve days were transplanted and their performance was compared with direct-seeded crop (Ginigaddara and Ranamukhaarachchi 2011). The age of seedlings at transplanting has influence on determining total and productive tillers. The ability of the plants to perform under water stress conditions with its physiological adaptation mechanisms are some of the key expectations of water saving rice production systems for high grain yield.

Morpho-physiological traits

Leaf parameters

Leaf area is an important plant trait which is directly linked with the rate of photosynthesis and crop yield. Total leaf area present at flowering greatly affects the amount of assimilates available to the panicles (De Datta 1981). The plant size or leaf area index has a major control over water use under stress. Short stature and small leaf area are generally lead to low productivity because they limit water use (Ball *et al* 1994). Therefore, leaf size is a criterion for selection for water saving in rice. Leaf pubescence is a xeromorphic trait that helps protect from excessive heat load. Hairy leaves reduce leaf temperature and transpiration (Sandquist and Ehleringer 2003), while inter-and intra-specific variation exists for the presence of this trait. Glaucousness or waxy bloom on leaves helps in reducing water losses and the maintenance of high tissue water potential, and is, therefore, considered as a desired trait for drought tolerance (Ludlow and Muchow 1990). In a study conducted by Mandal *et al* (2013), rate of moisture loss was more in transplanted rice as compared to aerobic rice (because there is more deposition of wax materials in the leaf of plants grown under aerobic culture).

The role of chlorophyll in photosynthesis is well established. An alteration in chlorophyll contents brings changes in photosynthetic rates in the plant (Reddy *et al* 2010). Under aerobic conditions there was decrease in chlorophyll content that was due to water stress under aerobic conditions (Deka and Baruah 2000). Absorbed photosynthetically active radiation (APAR) was significantly different between the flooded and aerobic control treatments. APAR consistently decreased with decreasing water input (Bouman *et al* 2006). Chlorophyll stability is a function of temperature and it is found to correlate with drought tolerance. Chlorophyll stability index is a measure of integrity of membrane or heat stability of the pigments under stress. The CSI is a single parameter used to measure frost or drought resistance of a plant. Chlorophyll stability index helped the plant to withstand water stress conditions through better availability of chlorophyll. This helps the plants under water stress to increase the photosynthetic rate and more dry matter production (Mohan *et al* 2000). Chlorophyll fluorescence, which indicates the photosynthetic efficiency of plant, is also a valuable indicator of water stress (Maxwell and Johnson 2000). Reddy *et al* (2010) recorded decreased chlorophyll fluorescence in crop under aerobic conditions. This was due partial breakdown of the photosynthetic apparatus (Tambussi *et al* 2000).

Singh *et al* (2013) reported a reduction in the number of leaves in water-stressed plants than control. These findings provide a comparison among the various water stress levels and provide information which may be used to decide which level of water stress can be adapted in paddy plants. The leaves of rice plant roll readily under water deficit conditions and it had been used as an

indicator of plant water status under stress (Courtois 2000). Rice cultivars with small degree of leaf rolling maintain higher leaf water potential under stress (Fukai and Cooper 1995). Leaf area and leaf area index was influenced by rice establishment method, with direct seeding having significantly higher mean maximum value than that of transplanted rice (McDonald *et al* 2006). Azihiri-Sigari *et al* (2005) and Bouman *et al* (2006) also recorded that the direct seeded seedling grew taller, with more leaf number and more leaf area. During vegetative growth stage, rice crop established by broadcasting have more rapid leaf area development, dry matter accumulation and N uptake than transplanted rice but growth rates and N uptake decreased after panicle initiation, particularly during grain filling period (Wiangsamut *et al* 2006). At maximum tillering, the highest leaf area was in transplanted rice while the lowest was in direct seeded rice. At flowering, leaf area was not significantly different between direct seeded rice and transplanted rice (Ginigaddara and Ranamukhaarachchi 2011). According to Zhong *et al* (2002) at panicle initiation, the reduction of tillering rate in direct seeded rice could be due to rapid increase in the leaf area and its shading effects. In contrast, the direct seeded rice in moistened soil produced more panicles and sterile spikelets than transplanted rice (Sarkar *et al* 2003).

Plant height

The plant height is an important morphological character that primarily helps to avoid potential competition by weeds (Nyarko and De Datta 1991). An increased plant height was recorded by Reddy *et al* (2010) in rice crop under aerobic conditions at vegetative stage as compared to flooded conditions. At flowering stage, the plant height was less in plants under aerobic condition than that of flooded rice. This decrease in height may be due to sensitivity of reproductive phase to water stress (Pirdasthi *et al* 2004). Sharp and LeNoble (2002) noted that shoot growth is restricted by roots during water stress. Osaki *et al* (1997) observed that the growth of roots is assumed to be restricted with the shoot growth. This is because shoots are more sensitive to water stress than the roots. Majeed *et al* (2011) reported reduced plant height under water stress. But Azihiri-Sigari *et al* (2005) and Bouman *et al* (2006) suggested that the direct seeded seedling grew taller with higher shoot dry weight and total dry weight.

Although, plant height is a varietal character, but is often regulated by environmental conditions (Yoshida 1981). Plant height was significantly higher in flooded rice than in direct-seeded aerobic rice (Ramanjaneyulu *et al* 2014). The negative effect of drought on plant height and grain yield (Mostajean and Eichi 2009; Ndjiondjop *et al* 2010) is a consequence of poor root development, altered leaf-surface traits such as form, shape, composition of cuticular and epicuticular wax, leaf pubescence, and leaf colour, which affect the radiation load on the leaf canopy, delay in or reduced rate of normal plant senescence and inhibition of stem reserves (Blum 2002). Plant height had

significant positive correlation with grain yield and harvest index (Ramanjaneyulu *et al* 2014). Variable response to water stress was observed at different growth stages of rice cultivars (Botwright *et al* 2008; Basu *et al* 2010). Tadesse *et al* (2013) and Thakur *et al* (2011) reported a higher value of CGR when the fields were aerated by draining the flood water for some time as compared to continuous flooding. This indicated that CGR was negatively affected by prolonged flooding.

Root parameters

For rice to succeed as an aerobic crop, breeders must overcome the legacy of anaerobic adaptation, enabling the crop to tolerate intermittent water deficits, high soil impedance, and low air humidity. Extensive genetic variation exists within cultivated rice and additional variation exists in wild relatives. Dramatic contrasts are observed among rice cultivars in response of root growth to soil drying; some cultivars cease root development, some increase root mass in superficial layers, and others show increased and deep root growth (Farooq *et al* 2009). The most efficient strategy for identifying cultivars for near saturation systems is to screen short-duration elite-irrigated varieties under non-stress management to eliminate cultivars vulnerable to soil drying (Atlin and Lafitte 2003). Several traits contributing to water saving and drought resistance in rice have been suggested (Fukai and Cooper 1995). Root characteristics such as thickness, rooting depth, root density, root-pulling force, and root penetration ability have been associated with drought avoidance in rice (Nguyen *et al* 1997). The root characters such as biomass, length, density and depth are very important in contributing to water saving (Turner *et al* 2001). Deep and thick root system allows access to deep water in the soil and is considered important in determining drought resistance in upland rice (Kaver *et al* 2007). It is the distribution and structure of roots that determines the most efficient strategy for extracting water during the crop-growing season.

The direct seeded rice had significantly deeper and longer root system with greater dry mass and hence a lower shoot: root ratio than transplanted rice (Ginigaddara and Ranamukhaarachchi 2011). This could be attributed to undisturbed growth of roots and availability of relatively longer time period for root growth of direct seeded compared to transplanted rice. Earlier, Azihiri-Sigari *et al* (2005) and Bouman *et al* (2006) had also reported that the direct seeded seedling had greater root length with higher root dry weight and total dry weight.

In contrast, Kato and Okami (2011) recorded the two morphological components of the rice root system, i.e. adventitious root emergence and lateral root proliferation were down-regulated under aerobic culture conditions, resulting in a significant decrease in total root length in this mode of cultivation. Root mass density recorded under traditional flooded rice was 60% higher than the aerobic rice.

Biochemical parameters

In rice, the effect of drought varies with the variety, degree and duration of stress and its coincidence with different growth stages (Dwivedi *et al* 2012).

Total soluble sugar and starch: Drought stress decreased accumulation of sugar markedly in leaves of rice at dough stage and reduction of sugar content in grains was greater at panicle initiation stage (Majeed *et al* 2011).

Under aerobic conditions, rice shoot contain seven times more soluble carbohydrates than roots. A four hour anaerobic treatment resulted in decline in carbohydrates content for both root and shoot, with two times higher depletion observed for rice shoot (Mustroph *et al* 2006). Guglielminetti *et al* (1995a) also stated that under submergence, the level of soluble sugars dropped in rice leaves.

Total sugar content increased at flowering stage as compared to tillering stage, including active synthesis of carbohydrates at flowering stage of rice under drought stress. Mai *et al* (2012) also suggested that the total sugar content was higher in fine rice as compared to aromatic rice under direct seeding. There was significant difference in total sugar content among the varieties both at tillering and flowering stages.

Protein content: Drought stress decreased accumulation of protein significantly in leaves of rice crop at soft dough stage whereas in grain decrease in protein content was greater at panicle initiation (Majeed *et al* 2011). Zhang *et al* (2001) reported that protein phosphorylation is enhanced under water stress due to increased concentration of ABA in rice. Under moisture stress condition the leaf protein content gradually decreases. The genotypes showing highest decrease in leaf protein content could be considered as drought resistant (Roy *et al* 2009). But Bartels and Sunkar (2005) reported increased content of late embryogenesis abundant proteins in vegetative tissue of plant in response to water stress in rice that may interact with carbohydrates to prevent cellular damage during dehydration. Mai *et al* (2012) indicated that soluble protein in aromatic-fine rice decreased at flowering stage as compared to that of maximum tillering stage under direct seeding conditions.

Proline content: Majeed *et al* (2011) reported an increase in proline content under drought stress in rice. Drought stress increased the accumulation of proline content significantly both in leaves and grains but the increase was more marked at the soft dough stage. Rontein *et al* (2002) suggested that under moisture stress, proline act as osmoregulator as well as osmoprotectant. ABA enhanced the accumulation of proline (Nayyer and Walia 2003) and carbohydrates (Ahmadi and Baker 2001) under moisture stress conditions in rice. It is the mechanism of ABA induced tolerance under drought stress that is involved in maintenance of water balance by affecting osmoregulation as observed by an increase in proline accumulation in rice (Majeed *et al* 2011). It was also reported by Singh *et al* (2013) that accumulation of more proline during water stress adversely affects the growth and development and the biochemical contents of rice because of reduced photosynthesis in the

leaves of water stressed plants. Singh *et al* (2013) suggested that proline accumulation in the leaves of water stressed plants may play a role as a stress indicator.

Proline may act as a free radical scavenger and may be important in overcoming stress. The reduced proline oxidase may be the reason for increasing proline accumulation. Increased proline in the stressed plants may be an adaptation to overcome the stress conditions. Proline accumulated under stressed conditions supplies energy for growth and survival and thereby helps the plant to tolerate stress. At cellular level, water stress induces the production of reactive oxygen species (ROS), such as superoxide radicals ($O_2^{\cdot-}$), hydrogen peroxide (H_2O_2), and hydroxyl radical ($OH^{\cdot}$), which ultimately cause membrane damage (Tambussi *et al* 2000). Proline may protect protein structure and membranes from damage, and reduce enzyme denaturation. High proline content is a good index for moisture resistance in genotypes. Under moisture stress condition the protein degrades and consequently the proline content increases (Roy *et al* 2009).

Antioxidant enzymes: One of the applications of water stress tolerant species/cultivars is the dominance of the defense system of antioxidant enzymes. These enzymes include superoxide dismutases (SOD), which scavenge superoxide radicals and convert them to O_2 and H_2O_2 . H_2O_2 is then detoxified by catalase (CAT) and ascorbate peroxidase (APOX). Catalase scavenges H_2O_2 by breaking down directly to form water and oxygen and an increase in its activity is related with increase in stress tolerance (Kraus *et al* 1995). Maintenance of membrane integrity and function under water stress were used as measure of drought tolerance was reported by Deshmukh *et al* (1991). The rice hybrid having higher significant mean values for catalase activity showed lesser percentage of leakage and were found to possess high membrane integrity (Amudha and Thiyagarajan 2008) under drought stress.

Yield benefits

Although, direct seeded rice is both cost and labour-saving, grain yield in direct seeded rice is comparatively less than transplanted rice (Farooq *et al* 2009c). Planting density is one of the most important factors determining the yield of rice. The growth, development and yield of rice are greatly influenced by plant spacing under field conditions. Closer spacing hampers intercultural operations, increases competition among the plants for nutrients, air, light, which results in weaker plants and favours more straw yield instead of grain yield. On the other hand, wider plant spacing reduces grain yield per unit area. Optimum plant spacing ensures proper plant growth by utilizing more solar radiation and nutrients (Miah *et al* 1990). The maximum benefit in respect of rice yield can be obtained where planting is done with proper spacing in aerobic rice (Sultana *et al* 2012). However, some reports claim similar or even higher yields of direct seeded rice with good management practices. Increased plant density in direct seeded rice (Dingkuhn *et al* 1990) resulted in more

biomass than in transplanted rice. Normal tillering is best for good yield as in case of excessive tillering, about 40% tillers did not produce panicles. Higher plant density than optimum, decreased the number of effective tillers per unit area (Dingkuhn *et al* 1991).

In direct seeding, plant density is much higher than with transplanted rice owing to its higher seeding rate, which is used to secure seedling establishment (Pandey *et al* 2002). This higher plant density in direct seeded rice may result in higher grain yield than transplanted rice through higher biomass production and panicle number under favorable water conditions (Naklang *et al* 1996). Higher plant density in direct seeded rice could be advantageous for early genotypes because it would compensate for their potentially low biomass production caused by the shorter growth duration (Hayashi *et al* 2007).

Total number tillers: Tillering is an important agronomic trait which finally determines the number of panicles, grains and grain yield per unit land area. Tillering dynamics of the rice plant greatly depends on the age of seedling at transplanting (Pasuquin *et al* 2008) which has significant effect on the number of total and productive tillers/hill at harvest, but the effect was insignificant at maximum tillering (MT) and at flowering. In contrast, the direct seeded rice reported the lowest number of tillers at maximum tillering, at flowering and at harvest and productive tillers at harvest (Ginigaddara and Ranamukhaarachchi 2011). Mandal *et al* (2013) recorded the number of tillers per hill, tiller height and dry biomass yield of rice grown under aerobic soil were significantly lower than those under traditional flooded rice with different irrigation regime. The row to row spacing had significant effect on yield and yield contributing characters of rice. Number of effective tillers per hill, non-effective tillers per hill and sterile spikelet per hill were affected significantly by row to row spacing while number of total tillers, panicle length, 1000-grain weight and harvest index remained unaffected. Higher grain yield was obtained from 25 cm apart row spacing due to the increased number of effective tillers per hill. Higher straw yield and biological yield were obtained from 20 cm apart row spacing under aerobic system of cultivation. Lower grain yield was obtained from 20 cm apart row spacing due to fewer effective tillers per hill and spikelets per panicle. Lower straw yield and biological yield were obtained from 25 cm apart row spacing (Sultana *et al* 2012). Hill to hill spacing also had significant effect on yield and yield contributing characters of rice. Among the different yield attributes number of total tillers per hill, non-effective tillers per hill, grains per panicle, sterile spikelet per panicle were affected significantly. The highest grain yield, straw yield and biological yield were obtained from 15 cm hill to hill spacing mainly due to the highest number of grains per panicle. The highest grain yield was possible due to combination of highest values for number of effective tillers per hill, number of grains panicle and 1000-grain weight under aerobic system of cultivation(Sultana *et al* 2012). The negative tillering rate occurred due to lesser number of

tillers produced in the plant after the flowering as well as death of latter formed tillers (Ginigaddara and Ranamukhaarachchi 2011).

In direct seeded aerobic rice when the seed is not planted too deep, tillering starts early in about fortnight from sowing. But, transplanted rice takes little longer time to start tillering as it first needs more time to recover from transplanting shock. Mobasser *et al* (2007) observed that when seedlings stay for a longer period of time in the nursery beds, primary tiller buds on the lower nodes of the main culm become degenerated leading to reduced tiller production. Tillering influences grain yield of rice as it is closely linked to the final panicle number produced per unit area of cultivated land (Quyen *et al* 2004). Pasuquin *et al* (2008) reported that tiller production could be optimized by transplanting seedlings at younger ages compared to direct seeding.

Total dry matter: The prerequisite for high yield is high total dry matter production per unit area. Dry matter production depends on photosynthesis for which adequate supply of solar radiation, CO₂ and favourable environment are necessary. Economic yield depends on as to how the net dry matter is distributed among different organs of the plant (Jabbar *et al* 2010). Genotypes with shorter growth duration have lower biomass production and lower potential grain yield in transplanted rice (Pantuwan *et al* 2002). Mandel *et al* (2013) also reported reduction in dry biomass in rice grown under aerobic conditions in experiment conducted on three rice varieties viz. ‘Surendra’, ‘Lalat’ and ‘Khandagiri’ and four irrigation regimes viz. irrigating the crop at 80-90% of field capacity soil moisture content throughout season (I₁), at 60-70% of field capacity during vegetative and at 80-90% of field capacity from panicle initiation to maturity (I₂), and at 60-70% of field capacity soil moisture throughout season (I₃) were imposed on aerobic rice cultivation, and traditional flooded transplanted rice (I₄). The number of tillers per hill, tiller height and dry biomass yield of rice grown under aerobic soil with irrigation regimes viz. I₁, I₂ and I₃ were significantly lower than those under traditional flooded rice with irrigation regime i.e., I₄. This difference might be due to the varietal difference i.e. genetic make up of the plants which influenced the differential crop growth and physiological behaviour of the plants in response to different soil moisture regimes under aerobic and cultures (Bouman *et al* 2006).

Total dry matter had positive direct effect on grain yield (Bidgoi *et al* 2006). Prolonged flooding led to the production of lower rice biomass and grain yields (Tadesse *et al* 2013). However, in an experiment involving rice cultivation under conventional transplanted and aerobic conditions for eight seasons, lower yield was observed in aerobic crop (Peng *et al* 2006). This yield gap was attributed to differences in biomass production and sink size (spikelet per meter square). Zhang *et al* (2010) reported a 6.6% increase in aboveground biomass with alternate wetting and drying compared to continuous flooding. Sanusan *et al* (2010) reported the effects of sowing depths on growth and

yield of rice under water stress conditions. Water stress was imposed at 30 days after sowing (DAS) for seven days. During vegetative stage, higher above-ground biomass was observed in crop sown at 1.0cm depth than that sown at 5.0 cm depth. However during later stages (60 DAS and 90 DAS) higher above-ground biomass was observed in crop sown at 5.0cm depth. This was attributed to greater root length and density under water stress which helped the plant to extract water from deeper soil layers.

Harvest index in direct seeded rice was lower than in transplanted rice. Reddy *et al* (2010) recorded a slight decrease in harvest index under aerobic conditions. This was due to reduced grain yield because of lower panicle number per meter square. Mandal *et al* (2013) recorded that the variation in harvest index was not significant but the yield difference was attributed to difference in biomass production than harvest index. The yield reduction due to aerobic method of cultivation was also observed by Bouman *et al* (2005). According to Ginigaddara and Ranamukhaarachchi (2011) the differences in harvest index (HI) among transplanted rice at all stages were not significant from direct seeded rice. This explained the non-variability of grain and shoot biomass among the treatments regardless of the method of establishment adopted and age of seedlings transplanted.

In general, conventional transplanted rice had higher yield than direct-seeded. It was observed that with a decreasing amount of water application, yield components decreased as well, though the effect was significant only for grain weight, filled grains panicle⁻¹ and percentage filled grains for the lowland variety (Yang *et al* 2012). Grain yield positively and significantly associated with grains per panicle, spikelet per panicle but negatively correlated with plant height (Seyoum *et al* 2012) in upland rice. Qamar *et al* (2005) also reported negative correlation between plant height and grain yield. Grain yield exhibited highly significant and positive correlation with harvest index, biological yield, and seedling height under drought and controlled transplanted condition in rice (Dwivedi *et al* 2012). For RILs with a higher biomass and harvest index the yield is higher. But there is also a compensatory mechanism with the number of grains per panicle and number of panicles per unit area. The rice cultivars showed differential response towards water stress at panicle initiation, anthesis and grain filling stages. Recent photosynthates must be generated at the time of grain filling to support the maximum number of grains per panicle, which is ensured by proper plant structure development before panicle initiation (Reddy *et al* 2010).

Grain yield: Grain yield per plant showed significant and positive correlation with grain yield per panicle and significant negative correlation with plant height, panicle number per plant and chaffy grain number per panicle (Borbora *et al* 2005) in transplanted crop. Grain yield per plant showed strong positive and significant association phenotypic levels in aerobic and transplanted environments with panicle bearing tillers per plant, harvest index, biological yield per plant,

length/breadth ratio (Kumar *et al* 2011). Under conventional transplanted condition harvest index showed negative correlation with grain yield. Reddy *et al* (2010) noted a considerable variation in marginal growth, grain yield performance and water relations under periodic water stress.

Yang *et al* (2002) reported that with a decreasing amount of water application, all yield components decreased, though the effect was statistically significant only for grain weight, and for filled grains panicle⁻¹ and percentage filled grains for the lowland variety. Reproductive stage is the most important period to achieve high yield of rice (Baker *et al* 1995). Grain yield exhibited highly significant and positive correlation with harvest index, biological yield seedling height (Dwivedi *et al* 2012) under drought conditions as well in controlled transplanted condition in rice. For RILs with a higher biomass and harvest index the yield is higher. The rice cultivars showed differential response towards water stress at panicle initiation, anthesis and grain filling stages. Growth stages also expressed varied response regarding impact of water stress on physiological performance of rice cultivars. Differential response of upland rice varieties was also observed by Botwright *et al* (2008), Kamoshita *et al* (2004) and Basu *et al* (2010). In somaclonal lines, under traditional cultivation studied by Dutta *et al* (2011) the number of grains per panicle increases. Recent photosynthates must be generated at the time of grain filling to support the maximum number of grains per panicle, which is ensured by proper plant structure development before panicle initiation.

Number of panicles: Low panicle number is the main factor limiting yield, resulting from a lower tiller emergence frequency and a low fraction of productive tillers in both the flooded and non-flooded soils (Yan *et al* 2010). There is significant positive relationship of grain yield with productive tillers, filled grain number per panicle, thousand grain weight and harvest index (Reddy *et al* 1995). Marekar and Siddiqui (1996) observed positive and significant correlations of yield per plot with length of panicle, days to maturity and 1000-grain weight. The disadvantages of earlier maturing genotypes as well as of genotypes with low tillering capacity and low panicle numbers can be reduced by introducing direct-seeding systems under favorable growing conditions that can attain high level of yield, by way of extending the effective duration of biomass production and increasing light interception with larger plant density (Hayashi *et al* 2007). However all the genotypes studied by Reddy *et al* (2010) showed higher grain yield in controlled conditions than under aerobic conditions. This was due to lesser number of panicles per meter square in case of aerobic rice. And this reduction in panicle number could be because water stress coincided with panicle development (Pirdasthi *et al* 2004).

Spikelet sterility: Spikelet sterility is an indicator of stress experienced by the rice crop during the period from pollination and fertilization of ovules to physiological maturity (Yoshida 1981). This could result due to nutrient deficiencies (Yoshida 1981), water stresses (Ekanayake *et al* 1989) and

many other causes (Jagadish *et al* 2007) during flowering to physiological maturity. The number of sterile spikelets, including abortive, opaque and chalky kernels are more in direct seeded rice compared with transplanted rice (Farooq *et al* 2006 a,b, 2007, 2009c). Fully filled grains decreased under aerobic cultivation in all the genotypes studied by Reddy *et al* (2010) as in aerobic cultivation, partially filled and chaffy grains increased. 1000-grain weight also decreases due to this reason in aerobic cultivation (Reddy *et al* 2010).

Genetic improvement for water productivity

Rice plays a major unique role in the genomic era of plant sciences because of the agronomic need for better tolerance to abiotic stress in major rice growing regions. Rice has the smallest genome among the cultivated cereals and it conserves much of the gene content and to some extent, gene order present in other species (Gale and Devos 2001). The rice gene pool can be best utilized for development of promising or superior varieties, if exhaustive characterization of the various germplasm collections that constitute the rice gene pool is fully characterized to identify the useful genetic diversity.

Development of early maturing and high-yielding rice varieties has substantially increased the average rice yield and reduced crop duration. This has contributed to a threefold increase in water productivity with respect to total water inputs (Bouman *et al* 2006). Hybrid rice has 9% greater yield potential than inbred, with comparable growth duration when grown under flood- irrigated conditions in the tropics (Peng *et al* 1999). This yield advantage offers an opportunity to increase the water productivity of flood-irrigated lowland rice (Peng and Bouman 2007). Even selecting for genetically important quantitative trait loci QTL to develop cultivars more efficiently utilizing water, strongly depends upon the understanding of yield-determining physiological processes (Kirigwi *et al* 2007). Genetic improvement for water adaptation to water-limited conditions is addressed through conventional approach by selecting for yield and secondary traits contributing to water saving (Farooq *et al* 2009). Many studies have been undertaken to find genetic variation in traits that are expected to influence the response of rice to water deficit, including deeper and thicker roots (Yadav *et al* 1997), root –pulling resistance (Pantuwan *et al* 2002), greater root penetration (Ali *et al* 2000), osmotic adjustment (Lilley and Lodlow 1996) and membrane stability (Tripathy *et al* 2000). For aerobic rice culture, promising varieties should possess improved lodging resistance and higher harvest index. Medium-stature and moderately drought-tolerant cultivars are preferred for aerobic culture (Atlin *et al* 2004, 2006).

Selection and breeding strategies: Understanding of physiological and molecular basis may help target key yield-limiting traits may complement conventional breeding programs and hasten yield improvement (Cattivelli *et al* 2008). Effort are being directed to developing molecular markers for

various traits such as maximum rooting depth (Champoux *et al* 1995), the capacity of roots to penetrate hard pans (Ray *et al* 1996), and ability of the plant to osmotically adjust to water deficit (Lilley and Ludlow 1996).

Molecular marker technology is a powerful tool to identify key genes that respond to drought and their adaptive regulation to stress (Bruce *et al* 2002). Peng *et al* (1998) reported that improved tropical japonica rice lines had 25–30% higher transpiration efficiency at the single-leaf level than indica varieties when grown under flooded conditions. This was because the indica varieties had a higher transpiration rate than the tropical japonica lines, whereas the differences in photosynthesis between the two types were relatively small and inconsistent across growth stages and years compared with the differences in transpiration rate. In another study, Yeo *et al* (1994) observed large differences in transpiration efficiency at the single-leaf level among *Oryza* species. *Oryza australiensis* had significantly greater transpiration efficiency than *O. sativa* at the same photosynthetic rates. This trait needs to be exploited for developing drought tolerant varieties.

Recent advances in genomics, the development of advanced analytical tools at the molecular level, and genetic engineering provide new avenues for improving yield potential and enhancing drought stress tolerance. Breeding efforts to improve water productivity may be accelerated by the discovery and subsequent manipulation of regulatory genes underlying the complex physiological and biochemical responses of rice plants to water deficit.

References:

- Akbar N and Ehsanullah (2004) Agro-economic efficiency of different direct sown techniques in fine rice (*Oryza sativa* L.) *Pak J Agri Sci* **41**: 3-4.
- Ali M M, Pathan M S, Zhang J, Bai G, Sarkarung S and Nguyen H T (2000) Mapping QTLs for root traits in a recombinant inbred population from two indica ecotypes in rice. *Theor Appl Genet* **101**: 756-66.
- Amuda K and Thiyagarajan K (2008) Identification of rice hybrid for aerobic condition based on physiological traits. *Madras Agric J* **95**: 315-19.
- Anonymous (2012) Package of practices for Kharif crop, pp 1-17. Punjab Agricultural University, Ludhiana.
- Atlin G N, Lafitte H R, Tao D, Laza M, Amante M, and Courtois B (2006) Developing rice cultivars for high-fertility upland systems in the Asian tropics. *Field Crops Res.* **97**: 43–52.
- Atlin G N and Lafitte H R (2003) Developuipg and testing rice varietiers for water-saving systems in the tropics. In : Bouman B A M, Hengsdijk H, Hardy B, Bindraban P S, Tuong T P and Ladha J K (eds) *Water-Rice Production: Proceedings of a Thematic Workshop on Water-Wise Rice Production* International Rice Research Institute, Los Banos, Philippines.

- Atlin G N, Laza M , Amante M and Lafitte H R (2004) Agronomic performance of tropical aerobic, irrigated, and traditional upland rice varieties in three hydrological environments at IRRI. In New Directions for a Diverse Planet. *Proceedings of the 4th International Crop Science Congress*, Brisbane, Australia.
- Azhiri-Sigari T, Gines H, Sebastian L S and Wade L (2005) Seedling vigor of rice cultivars in response to seeding depth and soil moisture. *Philippine J of Crop Sci* **30**: 53-8.
- Baker J T, Boote K J, Allen L H J (1995) Potential climate change effects on rice: Carbon dioxide and temperature. In Rosenzweig C *et al* (ed) Climate change and agriculture: *Analysis of potential international impacts*. Pp. 31-47. ASA Spec. Publ. No. 59. ASA, Madison, WI.
- Bartels D and Sunkars R (2005) Drought and salt tolerance in plants. *Critical Reviews in Plant Sci* **24**: 23–58.
- Basu S , Roychoudhury A, Saha P P , Sengupta D (2010) Differential antioxidative responses of indica rice cultivars to drought stress. *Plant Growth Regul* **60**: 51-59.
- Borbora T K, Hazarika G N and Medhi A K (2005) Correlation and path analysis for panicle characters in rice. *Crop Research*, **30**: 215-22.
- Botwright Acuna T L, Pasuquin E and Wade L J (2008) Genotype environment interactions for grain yield of upland rice backcross lines in diverse hydrological environments. *Field Crops Res* **108**: 117-25.
- Bouman B A M , Peng S, Castaneda A R and Visperas R M (2005) Yield and water use of irrigated tropical aerobic systems. *Agric. Water Manage.* **74**: 87-105.
- Bouman B A M , Yang X , Wang H , Wang Z , Zhao J and Chen B (2006) Performance of aerobic rice varieties under irrigated conditions in North China. *Field Crops Res* **97**: 53–65.
- Bruce W B, Edmeades, G O and Barker T C (2002) Molecular and physiological approaches to maize improvement for drought tolerance. *J Exp Bot* **53**: 13-25.
- Cattivelli L, Rizza F, Badeck F W, Mazzucotelli E, Mastrangelo A M, Francia E, Mare C, Tondelli A and Stanca A M (2008) Drought tolerance improvement in crop plants: An integrative view from breeding to genomics. *Field Crops Res* **105**: 1-14.
- Champoux M C, Wang G, Sarkarung S, Mackill D J, OOTOOLE J C, Huang N and McCouch S R (1995) Locating genes associated with root morphology and drought avoidance in rice via linkage to molecular markers. *Theor Appl Genet* **90**: 969-81.
- Courtois B and H T Nguyen (2000) Quantitative trait loci for root penetration ability and root thickness in rice: Comparison of genetic background. *Genome* **43**: 53-61.
- De Datta S K (1981) Principles and practices of rice production. Singapore: A Wiley Ey-Interscience Publication.
- Deka M and Baruah K K (2000) Comparable studies of rainfed upland rice (*Oryza sativa* L.) cultivars for drought tolerance. *Indian J. Agri. Sci.* **70**: 135-39.
- Deshmukh P S , Sairam R F and Shukla D S (1991) Measurement of ion leakage as a screening technique for drought resistance in wheat genotypes. *Indian J Plant Physiol* **34**: 89-91.

- Dingkuhn M , Schnier H F , De Datta S K , Wijangco E and Doeffling K (1990) Diurnal and developmental changes in canopy gas exchange in relation to growth in transplanted and direct seeded flooded rice. *Aust J Plant Physiol* **17**:119–34.
- Dutta T K, Powers S J, Kerry B R, Gaur H S, Curtis R H C (2011). Comparison of host recognition, invasion, development and reproduction of *Meloidogyne graminicola* and *M. incognita* on rice and tomato. *J. Nematol.*, **13**: 509-20.
- Dwivedi D K, Kumar A, Mishra V K, Dwivedi S (2012) Phenotypic correlation and path coefficient analysis in rice (*Oryza sativa* L.) introgression lines under drought and controlled conditions. **4**: 7-12.
- Ekanayake I J, Datta S K D and Steponkus P L (1989) Spikelet Sterility and Flowering Response of Rice to Water Stress at Anthesis. *Ann. Bot. London* **63**: 257-64.
- Farooq M , Basra S M A and Ahmad N (2007) Improving the performance of transplanted rice by seed priming. *Plant Growth Regul* **51**:129–37.
- Farooq M , Basra S M A , Tabassum R and Afzal I (2006b) Enhancing the performance of direct seeded fine rice by seed priming. *Plant Prod Sci* **9**: 446–56.
- Farooq M , Basra S M A and Asad S A (2008) Comparison of conventional puddling and dry tillage in rice–wheat system. *Paddy Water Environ* **6**: 397–404.
- Farooq M , Basra S M A and Wahid A (2006a) Priming of field-sown rice seed enhances germination, seedling establishment, allometry and yield. *Plant Growth Regul* **49**: 285–94.
- Farooq M , Basra S M A, Ahmad N and Murtaza G (2009c) Enhancing the performance of transplanted coarse rice by seed priming. *Paddy Water Environ* **7**: 55–63.
- Farooq M , Basra S M A , Tabassum R and Afzal I (2006a) Enhancing the performance of direct-seeded fine rice by seed priming. *Plant Prod Sci* **9**: 446–56.
- Farooq M, Wahid A, Kabayashi N, Fujita D and Basra S M A (2009) Plant drought stress: Effects, mechanisms and management. *Agron Sustain Dev* **29**: 185-212.
- Fukai S and Cooper M (1995) Development of drought-resistant cultivars using physiological traits in rice. *Field Crop Res* **40**: 67–86.
- Gale M D and Devos K M (2001) Comparative genetics and cereal evolution. *Israel J of Plant Sci* **49**:19-23.
- Gill M S , Kumar P and Kumar A (2006) Growth and yield of direct-seeded rice (*Oryza sativa*) as influenced by seeding technique and seed rate under irrigated conditions. *Indian J Agron* **51**: 283–87.
- Ginigaddara G A S and Ranamukhaarachchi S L (2011) Study of age of seedling at transplanting on growth dynamics and yield of rice under alternating flooding and suspension of irrigation of water management. *Recent Research in Sci and Technol* **3**: 76-88.
- Guglielminetti L, Perata P, Alpi A (1995a) Effect of anoxia on carbohydrate-metabolism in rice seedlings. *Plant Physiol* **108**: 735–41.

- Gupta R K , Naresh R K , Hobbs P R , Jiaguo Z and Ladha J K (2003) Sustainability of post-green revolution agriculture. The rice–wheat cropping systems of the Indo-Gangetic plains and China. *In: Improving the Productivity and Sustainability of Rice–Wheat Systems: Issues and Impacts*, ASA Special Publication 65, Wisconsin, USA.
- Hayashi S, Kamoshita A, Yamagishi J, Kotchasatit A and Jongdee B (2007) Genotypic difference in grain yield of transplanted and direct-seeded rainfed lowland rice (*Oryza sativa* L.). *Field crop Res* **102**: 9-21.
- Jabbar A, Ahmad R, Bhatti I H, Wasi-U-Din, Nadeem M and Khan M M (2010) Evaluating the Performance of Direct Seeded Rice in Different Intercropping Systems under Strip Plantation. *Int J Agric Biol* **12**: 501-08.
- Jagadish S V K, Craufurd P Q and Wheeler T R (2007) High temperature stress and spikelet fertility in rice (*Oryza sativa* L.). *J of Exp Bot* 1-9.
- Kamoshita A, Rodriguez R, Yamauchi A and Wade L J (2004) Genotypic variation in response of rainfed lowland rice to prolonged drought and re-watering. *Plant Product Sci* **7**: 406–20.
- Kato Y and Okami M (2011) Root morphology, hydraulic conductivity and plant water relations of high-yielding rice grown under aerobic conditions. *Annals of bot* 1-9
- Kavar T, Maras M, Kidric M, Sustar-Vozlic J and Meglic V (2007) Identification of genes involved in the response of leaves of *Phaseolus vulgaris* to drought stress. *Mol Breed* **21**: 159-72.
- Kirigwi F M, Van Ginkel, M Brown-Guedira G, Gill B S, Paulsen G M and Fritz A K (2007) Markers associated with QTL for grain yield in wheat under drought. *Mol Breed* **20**: 401-13.
- Kobata T, Uemuki N (2004) High temperatures during the grain-filling period do not reduce the potential grain dry matter increase of rice. *Agron J*. **96**: 406-14
- Kraus E, Mc Kersie B D, Fletcher R A (1995) Pachobutrazol induced tolerance of wheat leaves to paraquat may involve increased antioxidant enzyme activity. *J Plant Physiol* **145**:570-76.
- Kumar J and Abbo S (2001) Genetics of flowering time in chickpea and its bearing on productivity in the semi-arid environments. *Adv Agron* **72**: 107-38.
- Lafitte H R and Bennett J (2002) Requirements for aerobic rice : physiological and molecular considerations. *In: Bouman B A M, Hengsdijk H , Hardy B, Bindraban P S, Twong J P and Ladha J K (eds) Water Wise Rice Production*. Proceedings of the International Workshop on Water-wise Rice Production IRRI. pp.259-71. Los Banos, Philippines.
- Laza R C, Peng S, Akita S, Saka H (2003) Contribution of biomass partitioning and translocation of grain yield under sub-optimum growing conditions in irrigated rice. *Plant Prod Sci* **6**:28–35.
- Lilley J M and Ludlow M M (1996) Expression of osmotic adjustment and dehydration tolerance in diverse rice lines. *Field Crops Res* **48**: 185-97.
- Ludlow M M and Muchow R C (1990) A Critical evaluation of traits of improving crops yields in water-limited environments. *Adv Agron* **43**: 107-53.
- Mai M A B, Shamsuddin Z H, Wahab Z, Marziah M (2010) Effect of plant growth and nitrogen incorporation of tissue-cultured Musa plantlets under nitrogen free hydroponics condition. *Aus J Crop Sci* **4**: 85-90

- Majeed A , Salim M, Bano A, Asim M and Hadees M (2011) Physiology and productivity of rice crop influenced by drought stress induced at different developmental stages. *Afr J Biotechnol* **10**: 5121–36
- Mandal K G, Kundu D K, Thakur A K, Kannan K, Brahmanand P S and Kumar A (2013) Aerobic rice response to irrigation regimes and fertilizer nitrogen rates. *J of Food, Agric & Environ* **11**: 1148 - 53.
- Marekar R V and Siddiqui M A (1996) Genetic variability and correlation studies in rice. *J Maharashtra Agril Univ* **21**: 249 - 51.
- Maxwell K, Johnson G N (2000) Chlorophyll fluorescence – a practical guide. *J Exp Bot* **51**: 659–68
- McDonald A J, Riha S J, Duxbury J M, Steenhuis T S and Lauren J G (2006) Water balance and rice growth responses to direct seeding, deep tillage, and landscape placement: Findings from a valley terrace in Nepal. *Field Crop Res* **95**: 367-82.
- McKersie B D and Leshem Y Y (1994) Stress and stress coping in cultivated plants. pp-256. Kluwer Academic Publishers, Dordrecht.
- Mobasser H R , Tari D B, Vojdani M, Abadi R S and Eftekhari A (2007) Effect of Seedling Age and Planting Space on Yield and Yield Components of Rice (Neda Variety). *Asian J of Plant Sci* **6**: 438-40.
- Mohan M M , Lakshmi S N and Ibrahim S .M (2000) Chlorophyll Stability Index (CSI): Its impact on salt tolerance in rice. *Int Rice Res. Notes* **25**: 38-39 .
- Mustroph A, Boamfa E I ,Laarhoven L J J, Harren F J M , Albrecht G and Grimm B (2006) Organ specific analysis of anaerobic primary metabolism in rice and wheat seedlings. I. Dark ethanol production is dominated by shoot. *Planta* **225**: 103-14.
- Naklang K, Fukai S and Nathabut K (1996) Growth of rice cultivars by direct seeding and transplanting under upland and lowland conditions. *Field Crops Res* **48**: 115-23.
- Nayyar H and Walia D P (2003) Water stress-induced Pro accumulation in contrasting wheat genotypes as affected by calcium and abscisic acid. *Biol Plant* **46**: 275-79.
- Ndjiondjop M N, Manneh B, Cissoko M, Dramé N K, Glele R, Kakai R, Bocco R, Baimey H and Wopereis M (2010) Drought resistance in an interspecific backcross population of rice (*Oryza spp.*) derived from the cross WAB56-104 (*O. sativa*) × CG14 (*O. glaberrima*). *Plant Sci* **179**: 364–73.
- Nguyen H T, Babu R C and Blum A (1997) Breeding for drought resistance in rice: Physiology and molecular genetics considerations. *Crop Sci* **37**: 1426-34.
- Nyarko K A and De Datta S K (1991) Weed control in irrigated rice. In: *Hand book for weed control in rice*, pp 73-80. IRRI , Manila, Philippines.
- Osaki M, Shinano T, Matsumoto M, Zheng T and Tadano T (1997) A root-shoot interaction hypothesis for high productivity of field crops. *Soil Sci. Plant Nutr* **43**: 1079-84.
- Pandey S, Velasco L E and Suphanchaimat N (2002) Economics of direct seeding in northeast Thailand. In: *Direct Seeding: Research Strategies and Opportunities*, pp139-59. International Rice Research Institute, Los Banos, Philippines.

- Pantuwan G, Fukai S, Cooper M, Rajatasereekul S and O'Toole J C (2002) Yield response of rice (*Oryza sativa* L.) genotypes to different types of drought under rainfed lowlands. *Field Crop Res* **73**: 181-200.
- Pasuquin E , Lafarge T and Tubana B (2008) Traansplanting young seedling in irrigated rice fields : Ear;y and high tiller production enhanced grain yield. *Field crop Res* **105**: 141-55.
- Peng S and Bouman B A M (2007) Prospects for genetic improvement to increase lowland rice yields with less water and nitrogen. In Spiertz J H J, Struik P C and Laar H H van (eds) Scale and Complexity in Plant System Research: *Gene-Plant-Crop Relations*. pp. 251-66. Springer, New York.
- Peng S, Bouman BAM, Visperas RM, Castañeda A, Nie L, Park HK (2006) Comparison between aerobic and flooded rice in the tropics: agronomic performance in an eight-season experiment. *Field Crops Res* **96**: 252–59.
- Peng S, Cassman K G, Virmani S S, Sheehy J and Khush G S (1999) Yield potential trends of tropical rice since the release of IR* and the challenge of increasing rice yield potential. *Crop Sci* **39**: 1552-59.
- Peng S, Laza R C, Khush G S, Sanico A L, Visperas R M and Garcia F V (1998) Transpiration efficiencies of indica and improved tropical japonica rice grown under irrigated conditions. *Euphytica* **103**: 103-08.
- Pirdashti H, Tahmasebi Sarvestani Z, Nassiri M (2004) Remobilization of dry matter and nitrogen in rice varieties at different date transplant. *Iranian J of Crop Sci* **4**: 55-46.
- Prasad P V V, Boote K J, Allen L H, Sheehy J E, Thomas J M G (2006) Species, ecotype and cultivar differences in spikelet fertility and harvest index of rice in response to high temperature stress. *Field Crops Res* **95**: 398-411.
- Quyen N V, Tan P S, Hach C V, Du P V and Zhong X (2004) Healthy rice canopy for optimal production and profitability. *Omonrice* **12**: 69-74.
- Ray J D, Yu L X, McCouch S R, Champoux M C, Wang G and Nguyen H T (1996) aping quantitative trait associated with root penetration ability in rice (*Oryza sativa* L.). *Theor Appl Genet* **92**: 627-36.
- Reddy V S, Dash S, Reddy A R (1995) Anthocyanin pathway in rice (*Oryza sativa* L.): identification of a mutant showing dominant inhibition of anthocyanins in leaf and accumulation of proanthocyanidins in pericarp. *Theor and App Genetics* **91**:301–12.
- Reddy J N, Sarkar R K, Patnaik S S C , Singh D P , Singh U S, Ismail A M and Mackill D J (2010) Improvement of rice germplasm for rainfed lowlands of eastern India. *SABRAO 13th International Congress*. Cairns, Australia.
- Rontein D, Basset G, Hanson A D (2002) Metabolic engineering of osmoprotectant accumulation in plants. *Meta Engg* **4**: 49–56.
- Roy R, Mazumder P B and Sharma G D (2009) Proline, catalase and root traits as indices of drought resistance in bold grained rice (*Oryza sativa*) genotypes. *Afri J of Biotech* **8**: 6521-28.

- Russo S (2004) Preliminary studies on rice varieties adaptability to aerobic irrigation, Cahiers options. *Mediterraneennes* **15**: 35-39.
- Sandquist D R and Ehleruinger J R (2003) Population and family-level variation of brittlebush (*Encelia farinosa*, Asteraceae) pubescent: Its relation to drought and implications for selection in variable environments. *Amm J Bot* **90**: 1481-86.
- Sanusan S, Polthane A, Audebert A, Seripong S and Mouret J C (2010) Growth and yield of rice (*Oryza sativa* L.) as affected by Seeding depth and water deficits at vegetative stage. *Asian J of Plant Sci* **9**: 36-43.
- Sarkar R K , Sanjukta D and Das S (2003) Yield of rainfed lowland rice with medium water depth under anaerobic direct seeding and transplanting. *Trop Sci* **43**: 192–98.
- Schnier H F, Dingkuhn M, De Datta S K, Mengel K and Faronilo J E (1990) Nitrogen fertilization of direct seeded flooded vs. transplanted rice: Nitrogen uptake , photosynthesis, growth and yield. *Crop Sci* **30**: 1276-84.
- Sharp R E and LeNoble M E (2002) ABA, ethylene and the control of shoot and root growth under water stress. *J of Exp Bot* **53**: 33-37.
- Singh A K , Choudhury B U and Bouman B A M (2002) Effects of rice establishment methods on crop performance, water use and mineral nitrogen. In: Bouman B A M , Hengsdijk H , Hardy B , Bihdraban B , Toung T P and Ladha J K (eds) Proceedings of the International Workshop on Water-wise Rice Production. pp. 237–46. International Rice Research Institute, Los Bano~s, Philippines.
- Singh Y V , Singh K K and Sharma S K (2013) Influence of crop nutrition on grain yield, seed quality and water productivity under two rice cultivation systems. *Rice Sci* **20**: 129-138.
- Singh D , Bhaskar B P , Baruah U and Sarkar D (2013) Economic appraisal of rice based cropping sequences in major soil series of upper Asom. *Ind J Agric Sci* **83**: 85–89.
- Sultana M R, Rahman M M and Rahman M H (2012) Effect of row and hill spacing on the yield performance of boro rice (cv. BRRI dhan45) under aerobic system of cultivation. *J Bangladesh Agri Univ* **10**: 39-42.
- Tadesse T F, Nigussie D R, Bayu W and Setegn G (2013) Impact of rainwater management on growth and yield of rainfed lowland rice. *J Agric Res* **2**: 108 – 14.
- Tambussi EA, Bartoli CG, Beltrano J, Guimant JJ, Araus JL (2000). Oxidative damage to thylakoid proteins in water stressed leaves of wheat (*Triticum aestivum*). *Plant Physiol* **108**:398-404.
- Thakur A K, Rath S, Patil D U and Kumar A (2011) Effects on rice plant morphology and physiology of water and associated management practices of the system of rice intensification and their implications for crop performance. *Paddy Water Environ* **9**: 13–24.
- Tripathy J N, Zhang J, Robin S, Nguyen T T and Nguyen H T (2000) QTLs for cell-membrane stability mapped in rice (*Oryza sativa* L.) under drought stress. *Theor Appl Genet* **100**: 1197-202.
- Turner N C, Wright G C and Saddique K H M (2001) Adaptation of grain legumes (pulses) to water-limited environments. *Adv Agron* **71**: 123-31.

- Wiangsamut B , Mendoza C T and Lafarge A T (2006) Growth dynamics and yield of rice genotypes grown in transplanted and direct-seeded fields. *J Agric Tech* **2**: 299-316.
- Yadav R, Courtois B, Huang N and McLaren G (1997) Mapping genes controlling root morphology and root distribution in a doubled-haploid population of rice. *Theor Appl Genet* **94**: 619-32.
- Yang X, Wang H, Wang Z, Zhao J, Chen B, Bouman B A M (2002) Yield of aerobic rice (Han Dao) under different water regimes in northern China: opportunities and challenges. In: Bouman B A M, Hengsdijk H, Hardy B, Bindraban P S, Tuong T P, Ladha J K (eds) Water-wise rice production. *Proc International Workshop on Water-wise Rice Production*, pp 155–63. International Rice Research Institute, Los Baños, Philippines.
- Yeo A R, Flowers T J and Yeo M E (1994) Photosynthetic and water use efficiencies in the genus *Oryza*: Prospects of yield enhancement. In: Witcombe J R and Wrigh D (eds) *Compendium of Current Research in Plant Sciences*. pp. 10-12. Overseas Development Administration, London, UK.
- Yoshida S (1981) Fundamentals of rice crop science. pp. 269. International Rice Research Institute, Los Banos, Phillipines.
- Zhang J, Zheng H G, Aarti A, Pantuwan G, Nguyen T T, Tripathy J N, Sarial A K, Robin S, Babu R C, Nguyen B D (2001) Locating genomic regions associated with components of drought resistance in rice: comparative mapping within and across species. *Theor Appl Genet* **103**: 19–29
- Zhong X, Peng S, Sheehy J E, Visperas R M and Liu H (2002) Relationship between tillering and leaf area index: quantifying critical leaf area index for tillering in rice. *The J of Agric Sci* **138**: 269-79.

Chapter – III

PUNLISHED/ ACCEPTED/ SUBMITTED RESEARCH ARTICLES

Sr. No.	Publication	Journal	NAAS Rating/ Impact Factor	Status
1	Biochemical characterization of a recombinant inbred line (RIL) population of rice (<i>Oryza sativa</i> L.) under direct seeded aerobic and conventional transplanted conditions	Proceedings of the National academy of Sciences, Biological Sciences (NASB)	6.00	Accepted
2	Path-Coefficient Analyses of Yield in Rice under Direct-seeded Aerobic and Conventional Transplanted Conditions	Journal of Crop Improvement	5.12	Accepted
3	Screening of morpho-physiological traits for yield enhancement in a recombinant inbred line population of rice under direct-seeded aerobic and conventional transplanted conditions.	International Journal of Advanced Research (IJAR)	1.659 (Impact Factor)	Published
4	Comparison of morpho-physiological traits and yield attributes in direct-seeded aerobic and conventional transplanted rice	International Journal of Life Science	--	Published
5	Regression analysis of the characters influencing grain yield in a RIL population of rice	National Symposium on “Crop Improvement for inclusive Sustainable Development”	--	Published

Chapter-IV

GENERAL DISCUSSION

Rice is one of the most important staple food crops in the world. In India, rice is grown in an area of 441 m ha with production of 157.98 m tonnes. In Punjab, it is grown in an area of 2821 thousand ha with annual production of 15813 thousand tonnes. The conventional procedure of raising rice crop involves growing rice seedlings in a nursery bed and later transplanting them into the main field. The main field preparation consists of soaking, ploughing and puddling after harvesting of previous crop. This procedure is water consumptive, labour intensive and may lead to environment damage. Direct seeding technique that involves growing the rice like an irrigated upland crop helps to overcome problems of conventional transplanted crop but at the cost of reduction in yield. Morpho-physiological and biochemical basis of yield gap between aerobic and flooded rice has not been studied extensively. The present study was planned with following objectives:

- To study the morpho-physiological traits in a recombinant inbred line population of rice under direct-seeded aerobic conditions.
- To correlate different physiological and biochemical traits with yield and yield components under direct-seeded aerobic conditions.

Recombinant inbred lines obtained from a cross between PR 120 x UPLRi 7 were used to obtain correlation between physiological traits and yielding ability under direct seeded aerobic conditions. PR 120 is semi dwarf variety while UPLRi 7 is upland rice variety. The F₈ generation of this cross produced by School of Agricultural Biotechnology, PAU was used in our studies. Irrigation management strategies under direct-seeded aerobic condition can be developed to reverse the yield decline only after the causes of yield decline are identified.

4.1. Morpho-physiological traits

4.1.1. Leaf parameters: Leaf area is an important plant trait which is directly linked with the rate of photosynthesis and crop yield. Total leaf area present at flowering greatly affects the amount of assimilates available to the panicles (De Datta 1981). Leaf area and leaf area index was influenced by crop establishment method, with direct seeding having significantly higher mean maximum value than that of transplanted rice (McDonald *et al* 2006). Azihiri-Sigari *et al* (2005) and Bouman *et al* (2006) also recorded that seedling from direct-seeded crop grew taller, with more number of leaf and more leaf area. In present study, under direct-seeded aerobic conditions, leaf area showed a positive correlation with chlorophyll content and a negative correlation with relative growth rate. However,

leaf area did not show any correlation with grain yield. Under conventional transplanted conditions, leaf area showed a positive correlation with membrane-thermo stability, crop growth rate (CGR), relative growth rate (RGR) and grain yield. Membrane thermo-stability (MTS) showed a negative correlation with CGR and RGR but positive correlation with grain yield under direct-seeded aerobic conditions. Under conventional transplanted conditions, MTS showed a positive correlation with CGR and grain yield. Membrane thermo-stability index is a measure of percent electrolyte leakage from the leaf cells. A higher value of MTS indicates higher resistance of plant to stress (Table 4, 5, 9, 10; Appendix IV).

The role of chlorophyll in photosynthesis is well established. An alteration in chlorophyll contents brings changes in photosynthetic rates in the plant (Reddy *et al* 2010). Under aerobic conditions there was decrease in chlorophyll content that was due to water stress under aerobic conditions (Deka and Baruah 2000). Chlorophyll content showed a positive correlation with crop growth rate and relative growth rate under direct-seeded aerobic condition but under conventional transplanted conditions, it did not show correlation with any of the parameters (Table 5, 9, 10; Appendix IV). Absorbed photosynthetically active radiation (APAR) was significantly different between the flooded and aerobic control treatments. APAR consistently decreased with decreasing water input (Bouman *et al* 2006).

At maximum tillering conventional transplanted crop showed a higher leaf area than in direct-seeded rice. At flowering, leaf area was not significantly different between direct seeded rice and transplanted rice (Ginigaddara and Ranamukhaarachchi 2011). According to Zhong *et al* (2002) at panicle initiation, the reduction of tillering rate in direct-seeded rice could be due to rapid increase in the leaf area and its shading effects. In contrast, the direct-seeded rice in moistened soil produced more panicles and sterile spikelets than transplanted rice (Sarkar *et al* 2003).

4.1.2. Plant height: In our study, plants in the crop raised under conventional transplanted method were taller than those under direct-seeded aerobic conditions (Table 4, 9, 10; Appendix IV). The plant height is an important morphological character that primarily helps to avoid potential competition by weeds (Nyarko and De Datta 1991). An increased plant height was recorded by Reddy *et al* (2010) in rice crop under aerobic conditions at vegetative stage as compared to flooded conditions. At flowering stage, the plant height was less in plants under aerobic condition than that of flooded rice. This decrease in height may be due to sensitivity of reproductive phase to water stress (Pirdasthi *et al* 2004). Majeed *et al* (2011) reported reduced plant height under water stress. But Azihiri-Sigari *et al* (2005) and Bouman *et al* (2006) suggested that the direct-seeded seedling grew taller with higher shoot dry weight and total dry weight. Although, plant height is a varietal character, but is often regulated by environmental conditions (Yoshida 1981). Also plant height is

correlated many growth and yield related parameters.

In the present study, under direct-seeded aerobic conditions in the year 2012, plant height at vegetative stage (V) showed a direct effect on crop growth rate at vegetative ($r=0.292$) and reproductive (R) stages ($r=0.257$) and also with above ground biomass ($r=0.414$). In the year 2013, plant height (V) showed a positive correlation with total dry weight at both vegetative ($r=0.508$) and reproductive stages ($r=0.266$), above ground biomass ($r=0.279$) and a negative correlation with harvest index ($r=-0.326$). Although in this year, plant height did not show any direct effect with CGR but total dry weight at reproductive stage correlated with CGR(R) ($r=0.294$). In the year 2012, plant height (R) showed a positive correlation with CGR (V) ($r=0.353$) and above ground biomass ($r=0.480$) while in 2013, plant height (R) correlated with harvest index ($r=0.369$). Harvest index in turn correlated with above ground biomass ($r=-0.410$).

Under control (conventional transplanted) conditions, in the year 2012, plant height (V) correlated with plant height at reproductive stage ($r=0.490$), above ground biomass ($r=0.271$) and harvest index ($r=-0.328$). Plant height at reproductive stage in turn correlated with CGR (V) ($r=0.573$). In the year 2013, plant height (V) correlated with dry weight at vegetative stage ($r=0.291$) which in turn correlated with CGR (V) ($r=-0.650$), above ground biomass ($r=0.520$) and dry weight at reproductive stage ($r=0.287$). Plant height (R), in the year 2013, correlates with plant height at vegetative stage ($r=0.490$), CGR (V) ($r=0.572$) and above ground biomass ($r=0.376$) while in the year 2013, plant height (R) correlated with CGR(R) ($r=0.249$).

4.1.3. Crop growth rate (CGR) and relative growth rate (RGR): In the present study, CGR and RGR were more in conventional transplanted rice than in direct seeded aerobic rice (Table 1, 2, 3, 9, 10, 21, 23, 28; Appendix IV). Variable response to water stress was observed at different growth stages of rice cultivars (Basu *et al.* 2010). Mostajean and Eichi (2009) have reported similar results with the observations that water shortage adversely affected growth of rice. Growth stages also expressed varied response regarding impact of water stress on physiological performance of rice cultivars. Differential response of upland rice varieties was also observed by Botwright *et al.* (2008) and Basu *et al.* (2010). However, Tadesse *et al.* (2013) demonstrated that continuous and prolonged flooding resulted in the lowest crop growth rate (CGR). Thakur *et al.* (2011) also reported a higher value of CGR with aerating rice fields by draining the flood water for some time as compared to continuous flooding. This indicated that CGR was negatively affected by prolonged flooding. In our study, crop growth rate and RGR correlated with grain yield and other traits under study.

In direct-seeded aerobic crop, in the year 2012, CGR (V) correlates with above ground biomass ($r=0.504$) and harvest index ($r=0.330$). CGR (V) also correlates with plant height at vegetative

($r=0.292$) and reproductive stages($r=0.353$). In the year 2013, CGR (V) correlates with CGR(R) ($r=0.607$). In the year 2012, CGR(R) correlates with plant height at vegetative stage ($r=0.257$) and in the year 2013, CGR(R) correlates with dry weight at vegetative stage ($r=-0.296$) and dry weight at reproductive stage ($r=0.294$) and CGR (V) ($r=0.607$). This dry weight at vegetative stage in turn correlates with plant height at vegetative stage ($r=0.508$) and also dry weight at reproductive stage ($r=0.308$), Dry weight (R) in turn, correlates with plant height at vegetative stage ($r=0.266$).

In control (conventional transplanted) conditions, in the year 2012, CGR (V) correlates with plant height at reproductive stage ($r=0.573$) and above ground biomass ($r=0.270$). In the year 2013, CGR (V) correlates with CGR(R) ($r=-0.552$), DW (V) ($r=-0.650$) and DW(R)($r=0.744$) and above ground biomass ($r=0.520$). In the year 2012, it has no correlation while in year 2013, it correlates with CGR (V) ($r=-0.552$) and plant height at reproductive stage ($r=0.249$) and above ground biomass ($r=-0.409$) indirectly.

RGR showed a positive correlation with chlorophyll content, CGR and a negative correlation with plant height, leaf area and MTS. However, under conventional transplanted conditions, RGR had a positive correlation with CGR and a negative correlation with plant height.

4.2. Anatomical studies

Transverse sections of roots from the crop raised under direct-seeded aerobic and conventional transplanted conditions, respectively, were obtained at 40 days after sowing (DAS). Aerenchyma was observed under both the sowing conditions. The development of aerenchyma was comparatively more in crop raised under conventional transplanted conditions than under direct-seeded aerobic conditions (Plate 1-6; Appendix V). This may be because aerenchyma is an important anatomical adaptive feature necessary for survival of the crops under flooded conditions (Uchimiya *et al* 2000) as it provides a diffusion path of low resistance for oxygen.

In the present study under direct-seeded aerobic conditions, UPLRi7 (parent) showed maximum aerenchyma followed by two high-yielding RILs (Ae-RIL-B-42 and Ae-RIL-B-44), while the two low-yielding RILs (Ae-RIL-B-7 and Ae-RIL-B-117) showed least amount of aerenchyma tissue. Under conventional transplanted conditions, PR120 (parent) showed maximum aerenchyma formation. Moderate aerenchyma was observed for two RILs having high yield (Ae-RIL-B-42 and Ae-RIL-B-44). The least aerenchyma was observed for two low-yielding RILs (Ae-RIL-B-7 and Ae-RIL-B-117).

Under field conditions the extensiveness of aerenchyma formation in adventitious roots was positively correlated with the yield of 17 spring wheat cultivars grown under intermittent flooding (Setter *et al* 1999). The formation of functional aerenchyma is the key adaptation to water logged conditions in cereals like rice, maize and wheat etc. (Yamauchi *et al* 2013). However, although the

benefits of aerenchyma are clear, the mechanisms that underlie the formation of this tissue are not yet fully understood.

4.3. Biochemical constituents

4.3.1. Total soluble sugar and total starch: At both vegetative and reproductive stage, there was significant difference in total soluble sugars in leaves of rice crop raised under conventional transplanted and direct-seeded aerobic conditions (Table 11, 12, 13, 19, 20; Appendix IV). In general, total soluble sugar content in rice crop was higher in direct-seeded aerobic conditions than that of conventional transplanted crop. However, there is a significant difference among RILs under each sowing condition (conventional transplanted and direct-seeded aerobic). Maximum sugar content was found to be in RILs Ae-RIL-B-158, Ae-RIL-B-27 and Ae-RIL-B-82 in direct seeded aerobic rice. While under transplanted conditions, maximum value of total soluble sugars was recorded for RILs Ae-RIL-B-27, Ae-RIL-B-191, Ae-RIL-B-100, and PR120 (parent).

At reproductive stage, there is significant difference in total soluble sugars in transplanted and direct-seeded aerobic conditions. In general, total soluble sugar content in rice crop was higher in direct-seeded aerobic conditions than that of conventional transplanted. However, there is a significant difference among RILs under each sowing condition (conventional transplanted and direct-seeded aerobic). RILs Ae-RIL-B-126, Ae-RIL-B-135, Ae-RIL-B-42, Ae-RIL-B-112, Ae-RIL-B-158 and GA2 (check) showed maximum sugar content in direct-seeded aerobic conditions. RILs Ae-RIL-B-100 and Ae-RIL-B-191 showed maximum value of total soluble sugar under transplanted rice.

At both vegetative and reproductive stage, there was significant difference in total soluble starch in leaves of rice crop raised under transplanted and direct-seeded aerobic conditions. In general, total soluble starch content in rice crop was higher in direct-seeded aerobic conditions than that of conventional transplanted crop. However, there is a significant difference among RILs under each sowing condition (conventional transplanted and direct-seeded aerobic). Maximum starch content was found to be in RILs Ae-RIL-B-158, Ae-RIL-B-27 and Ae-RIL-B-82 in direct-seeded aerobic condition. While under conventional transplanted conditions, maximum value of total soluble starch was recorded for RILs Ae-RIL-B-27, Ae-RIL-B-191, Ae-RIL-B-100 and PR120 (parent).

At reproductive stage, there is significant difference in total soluble starch in conventional transplanted and direct-seeded aerobic conditions. In general, total soluble starch content in rice crop was higher in direct-seeded aerobic conditions than that of conventional transplanted. However, there is a significant difference among RILs under each sowing condition (conventional transplanted

and direct-seeded aerobic). RILs Ae-RIL-B-82, Ae-RIL-B-158 and Ae-RIL-B-27 showed maximum starch content in direct-seeded aerobic condition. RILs Ae-RIL-B-27, Ae-RIL-B-191, Ae-RIL-B-100 and PR120 (parent) showed maximum value of total soluble starch under conventional transplanted rice.

Drought stress markedly decreased accumulation of sugar in leaves of rice at dough stage and reduction of sugar content in grains was greater at panicle initiation stage (Majeed *et al* 2011). Under aerobic conditions, rice shoot contain seven times more soluble carbohydrates than roots. A four hour anaerobic treatment resulted in decline in carbohydrates content for both root and shoot, with two times higher depletion observed for rice shoot (Mustroph *et al* 2006). Guglielminetti *et al* (1995a) also stated that under submergence, the level of soluble sugars dropped in rice leaves. Total sugar content increased at flowering stage as compared to tillering stage, including active synthesis of carbohydrates at flowering stage of rice under drought stress. Mai *et al* (2010) also suggested that the total sugar content was higher in fine rice as compared to aromatic rice under direct seeding. There was significant difference in total sugar content among the varieties both at tillering and flowering stages.

4.3.2. Proline content: At both vegetative and reproductive stage, there was significant difference in proline content in leaves of rice crop raised under conventional transplanted and direct-seeded aerobic conditions (Table 14, 15, 19, 20; Appendix IV). In general, at vegetative stage, proline content in rice crop was higher in conventional transplanted crop than that of direct-seeded aerobic conditions. Proline is known to accumulate during stress and transplanting shock at vegetative stage could be responsible for enhanced level of proline in transplanted crop. At reproductive stage, proline content is generally higher in direct-seeded aerobic crop which may be because of water stress. High proline content is a good index for moisture resistance in genotypes. Under moisture stress condition the protein degrades and consequently the proline content increases (Roy *et al* 2009). However, there is a significant difference among RILs under each sowing condition (conventional transplanted and direct-seeded aerobic). In the direct-seeded aerobic crop maximum proline content at vegetative stage was in RILs Ae-RIL-B-112, Ae-RIL-B-158 and Ae-RIL-B-132, and at reproductive stage maximum proline content was in Ae-RIL-B-7 and PR120(parent). While under conventional transplanted conditions, maximum value of proline content at vegetative stage was recorded for RILs Ae-RIL-B-44 and Ae-RIL-B-135 and at reproductive stage RILs Ae-RIL-B-191 and IR64 (check).

Osmotic adjustment is considered as an important physiological mechanism of drought adaptation in many plants (Subbrao *et al* 2000). Proline is one of the important osmolytes which accumulates during moisture stress condition. It helps to maintain turgor and promotes continued

growth in low water potential soils (Mullet and Whitsitt 1996). Singh and Singh (1983) observed that proline accumulation under drought condition is a good indicator of drought resistance capacity of plants.

4.3.3. Storage proteins: The quantity of soluble protein is one of the important factors for synthesis of other plant material. The synthesis of soluble protein by plants depends upon their capacity to utilize N and production of reduced-N needed for protein synthesis. There was significant difference in storage protein in seeds of rice crop raised under conventional transplanted and direct-seeded aerobic conditions. In general, storage protein in seeds in rice crop was higher in direct-seeded aerobic conditions than that of conventional transplanted crop (Table 16, 17, 19, 20; Appendix IV). However, there is a significant difference among RILs under each sowing condition (conventional transplanted and direct-seeded aerobic). Maximum storage protein in seeds was found to be in RILs Ae-RIL-B-92, Ae-RIL-B-100, Ae-RIL-B-132 and UPLRi7 (parent) in direct-seeded aerobic rice. While under conventional transplanted conditions, maximum value of storage protein in seeds was recorded for RILs Ae-RIL-B-116, Ae-RIL-B-132, Ae-RIL-B-135 and Ae-RIL-B-158.

Under moisture stress condition the leaf protein content gradually decreases. The genotypes showing highest decrease in leaf protein content could be considered as drought resistant (Roy *et al* 2009). Mai *et al* (2010) indicated that soluble protein in aromatic-fine rice decreased at flowering stage as compared to that of maximum tillering stage. However, in the present study, there was no significant difference in soluble protein content among varieties at both tillering and flowering stages.

4.3.4. Total free amino acids: There is non-significant difference in total free amino acid in both the direct-seeded aerobic and conventional transplanted conditions (Table 16, 18, 19, 20; Appendix IV). However, there is a significant difference among RILs under each sowing condition (conventional transplanted and direct-seeded aerobic). The RIL Ae-RIL-B-82 and GA2 (check) have least amount of total free amino acids under direct-seeded aerobic conditions and RILs Ae-RIL-B-126, Ae-RIL-B-132 and APO (check) have the least total free amino acid under conventional transplanted conditions.

In a study conducted by Mai *et al* (2010) on four rice varieties there was significant difference of total free amino acid content at tillering and flowering stages. The amino acid content was increased at flowering stage as compared to that of tillering stage. During the first 4 d of anoxic germination, the accumulation of amino acids is known to derive from the assimilation of the nitrate stored in the seeds (Mattana *et al* 1993), whereas later, most of the amino acids present in the rice coleoptiles probably come from the breakdown of storage protein followed by the translocation of amino acids (Reggiani *et al* 1993c).

4.4. Yield attributes

4.4.1. Above-ground biomass: In general, above ground biomass was more in conventional transplanted rice than in direct-seeded aerobic rice (Table 7, 24, 25, 28; Appendix IV). Prolonged flooding led to production of lower rice biomass and grain yields (Tadesse *et al.* 2013). However, in an experiment involving rice cultivation under conventional transplanted and aerobic conditions for eight seasons, lower yield was observed in aerobic crop (Peng *et al.* 2006). This yield gap between direct-seeded aerobic and transplanted rice was attributed to differences in biomass production and sink size (spikelet per meter square). Zhang *et al.* (2001) reported a 6.6% increase in aboveground biomass yield with alternate wetting and drying compared to continuous flooding. It was reported that prolonged flooding led to the production of lower rice biomass and grain yields (Tadesse *et al.* 2013). Sanusan *et al.* (2010) also investigated the effects of different seeding depths and water stress on growth and yield of direct-seeded rice and revealed that above-ground biomass was significantly affected by rice cultivars, seeding depths and water stress. There was significant increase in above ground biomass between rice cultivars when vegetative stage at seven days of stress. This was because of higher root length density under stress.

In the present study, under direct-seeded Aerobic condition, in the year 2012, above ground biomass correlates with plant height at vegetative ($r=0.414$) and reproductive stages ($r=0.480$) and CGR (V) ($r=0.504$) while in the year 2013, above ground biomass correlates with plant height vegetative stage ($r=0.279$), dry weight at vegetative stage ($r=0.37$). This dry weight at vegetative stage in turn correlates with plant height at vegetative stage ($r=0.508$). Above ground biomass also correlates with harvest index ($r=-0.410$) which also in turn correlates with plant height at vegetative ($r=-0.326$) and reproductive stages ($r=0.369$) and dry weight at vegetative stage ($r=0.374$).

Under control (conventional transplanted) condition, in the year 2012, above ground biomass correlates with plant height at vegetative ($r=0.271$) and reproductive stages ($r=0.376$) and CGR(V) ($r=0.270$) while in the year 2013, above ground biomass correlates with CGR(V) ($r=0.520$), CGR(R) ($r=-0.409$) and dry weight at vegetative stage ($r=-0.342$) which further correlates with plant height at vegetative stage ($r=0.291$).

4.4.2. Harvest index (HI): In general, harvest index was more in conventional transplanted rice than in direct-seeded aerobic rice (Table 8, 24, 26, 28; Appendix IV). In a study conducted by Peng *et al.* (2006) a few second-generation lines produced significantly higher yield than the indica check variety, IR72, in several seasons than aerobic conditions. This increase was due to improved aboveground total biomass production or improved harvest index. The poor yield of the first generation lines was attributed to low harvest index, which was the result of small sink size (i.e.,

few spikelets m^{-2}), low grain-filling percentage, and poor translocation of biomass accumulated before flowering to the grains during grain filling (Peng *et al.* 2006) under water stress. According to Ginigaddara and Ranamukhaarachchi (2011) the differences in harvest index (HI) among transplanted rice at all stages were not significant from direct-seeded rice. This explains the non-variability of grain and shoot biomass among the treatments regardless of the method of establishment adopted and age of seedlings transplanted.

In the present study, in direct-seeded aerobic condition, in the year 2012, HI correlates with CGR(V) ($r=0.331$) which in turn correlates with plant height at vegetative ($r=0.292$) and reproductive stages ($r=0.353$) while in the year 2013, HI correlates with plant height at vegetative ($r=-0.326$) and reproductive stages ($r=0.369$) and dry weight at vegetative stage ($r=-0.374$) and above ground biomass ($r=-0.410$) which in turn correlates with plant height at vegetative stage ($r=0.279$) and dry weight at vegetative stage ($r=0.370$).

Under control (conventional transplanted) condition, in the year 2012, HI correlates to plant height at vegetative stage ($r=-0.328$) which in turn correlates to plant height at reproductive stage ($r=0.490$). In the year 2013, HI correlates with yield ($r=0.439$). There is no correlation of HI with other traits.

4.4.3. Grain yield and yield attributes: Yang *et al.* (2002) reported that with a decreasing amount of water application, all investigated yield components decreased as well, though the effect was statistically significant only for grain weight, and for filled grains per panicle and percentage filled grains for the lowland variety. Geethalakshmi *et al.* (2011) studied growth parameters under system of rice intensification (SRI) which includes proper land leveling, water management for intermittent irrigation, transplanting 12-15 days old seedling, planting single seedling per hill with spacing of approx. 20-25x20-25 cm and proper weed management. Grain yields were significantly higher in SRI than those using conventional management (CM), mechanical transplanting (MT) and transplanting (manual) (TP) (Chen *et al.* 2013). Reproductive stage is the most important period to achieve high yield of rice (Baker *et al.* 1995). Grain yield exhibited highly significant and positive correlation with harvest index, biological yield seedling height (Dwivedi *et al.* 2012) under drought conditions as well in controlled transplanted condition in rice. For RILs with a higher biomass and harvest index the yield is higher. But there is also a compensatory mechanism with the number of grains per panicle and number of panicles per unit area. The rice cultivars showed differential response towards water stress at panicle initiation, anthesis and grain filling stages. Growth stages expressed varied response regarding impact of water stress on physiological performance of rice cultivars. Recent photosynthates must be generated at the time of grain filling to support the maximum number of grains per panicle, which is ensured by proper plant structure development before panicle initiation

(Reddy *et al.* 2010). In present study, total number of tillers, spikelet per panicle, grain filling percentage was lower under direct-seeded aerobic conditions. However, sterile grains per panicle were higher in direct-seeded aerobic crop than conventional transplanted crop (Table 7, 8, 24, 27, 28; Appendix IV).

In direct-seeded aerobic crop, in the year 2012, yield exhibited correlation with plant height at vegetative stage ($r=0.301^*$), at reproductive stage ($r=0.183$), CGR (V) ($r=0.493^*$), CGR(R) ($r=0.128$). Yield also exhibited correlation with above-ground biomass ($r=0.580^*$) and harvest index($r=0.858^*$). In the year 2013, yield exhibited negative correlation with plant height at vegetative stage ($r=-0.04$), positive correlation with plant height at reproductive stage ($r=0.468^*$), CGR (V) ($r=0.151$), CGR(R) ($r=0.056$) above-ground biomass ($r=0.354^*$), harvest index ($r=0.669^*$).

In conventional transplanted crop, in the year 2012, yield exhibited correlation with plant height at vegetative stage ($r=0.064$), at reproductive stage ($r=0.370^*$), CGR (V) ($r=0.398^*$), CGR(R) ($r=0.209$). Yield also exhibited correlation with above-ground biomass ($r=0.792^*$) and harvest index($r=0.269^*$). In the year 2013, yield exhibited negative correlation with plant height at vegetative stage ($r=-0.171$), reproductive stage ($r=0.052$), CGR(R) ($r=0.028$) and positive correlation with CGR (V) ($r=0.465^*$), above-ground biomass ($r=0.373^*$), harvest index ($r=0.439^*$).

Path analyses: Correlation coefficients obtained among various traits were partitioned in direct and indirect effects via path-coefficient analysis (Dewey and Lu 1959; Kang 2015) with the help of computer program Kang SASPath. Path coefficient analyses revealed that under direct-seeded aerobic conditions, in the year 2012, a significant positive direct effect on grain yield was exhibited by plant height at both vegetative ($P_{1,7}=0.031$) and reproductive stages ($P_{2,7}=0.014$), above-ground biomass ($P_{5,7}=0.509$) and harvest index ($P_{6,7}=0.821$) and negative effect on crop growth rate at both vegetative ($P_{3,7}=-0.056$) and reproductive stages ($P_{4,7}=-0.035$). However in the year 2013, the yield showed significant positive direct effect on plant height at vegetative ($P_{1,7}=0.011$) and reproductive stages ($P_{2,7}=0.052$), crop growth rates at vegetative ($P_{3,7}=0.009$) and reproductive stages ($P_{4,7}=0.034$), above-ground biomass ($P_{5,7}=0.704$), harvest index ($P_{6,7}=0.990$).

Under conventional transplanted conditions, in the year 2012, crop yield showed positive direct effect on crop growth rate at vegetative stage ($P_{3,7}=0.054$), above-ground biomass ($P_{5,7}=0.999$), and harvest index($P_{6,7}=0.604$) and negative effect on plant height at vegetative ($P_{1,7}=0.017$) and reproductive stages ($P_{2,7}=0.010$)and CGR(R)($P_{4,7}=-0.014$). In the year 2013, a positive direct effect between yield and plant height at vegetative stage ($P_{1,7}=0.209$), above-ground biomass ($P_{5,7}=0.501$) and harvest index ($P_{6,7}=0.598$) was observed while a negative effect was seen with plant height at reproductive stage ($P_{2,7}=-0.078$), CGR(V)($P_{3,7}=-2.15$) and CGR(R)($P_{4,7}= -1.62$).

References:

- Azhiri-Sigari T, Gines H, Sebastian L S and Wade L (2005) Seedling vigor of rice cultivars in response to seeding depth and soil moisture. *Philippine J of Crop Sci* **30**: 53-58.
- Baker J T , Boote K J and Allen L H J (1995) Potential climate change effects on rice: Carbon dioxide and temperature. In Rosenzweig C *et al* (ed) Climate change and agriculture: *Analysis of potential international impacts*. Pp. 31-47 ASA Spec. Publ. No. 59. ASA, Madison, WI.
- Basu S , Roychoudhury A , Saha P P and Sengupta D (2010) Differential antioxidative responses of indica rice cultivars to drought stress. *Plant Growth Regul* **60**: 51-59.
- Botwright Acuna T L, Pasuquin E and Wade L J (2008) Genotype environment interactions for grain yield of upland rice backcross lines in diverse hydrological environments. *Field Crops Res*.
- Bouman B A M , Yang X , Wang H , Wang Z , Zhao J and Chen B (2006) Performance of aerobic rice varieties under irrigated conditions in North China. *Field Crops Res* **97**: 53–65.
- De Datta S K (1981) Principles and practices of rice production. Singapore: A Wiley Ey-Interscience Publication.
- Deka M and Baruah K K (2000) Comparable studies of rainfed upland rice (*Oryza sativa* L.) cultivars for drought tolerance. *Indian J Agri Sci* **70**: 135-39.
- Dewey D R and Lu K H (1959) A correlation and path coefficient analysis of components of crested wheat grass seed production. *J of Agron* **51**: 515-18
- Dwivedi D K, Kumar A , Mishra V K and Dwivedi S (2012) Phenotypic correlation and path coefficient analysis in rice (*Oryza sativa* L.) introgression lines under drought and controlled conditions. *Inter J of Curr Res* **4**: 7-12.
- Geethalakshmi V, Lakshmanan A and Ramesh T (2011) Assessment of water requirement for different systems of rice cultivation. Tamil Nadu Agricultural University, Coimbatore, Tamil Nadu, India.
- Ginigaddara G A S and Ranamukhaarachchi S L (2011) Study of age of seedling at transplanting on growth dynamics and yield of rice under alternating flooding and suspension of irrigation of water management. *Recent Research in Sci and Technol* **3**: 76-88.
- Guglielminetti L, Perata P, Alpi A (1995a) Effect of anoxia on carbohydrate-metabolism in rice seedlings. *Plant Physiol* **108**: 735–41.
- Kang M S (2015) Efficient SAS programs for computing path coefficient and index weights for selection indices. *J Crop Improve* **29**:1-17
- Mai M A B, Shamsuddin Z H, Wahab Z and Marziah M (2010) Effect of plant growth and nitrogen incorporation of tissue-cultured Musa plantlets under nitrogen free hydroponics condition. *Aus J Crop Sci* **4**: 85-90.
- Majeed A , Salim M, Bano A, Asim M and Hadees M (2011) Physiology and productivity of rice crop influenced by drought stress induced at different developmental stages. *Afr J Biotech.***10**: 5121–36.

- Mattana M, Bertani A, Aurisano N and Reggiani R (1993) Preliminary evidence of nitrate assimilation during the anaerobic germination of rice. In: Jackson M B, Black C R, (eds) *Interacting stresses on plants in a changing climate*. pp 365-74. Berlin: Springer-Verlag; NATO ASI Series.
- McDonald A J, Riha S J, Duxbury J M, Steenhuis T S and Lauren J G (2006) Water balance and rice growth responses to direct seeding, deep tillage, and landscape placement: Findings from a valley terrace in Nepal. *Field Crop Res* **95**: 367-82.
- Mostajean A and Eichi V R (2009) Effects of drought stress on growth and yield of rice (*Oryza sativa* L.) Cultivars and accumulation of proline and soluble sugars in sheath and blades of their different ages leaves. *J Agric Environ Sci* **5**:264-72.
- Mullet J E, Whitsitt M S (1996) Plant cellular responses to water deficits. *Plant Growth Regul* **20**:119-24.
- Mustroph A, Boamfa E I ,Laarhoven L J J, Harren F J M , Albrecht G and Grimm B (2006) Organ specific analysis of anaerobic primary metabolism in rice and wheat seedlings. I. Dark ethanol production is dominated by shoot. *Planta* **225**: 103-14.
- Nyarko K A and De Datta S K (1991) Weed control in irrigated rice. In: *Hand book for weed control in rice*, pp 73-80. IRRI , Manila, Philippines.
- Peng S, Bouman B A M, Visperas R M, Castañeda A, Nie L, Park H K (2006) Comparison between aerobic and flooded rice in the tropics: agronomic performance in an eight-season experiment. *Field Crops Res* **96**: 252–59.
- Pirdashti H, Tahmasebi Sarvestani Z and Nassiri M (2004) Remobilization of dry matter and nitrogen in rice varieties at different date transplant. *Iranian J of Crop Sci* **4**: 55-46.
- Reddy J N , Sarkar R K , Patnaik S S C , Singh D P , Singh U S , Ismail A M and Mackill D J (2010) Improvement of rice germplasm for rainfed lowlands of eastern India. *SABRAO 13th International Congress*. Cairns, Australia.
- Reggiani R, Mattana M, Aurisano N and Bertani A (1993) The rice coleoptiles: an example of anaerobic nitrate assimilation. *Physiol Plant* **89**: 640–43.
- Roy R, Mazumder P B and Sharma G D (2009) Proline, catalase and root traits as indices of drought resistance in bold grained rice (*Oryza sativa*) genotypes. *African J of Biotech* **8**: 6521-28
- Sanusan, S, Polthane A , Audebert A , Seripong S and Mouret J C (2010) Growth and yield of rice (*Oryza sativa* L.) as affected by Seeding depth and water deficits at vegetative stage. *Asian J of Plant Sci* **9**: 36-43.
- Sarkar R K , Sanjukta D and Das S (2003) Yield of rainfed lowland rice with medium water depth under anaerobic direct seeding and transplanting. *Trop Sci* **43**: 192–98.
- Setter T L, Burgess P, Waters I and Kuo J (1999) Genetic diversity of barley and wheat for waterlogging tolerance in western Australia. pp. 2.17.1-2.17.7. In: *9th Australian Barley Technical Symposium* , Melbourne.

- Singh K P and Singh K (1983) Influence of stimulated water stress on free proline accumulation in *Triticum aestivum* L. *Indian J Plant Physiol* **26**: 319-21.
- Subbrao G V, Chauhan Y S, Johannsen C (2000) Patterns of osmotic adjustment in pigeonpea- its importance as a mechanism of drought resistance. *Eur J Agron* **12**: 239-49
- Tadesse T F , Nigussie D R , Bayu W and Setegn G (2013) Impact of rainwater management on growth and yield of rainfed lowland rice. *J of Agric Res* **2**: 108-14.
- Thakur A K , Rath S , Patil D U and Kumar A (2011) Effects on rice plant morphology and physiology of water and associated management practices of the system of rice intensification and their implications for crop performance. *Paddy Water Environ* **9**:13–24.
- Uchimiya H, Samarajeewan P K and Kawai M (2000) Plant programmed cell death and environmental constraints – adenylate homeostasis and aerenchyma formation. *In: Proceeding of the 12th Toyota Conference: Challenges of Plant and Agricultural Sciences to the Crisis of Biosphere on the Earth in the 21st Century*, (eds.) Kazuo Watanabe and Atsushi Komamine.
- Yamauchi T, Shimamura S, Nakazono M and Mochizuki T (2013) Aerenchyma formation in crop species: A review. *Field Crop Res* **152**:8-16.
- Yang X, Wang H, Wang Z, Zhao J, Chen B and Bouman B A M (2002) Yield of aerobic rice (Han Dao) under different water regimes in northern China: opportunities and challenges. *In: Bouman B A M, Hengsdijk H, Hardy B, Bindraban P S, Tuong T P, Ladha J K (eds), Water-wise rice production. Proc International Workshop on Water-wise Rice Production*, pp 155–63. International Rice Research Institute, Los Baños, Philippines.
- Yoshida S (1981) Fundamentals of rice crop science: pp.269 International Rice Research Institute, Los Banos, Phillipines.
- Zhang J, Zheng H G, Aarti A, Pantuwan G, Nguyen T T, Tripathy J N, Sarial A K, Robin S, Babu R C and Nguyen B D (2001) Locating genomic regions associated with components of drought resistance in rice: comparative mapping within and across species. *Theor Appl Genet* **103**: 19–29.
- Zhong X, Peng S, Sheehy J E, Visperas R M and Liu H (2002) Relationship between tillering and leaf area index: quantifying critical leaf area index for tillering in rice. *The J of Agric Sci* **138**: 269-79.

Chapter-V

SUMMARY

Rice is one of the most important food crops of the world and staple food for more than half of global population. Traditionally, rice is grown by transplanting 3- to 5- week old seedlings into puddled fields. Along with high water requirement, continuous puddling causes deterioration of soil physical properties through structural breakdown of soil aggregates, forms a plough pan that restricts percolation of water causing temporary water logging and restricts root penetration and growth for succeeding crops (Gill *et al* 2006). Further, rice transplanting is labour intensive operation. Therefore, alternative methods of establishing rice crop that require less water and labour without sacrificing productivity are needed.

Aerobic rice has a great potential for saving water but all this is at the cost of severe reduction in yield. A substantially lower grain yield has been reported in aerobic rice as compared with flooded lowland rice (Wei *et al* 2011). Less water availability at reproductive stage is found to be a reason for low yield of aerobic rice (Bouman *et al* 2002).

Physiological basis of yield gap between aerobic and flooded rice has not been studied extensively. Keeping in view the above facts, the present study was planned to study the morpho-physiological traits in a recombinant inbred line population of rice under direct-seeded aerobic conditions and also to correlate different physiological and biochemical traits with yield and yield components under direct-seeded aerobic conditions.

The experiment was conducted on a recombinant inbred line (RIL) population obtained from a cross between PR120 (semi dwarf) x UPLRi7 (upland) varieties. F₈ generation of this cross was raised at the School of Agricultural Biotechnology, Punjab Agricultural University, Ludhiana. The crop was raised in two sets viz., by conventional transplanted method and by direct-seeded aerobic method following standard practices. Observations were recorded at 40 DAS (days after sowing), 50% anthesis and at the time of harvesting.

At 40 DAS and at 50% anthesis, morpho-physiological parameters were recorded on crop and various biochemical components were estimated from the pooled leaf sample. At the time of harvest, various yield attributing parameters were recorded and biochemical components were estimated from harvested seeds. Morpho-physiological traits included canopy height, dry matter accumulation, crop growth rate, relative growth rate, leaf area, chlorophyll content in leaves and radiation use efficiency. Biochemical traits included estimation of total soluble sugars, total starch, total soluble proteins, proline content, storage proteins and total free amino acids. Yield attributing parameters included above ground biomass, total number of tillers per 0.5m row, number of fertile

tillers per panicle per 0.5m row, spikelets per panicle, sterile grains per panicle, grain filling %age, grain yield per 0.5m row, harvest index, 1000 grain weight.

Additionally, at 40 DAS, the development of aerenchyma in the root was observed. Transverse sections at a distance of 1 inch from the root base were observed under scanning electron microscope (SEM).

The salient findings of the study on crop raised under the two sowing conditions, viz., conventional transplanted and direct seeded aerobic are:

Vegetative stage (40 DAS):

Morpho-physiological traits: In general, plant height dry matter, crop growth rate (CGR), relative growth rate (RGR), leaf area and chlorophyll content were lower under direct-seeded aerobic conditions than under conventional transplanted conditions. Plant height and crop growth rate showed a positive correlation with grain yield and had a direct effect on grain yield. Dry matter accumulation showed no correlation but had an indirect effect on grain yield. Relative growth rate, leaf area and chlorophyll content did not show any correlation or effect on grain yield.

Anatomical observation: A transverse section of root obtained from crop raised under conventional transplanted condition showed higher proportion of aerenchyma as compared to root sections from direct-seeded aerobic crop. High-yielding RILs had relatively more aerenchyma than the low-yielding RILs.

Biochemical traits: In general, the contents of total soluble sugars and starch estimated from pooled leaf samples were more under direct-seeded aerobic crop. RIL, Ae-RIL-B-158 showed maximum total soluble sugar and starch content under direct seeded-aerobic conditions. On the other hand, proline content was recorded lower in direct-seeded aerobic crop. Maximum proline content at vegetative (40 DAS) stage recorded in RIL Ae-RIL-B-158.

Reproductive stage (50 % anthesis):

Morpho-physiological traits: At reproductive stage, observations pertaining to plant height, crop growth rate, dry matter accumulation, relative growth rate, leaf area and chlorophyll contents were similar to the observations at vegetative stage.

Biochemical traits: Total soluble sugars and starch were higher in direct-seeded aerobic crop. Ae-RIL-B-158 showed maximum total soluble sugar and starch content at reproductive stage (50% anthesis). Contrary to observation at vegetative stage, proline content was higher in direct-seeded aerobic condition.

Harvest stage: All the yield contributing traits viz., above ground biomass, total number of tillers per 0.5m row, number of fertile tillers/panicle per 0.5m row, spikelets per panicle, grain filling %age, grain yield per 0.5m row, harvest index, 1000 grain weight were lower in direct-seeded aerobic

condition. Above ground biomass and harvest index showed correlation with yield and had a direct effect on grain yield under both direct-seeded aerobic and conventional transplanted conditions.

Biochemical composition of seeds: Seeds obtained from direct-seeded aerobic crop showed a higher value of storage proteins. Among the RILs, Ae-RIL-B-92, Ae-RIL-B-100, Ae-RIL-B-158 showed higher storage protein under direct seeded aerobic conditions while under conventional transplanted conditions, Ae-RIL-B-116, Ae-RIL-B-132, Ae-RIL-B-135 and Ae-RIL-B-158 showed higher storage proteins. The RIL Ae-RIL-B-82 had least total free amino acids and lower value of proline. It had higher value of storage proteins which indicates least degradation of proteins.

Conclusion:

Under direct-seeded aerobic conditions, morpho-physiological traits viz., plant height and crop growth rate, and yield attributing parameters viz., above ground biomass and harvest index exhibited maximum correlation with grain yield. These traits also showed high direct effect on grain yield under both the sowing conditions. These characters could be used as criteria for selecting RILs for incorporating into breeding programmes for yield enhancement under direct-seeded aerobic conditions

Under direct-seeded aerobic conditions, total soluble sugars and proline contents increased that may be due to moisture stress conditions (direct-seeded aerobic). Under both the sowing conditions, Ae-RIL-B-158, showed higher proline and sugar contents. Interestingly, under both the sowing conditions, this RIL showed least reduction in yield in comparison to conventional transplanted condition. This suggests that this RIL may be suitable for sowing under direct-seeded aerobic as it accumulated highest proline and sugars.

References:

- Bouman B A M, Xiaoguang Y, Huaqui W, Zhiming W, Junfang Z, Changgui W and Bin C (2002) Aerobic rice (Han Dao) A new way growing rice in water short areas *In: Proceedings of 12th International Soil conservation Organization Conference* pp 175-81. Beijing China.
- Gill M S, Kumar P and Kumar A (2006) Growth and yield of direct-seeded rice (*Oryza sativa*) as influenced by seeding technique and seed rate under irrigated conditions. *Indian J Agron* **51**: 283–87.
- Wei F, Hongbin T, Shan L, Bouman B A M, Zhang L, Wang P and Dittert K (2011) Rate and duration of grain filling of aerobic rice HD297 and their influence on grain yield under different growing conditions. *Sci Asia* **37**: 98–104.

MATERIALS AND METHODS

The present investigation entitled, “Morpho-physiological and biochemical characterization of a recombinant inbred line population of rice (*Oryza sativa* L.) under direct seeded aerobic conditions” was carried out in the laboratories of Department of Botany and the field area of School of Agricultural Biotechnology, Punjab Agricultural University, Ludhiana during summer season (May-September) in the year 2012 and 2013 respectively. The experiment was conducted on recombinant inbred line (RIL) population obtained from a cross between PR120 x UPLRi7. PR 120 is a semi-dwarf variety while UPLRi7 is an upland variety. F₈ generation of this cross was raised at the School of Agricultural Biotechnology, Punjab Agricultural University, Ludhiana.

1. Agro-climatic conditions

Ludhiana represents the Indo-Gangetic alluvial plains and is situated at 30°-55'N latitude, 75°-54'E longitude and at an altitude of 247 m above the mean sea level. It is placed in south- central plain region of Punjab and has subtropical and semi-arid climate. The meteorological data for the years 2012 and 2013 were obtained from meteorological observatory, Punjab Agricultural University, Ludhiana (Appendix II and III).

2. Sowing and raising of the Crop

Crop establishment: The experiment was laid out in two sets viz., by conventional puddled method and direct-seeded aerobic method.

Conventional puddled method: The crop was raised as nursery during May, 2012 and 2013 respectively. Nursery area was prepared by mixing twelve tonnes per acre of well rotten farm yard manure, fields were irrigated and left fallow for 15 days. Thereafter, the field was ploughed twice and at the time of ploughing 65 kg urea and 64 kg of zinc sulphate monohydrate per acre were applied. Small sized beds were prepared. Seeds of all the RILs were sown in rows on the beds and field was kept moist for germination of seeds.

The main field was prepared by two ploughings with disc harrow and one ploughing with cultivator followed by planking. Thereafter, the field was irrigated and good puddled conditions were obtained. Nitrogen @ 42 kg/ha in the form of urea and P₂O₅ @ 30 kg/ha in the form of SSP were applied during puddling. Thirty day old seedlings were transplanted in puddled field at row-to-row spacing of 20 cm and plant-to-plant spacing of 15 cm with two seedlings per hill. For weed control Butachlor 50 EC was applied @ 3000 ml/ha two days after transplanting by mixing it with 150 kg/ha sand in standing water. Water was kept ponded for two weeks for proper establishment of seedlings.

Appendix-I

Remaining nitrogen was applied in two splits, one at three weeks after transplanting and second at six weeks after transplanting (Anon.2012).

Direct-seeded aerobic method: The crop was raised in well-ploughed field. Seeds were sown manually at the rate of 25 kg seed per ha. in four rows of 1.5m length with row-to-row spacing of 20 cm. Nitrogen was applied @ 150 kg/ha in four equal splits at two, four, seven and ten weeks after sowing. For weed control Stomp 30 EC (pendimethalin) @ 2.5 l/ha was applied one day after sowing followed by Nominee Gold 10 SC (bispiribac) @2250 ml/ha 35 days after sowing. The crop was irrigated at 3-to-5 days interval. The interval was adjusted depending upon the rainfall. Irrigation was withheld 10 days before harvesting (Anon2012).

Harvesting and threshing: The crop was harvested manually during September 2012 and 2013 respectively when straw had turned yellow. The harvested crop was threshed manually. Grain samples were collected from respective RILs.

3. Experimental details and Layout

3.1 Experiment No.1

Name of experiment: Study of morpho-physiological, anatomical and biochemical traits in some high and low yielding a Recombinant Inbred Line (RIL) population under direct seeded conditions.

A Recombinant Inbred Line (RIL) population generated from a cross PR 120 x UPLRi 7 was obtained from School of Agricultural Biotechnology. Twenty RILs with yield potential at two extremes under aerobic conditions, i.e., 10 high yielding and 10 low yielding RILs was selected for crop season 2012. The experiment was planted in two sets, one for direct seeded aerobic conditions and the second for conventional transplanted method (control). APO, CT-6510-24-1-2 and IR64 were used as checks. Parents of the cross were also planted. The selected RILs were planted in a randomized block design (RBD). The experiment was replicated twice.

Total Number of Treatments	: $20+2+3 = 25$ (RILs + Parents + Checks)
Number of replications	: 2
Total Number of Plots	: 50
Design	: Randomized Block Design (RDB)
Likewise, a similar set was planted for control (conventional transplanted method)	

Observations recorded

3.1.1 Physiological observations

The observations were recorded from five tagged plants from each plot at vegetative and reproductive stages.

Appendix-I

i. Plant height (cm) (Wiangesamnt *et al* 2006).

Plant height was measured using a meter scale from soil to the highest tip of the topmost leaf at vegetative (40 days after sowing) and reproductive (50% anthesis) stages and expressed in centimetres.

ii. Dry matter accumulation (g)

Five plants were cut at ground level from each plot of two replications for determining the dry matter accumulation at various stages of growth. The plants were separated into different parts and then oven dried at 60-65°C to a constant weight for 10 days. Dry weight was recorded at vegetative (40 DAS) and reproductive (50% anthesis) stages to assess dry matter accumulation in plant parts and total dry matter production was expressed as g per plant.

iii. Crop growth rate (CGR) (Watson 1952)

CGR is the rate of dry matter production per unit land area per unit time and is intensively used in growth analysis of field crops. Crop growth rate was calculated using formula Watson (1952) and expressed as $\text{g plant}^{-1}\text{day}^{-1}$.

$$\text{CGR} = (W_2 - W_1) / (T_2 - T_1)$$

(Where, W_2 = final dry weight of plant; W_1 = previous dry weight of plant material; and T_2 = time (days) when final weight is recorded; T_1 = times (days) when previous weight is recorded).

iv. Relative crop rate (RGR) (Radford 1967)

RGR is expressed as an increase in dry weight in a time interval in relation to the initial weight. Relative growth rate (RGR) was calculated by using formula given by Radford (1967)

$$\text{RGR} = (\ln W_2 - \ln W_1) / (T_2 - T_1)$$

(Where, $\ln$ = natural log; and W_2 = final dry weight of plant; W_1 = previous dry weight of plant material; and T_2 = time (days) when final weight is recorded; T_1 = times (days) when previous weight is recorded).

v. Leaf area (Montgomery 1911)

Leaf area was measured *in situ* ($L \times B \times 0.75$). Leaf area of top most and middle flag leaf, two middle leaves, was measured at vegetative and reproductive stage. Lengths of fully opened leaf lamina were measured from the leaf base to the tip. Breadth was taken at the widest point of the leaf lamina. Leaf area was determined according to the formula given by Montgomery (1911)

$$\text{Leaf area} = L \times B \times k$$

(Where, L = length (cm); B = leaf breadth (cm); k = shape factor with value of 0.75)

Appendix-I

vi. Chlorophyll content in leaves (Dwyer *et al* 1995)

Chlorophyll content in leaves was calculated from five plants by Soil Plant Analysis Development (SPAD) value, which was determined by chlorophyll meter (SPAD-502, Minolta). SPAD reading were taken at two-thirds of the distance from the tip (without the midrib) towards the stem of the top-most leaf. Because insufficient sample size does not allow for the detection of small, but real differences between treatment means according to recommendation of Costa *et al* (2001), five leaves were measured at random in the plot and a mean SPAD value was calculated for each plot.

vii. **Radiation use efficiency (RUE)** (Cirilo *et al* 2009)

The fraction of incident photosynthetically active radiation (PAR) intercepted by plots (FRI) were measured on clear days around noon using a Ceptometer Accu PAR Model LP-80 (Decagon Device, Pullman). The fraction of PAR intercepted (FRI) was calculated by taking ten readings in rapid succession above the canopy (I_o) and ten readings just below the lowermost green leaf layer (I_l). The average of ten reading was taken for further calculations. The following equations were used for calculating radiation use efficiency (RUE).

- FRI (Fraction of PAR intercepted by plants) = $I - (I_t)/(I_o)$
- Intercepted PAR = Incident PAR x FRI
- RUE (For vegetative period) = $DM (V)/\text{Intercepted PAR (accumulated)}$
- RUE (For reproductive period) = $DM (R)/\text{Intercepted PAR (accumulated)}$

(Where, DM (V) and DM (R): are total plant dry matters at vegetative and reproductive stages respectively)

viii. Membrane integrity (per cent electrolyte leakage) (Deshmukh *et al* 1991)

Five discs of 1 cm each were used. Discs were put in double distilled water and conductivity was measured using conductivity meter. The samples were kept overnight. After 24 hours, conductivity was again measured. Then samples were heated. Then again conductivity was measured. Per cent leakage was calculated by using formula:

$$\text{Per cent leakage} = [(C_A - C_B)/C_A] \times 100$$

(Where C_A = conductivity after heating; C_B = conductivity before heating)

3.1.2. Anatomical observations:

The anatomical structure of root was studied in seedlings at 40 days after seeding. The seedlings were uprooted and washed under running tap water. Root samples were cut into 1 cm pieces. These samples were kept in 2.5% glutaraldehyde solution for 24 hours. The

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samples were then washed three times with 0.2M calcol (CaCo) buffer solution by keeping the samples in this sol for 15 min. in refrigerator during each washing. Thereafter, the samples were dipped in 1% Osmium tetroxide (OsO₄) for 2-3 hours in refrigerator (or till the samples had blackened enough). Again the samples were washed three times with 0.2M Calcol. The samples were then dehydrated by passing them through a series of alcohol concentrations (viz. 30%, 50% and 70%) soaking for 20 minutes at each concentration. These dehydration steps were conducted in refrigerator. For further dehydrations, the samples were moved to room temperature and passed through further series of alcohol concentration (viz. 90%, 95%, and 100%) soaking for 20 minutes. In 100% alcohol the process was repeated three times. The alcohol was evaporated by placing the samples in desiccators. Thereafter, the samples on a plate (called stubplate) with markers and subjected to stubbing. The samples were scanned under scanning electron microscope.

3.1.3 Observations at harvest

i. Above-ground biomass

It was determined by taking the weight of above-ground dry straw along with the panicle from the plants cut from 0.5m row. The above-ground biomass was expressed as g/plant.

ii. Total number of tillers per 0.5m row

Half meter row was marked using a meter scale and total number of tillers (tillers having panicles as well as tillers without panicles) were counted manually from this marked half meter row from two replications of each RIL.

iii. Number of fertile tillers per 0.5m row

It was determined by counting number of tillers bearing panicles in a half meter row marked by using a meterscale.

iv. Spikelets per panicle

Panicles from five randomly selected plants were collected from each RIL and number of spikelets was counted from each panicle of five plants.

v. Sterile grains per panicle

Panicles from five randomly selected plants were collected. Then those panicles were threshed manually and grains were separated. Fertile and sterile grains were separated. Total number of grains, total fertile grains and number of sterile grains were counted.

vi. Grain filling %age

Panicles from five randomly selected plants were collected. Then those panicles were threshed manually and grains were separated. Fertile and sterile grains were separated. Total number of grains, total fertile grains and number of sterile grains (blank) recorded.

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Grain filling percentage was calculated by using formula given below and expressed in %age:

$$[\text{No. of filled grains} / (\text{No. of filled grains} + \text{blanks})] \times 100$$

vii. Grain yield per 0.5m row

Plant were cut at ground level from half meter row and panicles were threshed manually. Grains were weighed and yield was recorded.

viii. Harvest index:

Harvest index (HI) is the physiological efficiency of plant to convert fraction of photoassimilates into grain yield. The harvest index was calculated as the ratio of grain yield to biological yield and expressed in percentage (Donald and Hamblin 1976).

$$\text{Harvest index (HI)} = (\text{Grain yield} / \text{Biological yield}) \times 100$$

ix. 1000 Grain weight

It was determined by counting thousand grains from each RIL and then weighed.

3.1.4. Biochemical observations

The following parameters were analysed from pooled leaf sample at vegetative (40DAS) and from pooled leaf samples at reproductive stages (50% anthesis stage).

i. Total soluble sugars (Dubois *et al* 1956)

Total soluble sugars were estimated in leaves as per Dubois *et al* (1956).

Principle: Sugars react with concentrated sulphuric acid to form a dehydration product i.e., furfural or 5-hydroxymethyl furfural. This dehydration product then reacts with phenol which acts as chromophore and gives orange yellow colour.

Reagents: Solution A: Phenol (5%)

Solution B: Chilled concentrated H₂SO₄

Extraction: Dried leaf material (100mg) was homogenized in 5 ml of ethyl alcohol (80%) with the help of pestle mortar, followed by centrifugation at 5000 rpm. The supernatant was collected, and then residue was again extracted in 3 ml of ethyl alcohol (80%) and recentrifuged. Then the supernatant was heated to evaporate ethyl alcohol and the final volume was adjusted to 10 ml with extraction medium which served as sugar extract.

Colour development: Extract (1.0ml) was taken in test tube and 1 ml of phenol (5%) was added to it. After 5 minutes, chilled conc. H₂SO₄ (5ml) was added slowly and was stirred continuously. After 10 minutes the tubes were cooled at room temperature under running water and optical density (OD) of greenish brown colour developed was recorded at 490 nm in spectrophotometer. Distilled water was used as blank. The quantity of sugars was

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calculated against the standard curve prepared by using pure glucose (10-100 μ g) and expressed as mg g⁻¹ dry weight.

ii. **Total starch (Dubois *et al* 1956)**

Total starch was estimated in leaves as per Dubois *et al* (1956).

Reagents: Solution A: Phenol (5%)

Solution B: Chilled concentrated H₂SO₄

Solution C: Perchloric acid (52%)

Extraction: Dried leaf material (100 mg) was homogenized in 5 ml of ethyl alcohol (80%) with the help of pestle mortar, followed by centrifugation at 5000 rpm. The residue was collected, and then residue was again extracted in 3 ml of 80% ethyl alcohol and recentrifuged. Then the residue was washed two-three times with distilled water. Added 5 ml of distilled water and boiled it. Added 6.5 ml 52% perchloric acid. Samples were kept at 0^o C for 20 minutes. Centrifuged it. Supernatant was collected. Final volume was made 10 ml with distilled water.

Colour development: 1 ml of extract was taken in test tube and 1 ml of 5 percent phenol was added to it. After 5 minutes, 5 ml of reagent B was added slowly and was stirred continuously. After 10 minutes the tubes were cooled at room temperature under running water and optical density (OD) of greenish brown colour developed was taken at 490 nm in spectrophotometer. Distilled water was used instead of extract in blank. The quantity of starch was calculated against the standard curve prepared by using pure glucose (10-100 μ g) and expressed as mg g⁻¹ dry weight.

iii. **Total soluble proteins (Lowry *et al* 1951)**

Total soluble proteins (mg g⁻¹ dry weight) were estimated in leaves as per Lowry *et al* (1951).

Principle: Protein (peptide bonds) in sample reacts with copper tartarate complex in alkaline solution. The protein-copper complex then reduces phosphomolybdate of folin reagent to a blue-coloured complex having maximum absorbance at 620nm.

Reagents: Solution A: 2% Na₂CO₃ in 0.1 NaOH

Solution B: 0.5% CuSO₄.5H₂O in 1% sodium potassium tartarate

Solution C: prepared by mixing 50 ml of reagent A and 1 ml of solution B. This reagent was freshly prepared at the time of use.

Solution D: Folin-Ciocalteu phenol reagent and distilled water were added in equal quantity at the time of use.

Solution E: standard protein solution: Bovine serum albumin (BSA)

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Extraction: 100 mg of dry material was homogenized in 5 ml of 0.1 N NaOH followed by centrifugation at 3000 rpm for 10 minutes. Supernatant was collected. Residue was again extracted with 3ml of 0.1 ml NaOH and recentrifuged. Final volume was adjusted to 10 ml. 1 ml of 15%TCA was added to 2 ml of supernatant in order to precipitate the protein fraction of extract and kept at 4°C for 24 hours. Mixture was centrifuged at 5000 rpm for 20 minutes to separate precipitated protein. Precipitates were dissolved in 5 ml of 0.1 N NaOH and allowed to stand for 2 hours.

Estimation: 5 ml of reagent E was added to the test tube containing 0.2 ml protein suspension (in 0.1N NaOH) and were allowed to stand for 10 minutes. Then added 0.5 ml of reagent C and mixed immediately. Allowed to stand at room temperature for 30 minutes and read the absorbance of blue colour at 520 nm against blank 0.1 N NaOH. The protein was quantified from the standard curve prepared by using Bovine serum albumin (BSA).

iv. **Proline content (Bates 1973)**

Proline content was estimated in leaves at two stages.

Reagents: Acid ninhydrin

Extraction mixture (Methanol (12 ml) + Chloroform (5 ml) + distilled water (1 ml)).

Extraction: 100mg of dried tissue was homogenized in 6 ml of extraction mixture. Centrifuged at 500 rpm for 10 minutes. To the residue added 4 ml of extraction mixture and recentrifuged. Total volume of supernatant was 10 ml

Estimation: Acid ninhydrin was prepared by dissolving 125 mg of ninhydrin in 3ml of acetic acid and 2 ml of orthophosphoric acid. Kept at 70 °C to get clear solution. 10 ml of extraction mixture was put into a separating funnel and 6 ml of chloroform and 4 ml of distilled water was added to the funnel. Then shaken gently. It was kept undisturbed for 15 minutes. Upper layer was collected and lower layer was rejected. Final volume of upper layer was made 10 ml by adding distilled water. To 5 ml of this added 2.5 ml of acid ninhydrin. Boiled at 100°C for 45 minutes. Cooled and again shifted to the separating funnel and to this 5 ml of benzene was added and shaken. Kept for 10 minutes. Upper layer was collected and lower layer was rejected. Absorbance of upper layer was read at 515 nm

From harvested seed

v. **Storage proteins (Lowry *et al* 1951)**

Storage proteins from seeds were calculated as per Lowry et al (1951) as discussed in total soluble proteins in leaves.

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vi. Total free amino acids (Lee and Takahashi 1956)

Total free amino acids were estimated in seeds.

Principle: The amino-group in amino acid reduces ninhydrin, thus giving rise to ammonia carbon-dioxide and an aldehyde. This reduced purple-violet coloured complex having maximum absorbance at 570nm.

Reagents: 1) Citrate buffer: 14.84 ml of 0.5M citric acid solution was added in 35.15 ml of 0.5M sodium citrate solution and volume was made 100 ml and pH was adjusted to 5.5

2) Ninhydrin solution: 1% Ninhydrin solution was prepared in 0.5M citrate buffer.

3) Pure glycerol

4) Ninhydrin solution was mixed with glycerol and citrate buffer in ratio of 5:12:2

Colour development: 0.2 ml of extract was taken and 3.8 ml of ninhydrin citrate and glycerol mixture was added. Then content were heated in boiling water bath for 20 minutes and cooled at room temperature. Blue colour was developed and absorbance was measured at 570nm. The quantity of total free amino acid was calculated from standard curve prepared by using glycine.

vii. Total nitrogen content (Micro Kjeldahl method)

It was determined in seeds by Micro Kjeldahl method.

Principle: N was converted into $(\text{NH}_4)_2\text{SO}_4$ by digestion with concentrated H_2SO_4 in presence of digestion mixture. The clear digested solution was distilled with excess alkali and liberated NH_3 was collected in boric acid and was back titrated with standard HCL, using mixed indicator.

Reagents: Digestion mixture ($\text{K}_2\text{SO}_4:\text{CuSO}_4:: 10:1$ W/W)

H_2SO_4 (concentrated)

N/100HCL

4% Boric acid

40% NaOH

Mixed indicator – Bromocresol green (0.5g) and methyl red (0.1g) dissolved in 100 ml of 95% alcohol and pH adjusted to 4.5 with diluted HCL.

Estimation: 0.5 g of dried sample was taken in digestion flask and 2 g of digestion mixture, 10 ml of conc. H_2SO_4 was added. The flasks were heated till clear solution was obtained. After cooling, 50 ml volume was made with distilled water. 5 ml of aliquot was distilled in microkjeldahl distillation apparatus with 5 ml of 40% NaOH. The liberated NH_3 was trapped in 20 ml boric acid containing 2-3 drops of mixed indicator. About 10 ml of distillate was

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collected in 250 ml conical flask and titrated with N/100 HCL till end point (pink to yellow).

A blank without sample was also run simultaneously.

N content was calculated according to the following formula:

$$\% \text{ N in sample} = \frac{(T - B) \times 0.00028 \times V}{V_2 \times S} \times 100$$

(Where, T = Volume of N/100 HCL used for sample titration; B = Volume of N/100 HCL used for blank titration; S = Sample weight (g); V_1 = Total volume made; V_2 = Volume used for distillation)

3.2 Experiment No.2

Name of experiment: Identification of morpho-physiological and biochemical traits correlated with yielding ability in direct seeded rice.

A Recombinant Inbred Line (RIL) population generated from a cross PR 120 x UPLRi 7 from School of Agricultural Biotechnology was selected for crop season 2013. The experiment was planted in two sets, one for direct seeded aerobic conditions and the second for conventional transplanted method (control). APO, CT-6510-24-1-2 and IR64 were used as checks. Parents of the cross were also planted. The selected RILs were planted in a randomized block design (RBD). The experiment was replicated twice.

Total Number of Treatments : 202+2+3 = **207**

(RILs + Parents + Checks)

Number of replications : 2

Total Number of Plots : **414**

Design : Randomized Block Design (RDB)

Likewise, a similar set was planted for control (conventional transplanted method)

Observations recorded

3.2.1 Physiological observations

The observations were recorded from five tagged plants from each plot at vegetative and reproductive stages following the same procedure as experiment no.1

- i. Plant height (cm)
- ii. Dry matter accumulation (g)
- iii. Crop growth rate (CGR)

3.2.2 Observations at harvest

- i. Above-ground biomass
- ii. Total number of tillers per 0.5m row

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- v. Sterile grains per panicle
- vi. Grain filling %age:
- vii. Grain yield per 0.5m row
- viii. Harvest index:

3.2.3. Biochemical observations

The following parameters were analysed from pooled leaf sample at vegetative (40DAS) and from pooled leaf samples at reproductive stages (50% anthesis stage).

- i. Total soluble sugars
- ii. Total starch
- iii. Total soluble proteins
- iv. Proline content

From harvested seed

- v. Storage proteins
- vi. Total free amino acids

References:

- Anonymous (2012) Package of practices for kharif crops of Punjab. pp1-17, Punjab Agricultural University, Ludhiana.
- AOAC (1970) *Official Methods of Analysis of Association of official Analytic Chemists*. pp127-12911th edition, Washington D C..
- Bates L S, Waldren R and Pand-Teare I D (1973) Rapid determination of free proline for water stress studies. *Plant Soil* **39**: 205-07.
- Costa C, Dwyer L M, Dutilleul P, Stewart D W, Ma B L and Smith D L (2001) Interrelationship of applied nitrogen , SPAD and Yield of leafy and non-leafy maize genotypes. *J Plant Nutr* **24**: 1173-94.
- Deshmukh P S , Sairam R F and Shukla D S (1991) Measurement of ion leakage as a screening technique for drought resistance in wheat genotypes. *Indian J Plant Physiol* **34**: 89-91.
- Donald C M and Hamblin J (1976) The biological yield and harvest index of cereals as agronomic and plant breeding criteria.pp- 361-405. *In Adv Agron.* **28**: News (eds).
- Dubois M, Giles K A, Hamilton J K, Roberes P A and Smith F (1956) Colorimetric method for determination of sugars and related substances. *Anal Chem* **28**:350-56.
- Dwyer L M , Anderson A M , Ma B L , Stewart D W , Tollenaar M and Gregorich E (1995) Quantifying the nonlinearity in chlorophyll meter response to corn leaf nitrogen accumulation. *Canadian J Plant Sci* **75**: 179-82.
- Lee Y P and Takahashi T (1956) An improved calorimetric determination of amino-acids with the use of ninhydrin. *Ann Biochem* **14**: 71-77.

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Lowry O H , Rosenbrough N J , Farr A L and Randell R J (1951) Protein measurement with folin-phenol reagent. *J Biol Chem* **193**: 265.

Montgomery E G (1911) Correlation studies in corn. *Neb Agric Exp Stn Annu Rep* **24**: 108-59.

Radford P J (1967) Growth analysis formulae-their use and abuse. *Crop Sci* **7**: 171-73.

Watson D J (1952) The physiological basis of variation in yield. *Annal Bot* **4**: 101-45.

Wiangsamut B , Mendoza C T and Lafarge A T (2006) Growth dynamics and yield of rice genotypes grown in transplanted and direct-seeded fields. *J of Agric Tech* **2** : 299-316.

Appendix-II

Meteorological Data for the First crop year (2012)

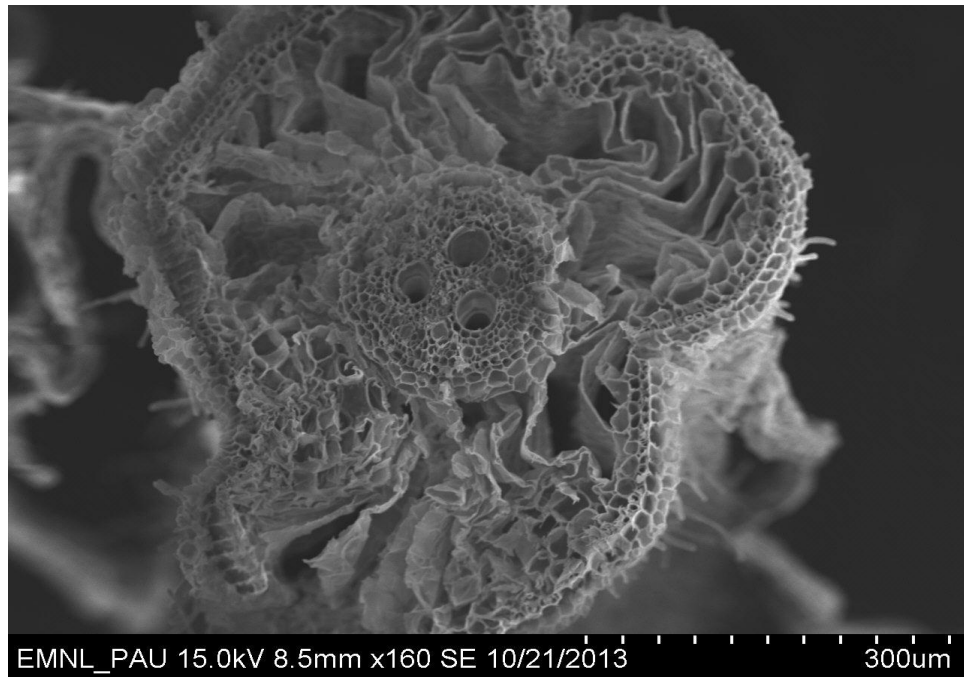
	Average Temperature	Relative Humidity (%)	Rainfall (mm)	Evaporation (mm)	Sunshine hours	Wind velocity (km per hr)
Ist week	27.1	35	0.0	51.4	10.0	4.4
IIInd week	31.1	35	0.0	64.2	9.1	5.2
IIIrd week	31.7	34	1.6	66.3	7.1	5.1
IVth week	32.0	31	0.0	72.4	9.8	6.1
Mean May 2012	31.1	33	1.6	295.9	9.7	5.2
Ist week	34.8	31	0.0	80.0	10.9	4.9
IIInd week	32.3	45	0.0	66.8	7.2	7.0
IIIrd week	33.9	42	0.0	88.0	11.4	6.6
IVth week	35.0	45	2.0	75.0	8.3	6.8
Mean June 2012	33.9	45	3.5	58.3	8.9	6.2
Ist week	33.6	51	0.0	70.3	8.7	5.4
IIInd week	32.7	61	9.5	641.0	6.6	10.2
IIIrd week	31.3	67	10.6	38.2	6.2	4.7
IVth week	32.1	62	1.6	48.0	9.3	4.7
Vth week	31.5	75	44.8	38.8	4.9	6.7
Mean July 2012	31.8	67	76.9	212.1	6.6	6.8
Ist week	30.5	73	11.4	35.0	4.7	7.8
IIInd week	30.5	80	24.3	25.3	3.4	3.6
IIIrd week	30.3	79	56.4	26.1	5.9	4.1
IVth week	28.7	84	40.2	25.6	3.3	5.5
Mean Aug. 2012	29.9	80	166.4	120.2	4.5	4.7
Ist week	29.5	80	40.7	21.4	4.1	3.2
IIInd week	29.6	75	18.8	27.9	6.5	4.7
IIIrd week	29.7	76	93.4	22.8	7.1	2.9
IVth week	26.7	81	27.1	22.8	17.9	3.3
Vth week	26.9	71	0.0	28.6	10.2	2.5
Mean Sept.2012	28.4	76	141.7	109.0	7.8	3.3

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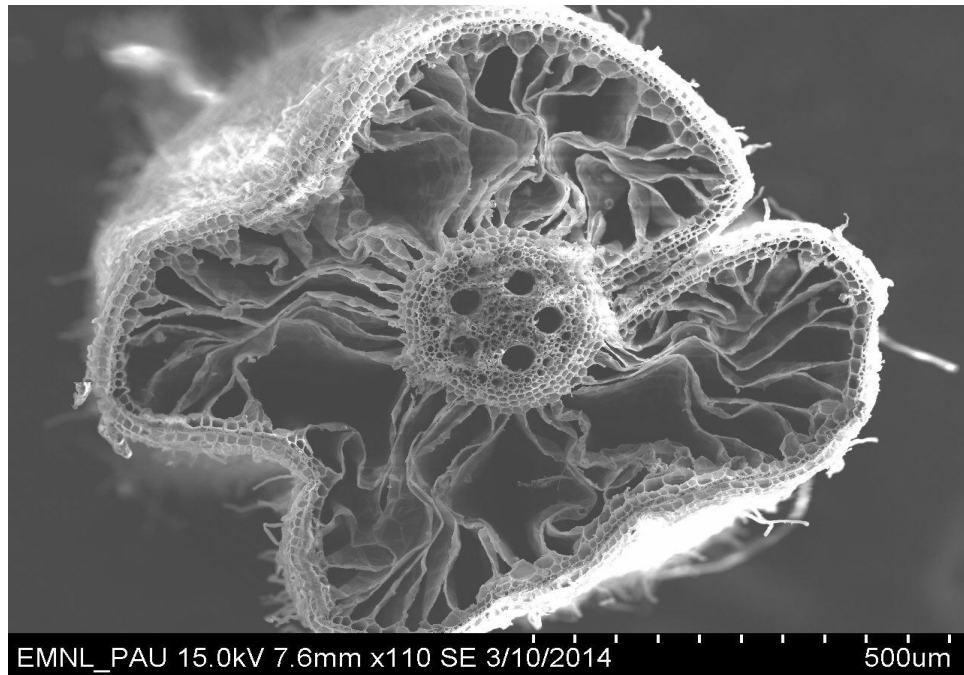
Meteorological Data for the Second crop year (2013)

	Average Temperature	Relative Humidity (%)	Rainfall (mm)	Evaporation (mm)	Sunshine hours	Wind velocity (km per hr)
Ist week	28.9	30	0.0	66.1	10.1	4.9
IIInd week	29.3	42	1.2	60.8	9.1	5.7
IIIrd week	32.3	38	0.0	71.7	9.9	4.6
IVth week	35.5	40	0.0	86.8	8.9	6.2
Mean May 2013	31.8	38	1.2	326.4	9.7	5.7
Ist week	33.2	50	0.0	82.3	9.3	9.1
IIInd week	35.6	52	5.2	65.4	9.8	10.1
IIIrd week	27.6	78	237.7	22.0	6.6	7.9
IVth week	32.7	59	0.0	49.5	9.6	5.1
Mean June 2013	31.9	65	296.4	246.4	7.5	8.3
Ist week	30.7	71	53.8	44.8	7.8	7.7
IIInd week	31.7	73	12.6	37.1	4.0	8.3
IIIrd week	31.0	73	31.5	36.1	7.2	6.2
IVth week	30.7	74	2.2	31.7	5.3	6.9
Vth week	31.8	73	34.4	39.4	8.7	5.7
Mean July 2013	31.3	73	111.0	155.3	6.5	6.5
Ist week	30.4	78	78.4	23.8	6.0	5.3
IIInd week	29.3	83	66.8	17.7	5.7	3.4
IIIrd week	28.4	83	130.6	18.8	4.2	6.3
IVth week	30.8	76	4.5	31.0	6.5	1.3
Mean Aug. 2013	29.7	79	252.1	107.2	5.4	3.7
Ist week	30.4	73	3.2	32.2	9.2	1.8
IIInd week	29.8	76	12.2	31.3	7.9	1.1
IIIrd week	29.3	71	0.0	30.8	8.7	1.4
IVth week	28.1	72	0.0	27.8	8.7	1.9
Mean Sept.2013	28.2	72	25.3	27.8	8.7	1.9

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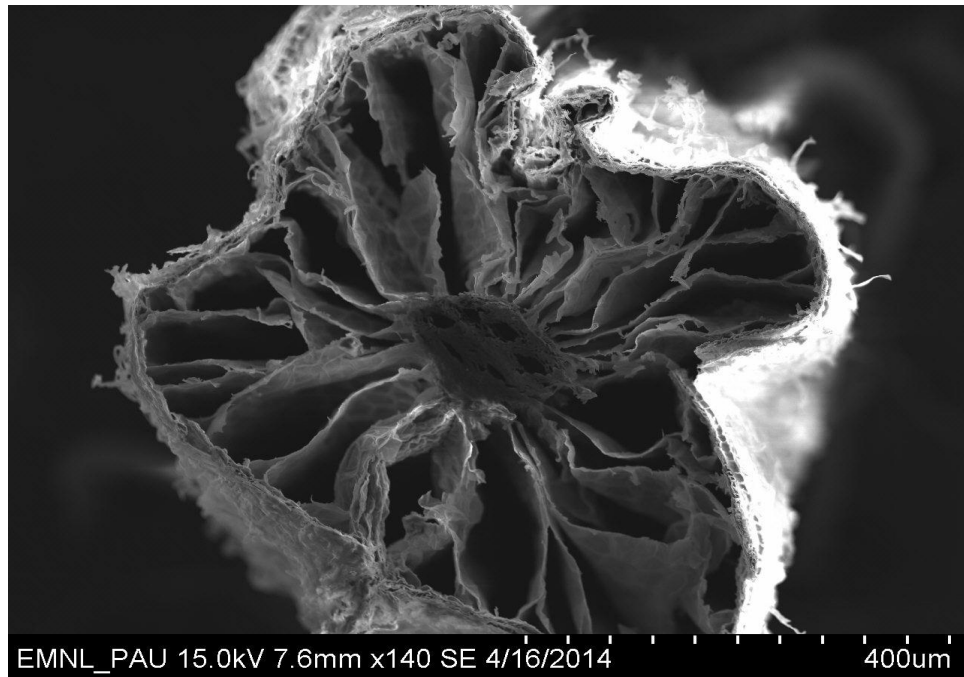
T.S. PR120 (Parent) under direct-seeded aerobic conditions



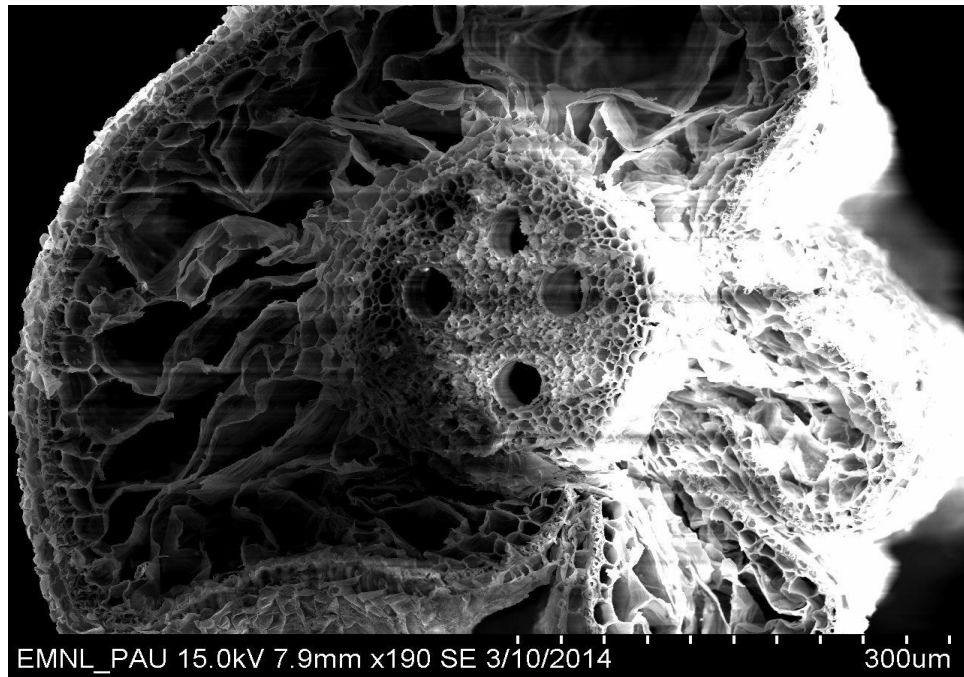
T.S. PR120 (Parent) under conventional transplanted condition

Plate 1. Effect of sowing methods (direct-seeded aerobic and conventional transplanted) on proportion of aerenchyma tissue in thickest root at 40 DAS in PR120 (T.S. was cut at 1 cm from the base).

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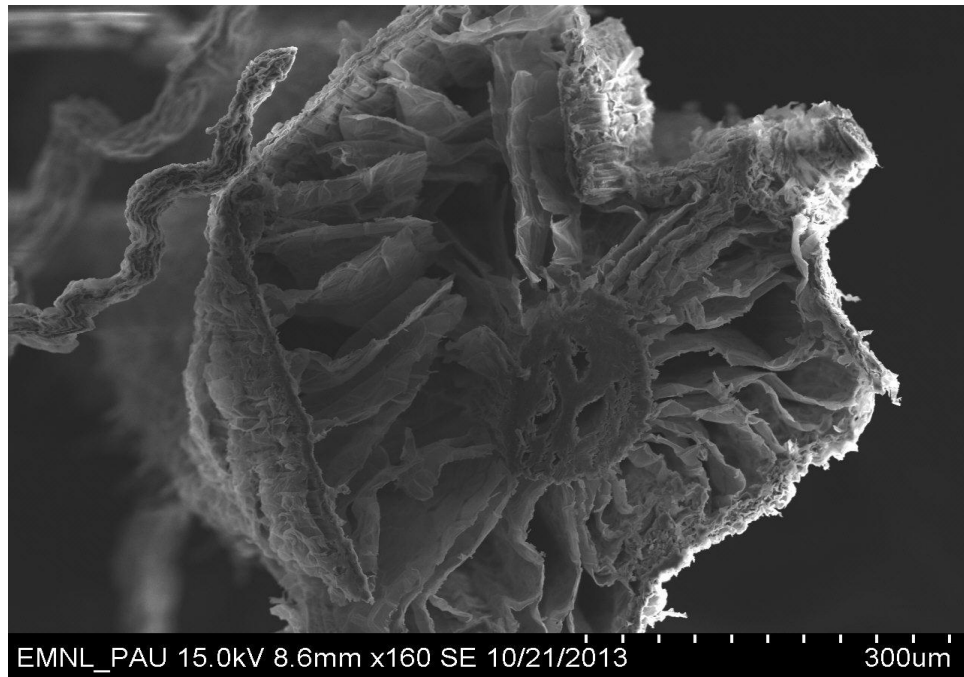
T.S. UPLRi7 (Parent) under direct-seeded aerobic conditions



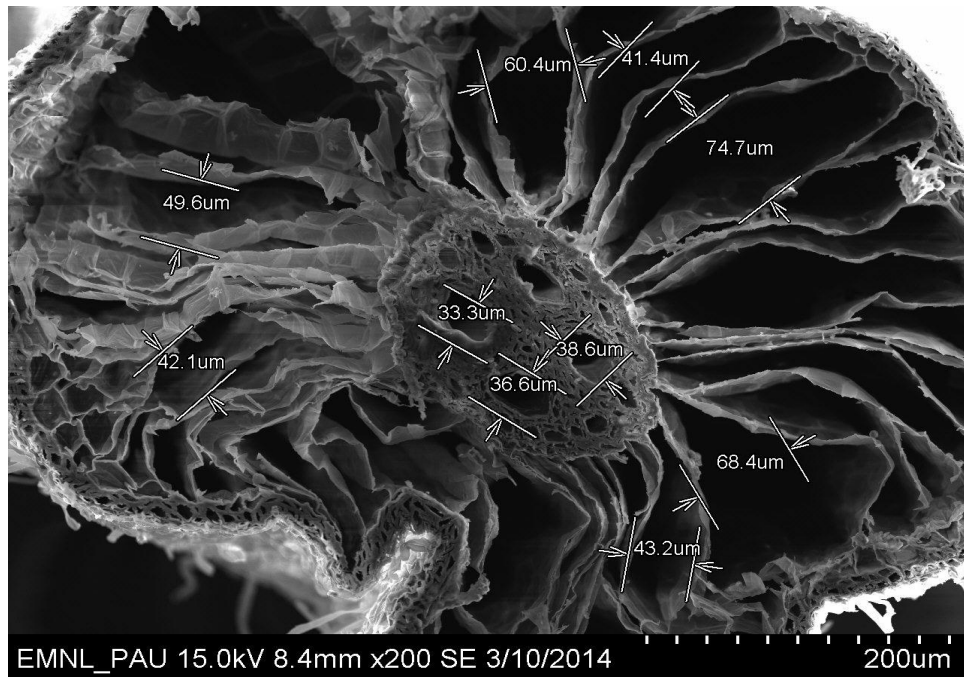
T.S. UPLRi7 (Parent) under conventional transplanted conditions

Plate 2. Effect of sowing methods (direct-seeded aerobic and conventional transplanted) on proportion of aerenchyma tissue in thickest root at 40 DAS in UPLRi7 (T.S. was cut at 1 cm from the base).

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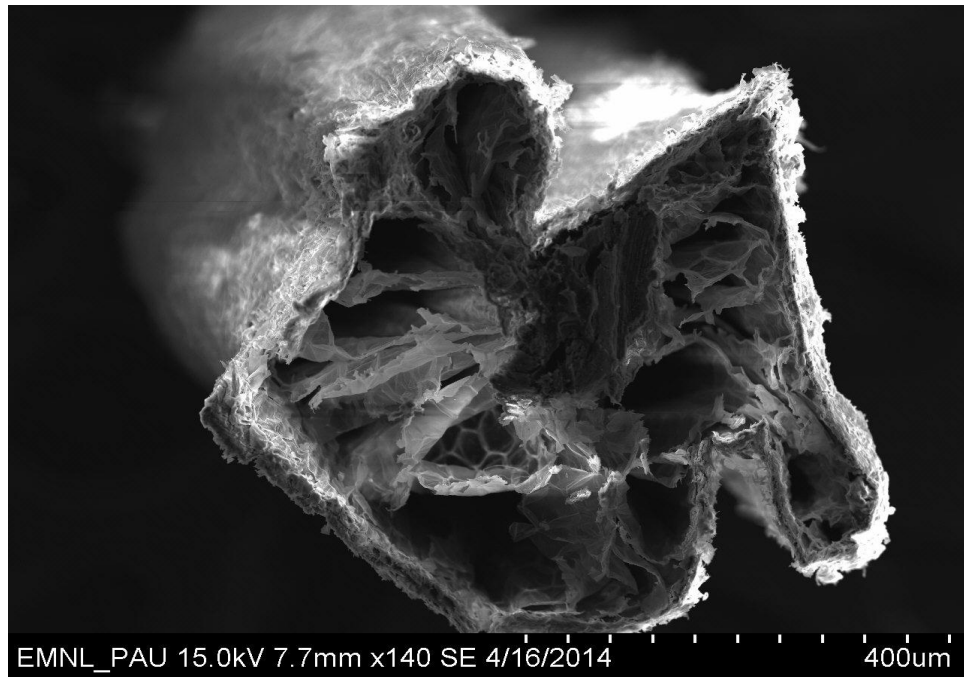
T.S. Ae-RIL-B-42(high-yielding RIL) under direct-seeded aerobic conditions



T.S. Ae-RIL-B-42(high-yielding RIL) under conventional transplanted conditions

Plate 3. Effect of sowing methods (direct-seeded aerobic and conventional transplanted) on proportion of aerenchyma tissue in thickest root at 40 DAS in Ae-RIL-B-42(high-yielding RIL) (T.S. was cut at 1 cm from the base).

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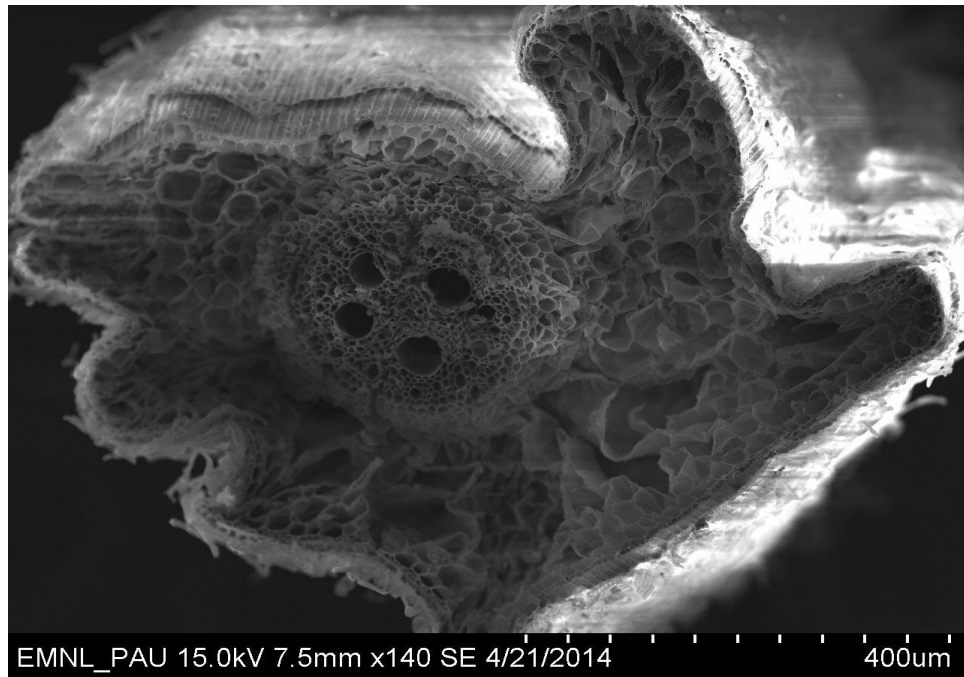
T.S. Ae-RIL-B-44(high-yielding RIL) under direct-seeded aerobic conditions



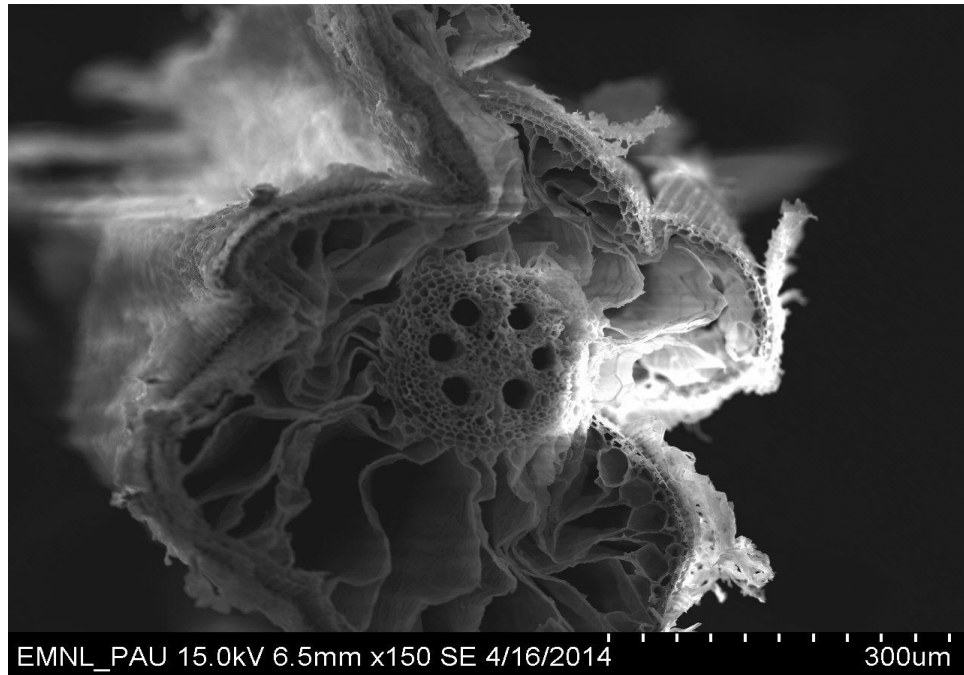
T.S. Ae-RIL-B-44(high-yielding RIL) under conventional transplanted conditions

Plate 4. Effect of sowing methods (direct-seeded aerobic and conventional transplanted) on proportion of aerenchyma tissue in thickest root at 40 DAS in Ae-RIL-B-44(high-yielding RIL) (T.S. was cut at 1 cm from the base).

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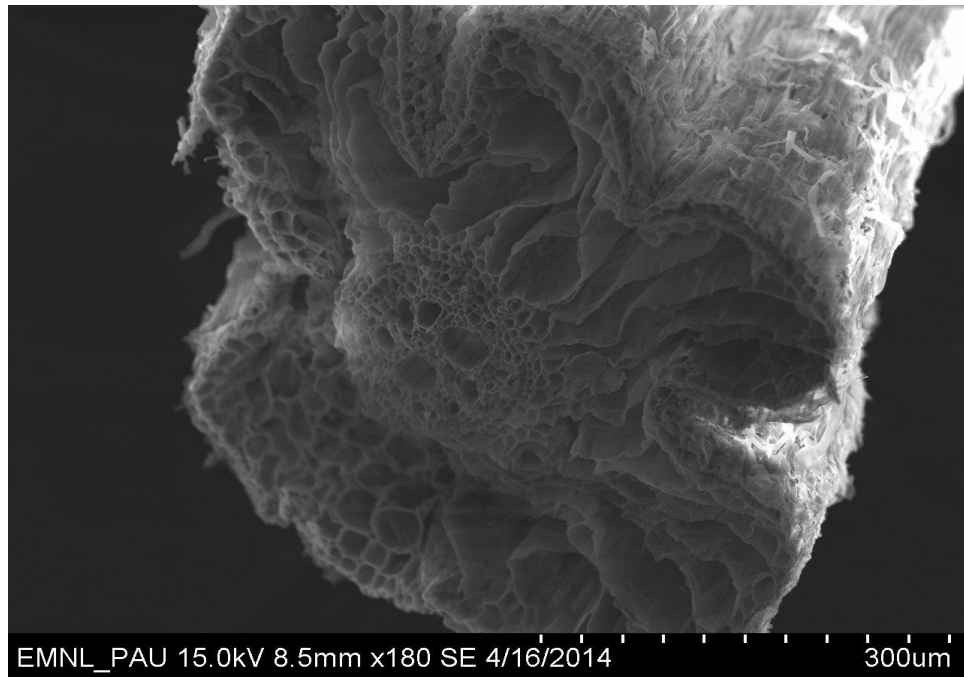
T.S. Ae-RIL-B-7(Low-yielding RIL) under direct-seeded aerobic conditions



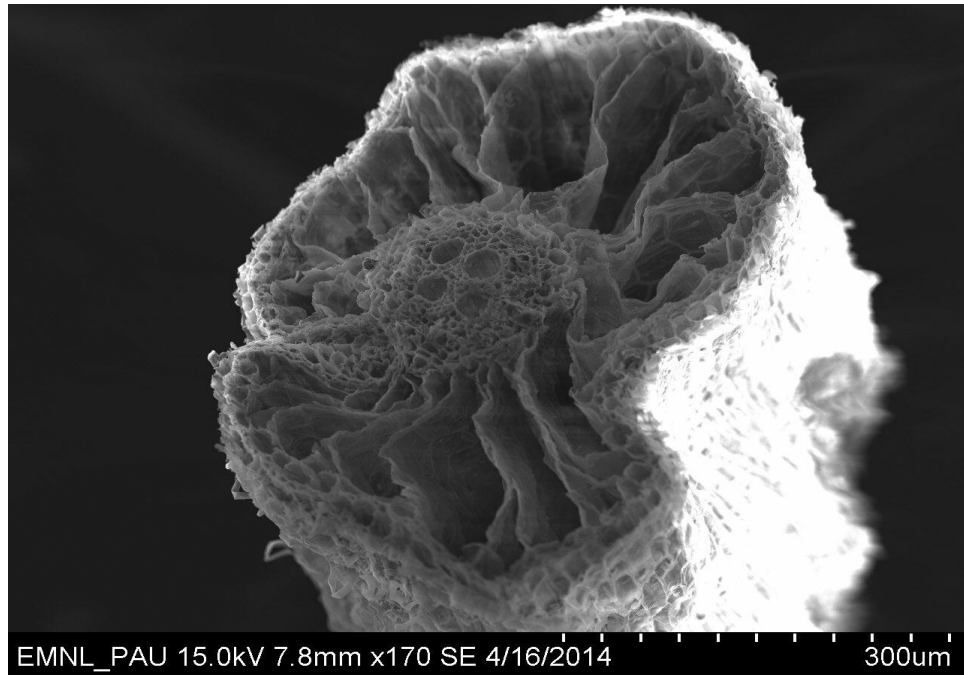
T.S. Ae-RIL-B-7(Low-yielding RIL) under conventional transplanted conditions

Plate 5. Effect of sowing methods (direct-seeded aerobic and conventional transplanted) on proportion of aerenchyma tissue in thickest root at 40 DAS in Ae-RIL-B-7(low-yielding RIL) (T.S. was cut at 1 cm from the base).

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T.S. Ae-RIL-B-117(Low-yielding RIL) under direct-seeded aerobic conditions



T.S. Ae-RIL-B-117 (Low-yielding RIL) under conventional transplanted conditions

Plate 6. Effect of sowing methods (direct-seeded aerobic and conventional transplanted) on proportion of aerenchyma tissue in thickest root at 40 DAS in Ae-RIL-B-117(low-yielding RIL) (T.S. was cut at 1 cm from the base).

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Table 1: Effect of sowing methods (direct-seeded aerobic and conventional transplanted) on crop growth rate (CGR) and relative growth rate (RGR) at vegetative (40DAS) and reproductive (50%anthesis) stage in a recombinant inbred line (RIL) population of rice (2012).

RILs	CGR (g plant ⁻¹ day ⁻¹)				RGR (g plant ⁻¹ day ⁻¹)			
	Aerobic		Transplanted		Aerobic		Transplanted	
	Vegetative	Reproductive	Vegetative	Reproductive	Vegetative	Reproductive	Vegetative	Reproductive
Ae-RIL-B-7	0.042 _o	0.376 _{kl}	0.875 _{ij}	2.138 _g	0.036	0.077	0.288	0.069
Ae-RIL-B-27	0.156 _{mn}	1.132 _a	0.470 _n	2.469 _c	0.068	0.082	0.212	0.090
Ae-RIL-B-42	0.342 _{ef}	0.692 _e	0.922 _{gh}	1.841 _i	0.108	0.047	0.209	0.061
Ae-RIL-B-44	0.285 _{ghi}	0.466 _i	1.076 _e	1.380 _n	0.109	0.041	0.217	0.049
Ae-RIL-B-82	0.140 _n	0.586 _g	1.364 _a	1.247 _o	0.059	0.062	0.247	0.042
Ae-RIL-B-92	0.323 _{fg}	0.353 _{lm}	1.010 _f	1.364 _n	0.112	0.032	0.246	0.052
Ae-RIL-B-100	0.295 _{gh}	0.270 _{op}	0.763 _k	1.423 _m	0.119	0.029	0.292	0.061
Ae-RIL-B-112	0.281 _{hij}	0.183 _r	1.008 _f	2.220 _{ef}	0.116	0.022	0.281	0.066
Ae-RIL-B-116	0.411 _{cd}	0.216 _{qr}	1.014 _f	2.214 _{ef}	0.136	0.019	0.297	0.066
Ae-RIL-B-117	0.422 _{cb}	0.754 _d	0.846 _j	2.188 _f	0.119	0.044	0.221	0.069
Ae-RIL-B-126	0.147 _n	0.771 _d	0.851 _{ij}	1.851 _i	0.078	0.073	0.289	0.066
Ae-RIL-B-129	0.293 _{gh}	0.763 _d	0.644 _i	1.696 _k	0.114	0.055	0.287	0.071
Ae-RIL-B-132	0.225 _{kl}	0.398 _{jk}	1.202 _{cb}	2.098 _g	0.096	0.042	0.281	0.059
Ae-RIL-B-135	0.399 _{cd}	0.326 _{mn}	1.374 _a	2.361 _d	0.128	0.027	0.337	0.060
Ae-RIL-B-142	0.470 _a	0.299 _{no}	1.150 _d	2.781 _a	0.121	0.022	0.243	0.068
Ae-RIL-B-155	0.297 _{gh}	0.508 _h	0.596 _m	1.791 _j	0.106	0.042	0.231	0.074
Ae-RIL-B-158	0.358 _{ef}	0.640 _f	1.161 _d	1.188 _p	0.095	0.043	0.312	0.046
Ae-RIL-B-171	0.190 _{lm}	0.355 _{lm}	0.933 _g	1.565 _i	0.104	0.045	0.263	0.058
Ae-RIL-B-173	0.380 _{ed}	0.250 _{pq}	1.000 _f	1.717 _k	0.118	0.022	0.295	0.059
Ae-RIL-B-191	0.243 _{jh}	0.840 _c	1.170 _{cd}	2.501 _c	0.119	0.064	0.260	0.065
Parents								
PR120	0.196 _{lm}	0.235 _{pq}	0.939 _g	2.242 _e	0.115	0.034	0.316	0.069
UPLRi7	0.411 _{cd}	0.683 _e	0.669 _i	1.911 _h	0.124	0.043	0.193	0.071
Checks								
APO	0.454 _{ab}	-0.130 _t	0.982 _f	2.607 _b	0.134	-0.016	0.254	0.071
Bas370	0.157 _{mn}	0.924 _b	0.596 _m	1.850 _i	0.071	0.076	0.176	0.072
IR64	0.401 _{cd}	-0.079 _s	0.890 _b	1.571 _{mn}	0.124	-0.010	0.223	0.058
GA2	0.248 _{ijk}	0.425 _j	0.731 _k	1.813 _{ij}	0.079	0.040	0.192	0.066

Similar subscript denotes non-significant differences at 5% probability level according to Duncan's multiple range test.

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Table 2: Dry matter accumulation at vegetative stage (40DAS) as affected by sowing methods (direct-seeded aerobic and conventional transplanted) in a recombinant inbred line (RIL) population of rice (2012).

RILs	Aerobic(g)			Transplanted(g)		
	Stem	Root	Leaf	Stem	Root	Leaf
Ae-RIL-B-7	0.24	0.24	0.55	0.20	0.20	0.32
Ae-RIL-B-27	0.21	0.27	0.88	0.18	0.33	0.47
Ae-RIL-B-42	0.17	0.33	0.73	0.46	0.89	0.85
Ae-RIL-B-44	0.26	0.27	0.48	0.44	0.55	0.95
Ae-RIL-B-82	0.29	0.38	0.93	0.46	0.40	0.80
Ae-RIL-B-92	0.27	0.25	0.51	0.25	0.74	0.70
Ae-RIL-B-100	0.20	0.21	0.40	0.14	0.23	0.30
Ae-RIL-B-112	0.23	0.06	0.38	0.19	0.25	0.46
Ae-RIL-B-116	0.19	0.15	0.40	0.16	0.12	0.39
Ae-RIL-B-117	0.24	0.23	0.63	0.31	0.41	0.73
Ae-RIL-B-126	0.26	0.21	0.53	0.13	0.18	0.37
Ae-RIL-B-129	0.17	0.14	0.49	0.11	0.10	0.28
Ae-RIL-B-132	0.26	0.45	0.52	0.30	0.38	0.47
Ae-RIL-B-135	0.23	0.25	0.44	0.15	0.16	0.35
Ae-RIL-B-142	0.27	0.38	0.65	0.42	0.43	0.68
Ae-RIL-B-155	0.12	0.46	0.70	0.22	0.47	0.44
Ae-RIL-B-158	0.47	0.52	0.81	0.23	0.49	0.31
Ae-RIL-B-171	0.23	0.20	0.31	0.25	0.28	0.47
Ae-RIL-B-173	0.25	0.25	0.56	0.25	0.22	0.31
Ae-RIL-B-191	0.20	0.16	0.30	0.36	0.52	0.58
Parents						
PR120	0.14	0.14	0.29	0.07	0.11	0.34
UPLRi7	0.26	0.23	0.50	0.38	0.32	0.76
Checks						
APO	0.16	0.26	0.50	0.22	0.46	0.63
Bas370	0.31	0.17	0.68	0.33	0.45	0.92
IR64	0.09	0.25	0.64	0.42	0.84	0.65
GA2	0.30	0.47	1.00	0.56	0.72	0.69

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Table 3: Dry matter accumulation at reproductive (50%anthesis) stage as affected by sowing methods (direct-seeded aerobic and conventional transplanted) in a recombinant inbred line (RIL) population of rice (2012).

RILs	Aerobic(g)				Transplanted(g)			
	Stem	Root	Leaf	Panicle	Stem	Root	Leaf	Panicle
Ae-RIL-B-7	5.65	4.77	2.68	2.68	34.53	21.08	23.60	15.27
Ae-RIL-B-27	18.10	9.08	10.82	3.58	39.07	19.08	24.27	16.07
Ae-RIL-B-42	14.79	9.07	6.31	3.92	32.70	15.35	19.82	13.24
Ae-RIL-B-44	10.46	6.00	5.92	1.69	24.49	7.00	16.40	12.66
Ae-RIL-B-82	11.55	8.49	6.33	0.79	24.29	8.81	16.03	12.00
Ae-RIL-B-92	8.86	6.10	5.49	1.71	23.51	5.70	15.82	12.63
Ae-RIL-B-100	7.85	3.19	3.79	1.60	22.85	8.68	17.23	10.66
Ae-RIL-B-112	7.03	8.36	2.58	1.19	37.17	6.64	21.40	18.78
Ae-RIL-B-116	9.01	17.62	4.83	0.37	37.12	7.42	21.30	18.70
Ae-RIL-B-117	18.59	8.78	7.67	1.90	38.02	9.46	22.24	14.87
Ae-RIL-B-126	14.92	3.03	6.71	1.38	31.50	7.38	20.35	12.70
Ae-RIL-B-129	14.72	10.59	5.36	5.53	27.48	6.23	18.40	11.83
Ae-RIL-B-132	8.45	4.68	3.96	2.82	40.02	12.92	23.66	12.06
Ae-RIL-B-135	13.45	5.77	2.53	0.82	45.66	12.42	24.95	14.44
Ae-RIL-B-142	10.80	10.70	5.44	1.56	50.69	12.46	29.67	15.66
Ae-RIL-B-155	10.87	6.85	6.45	2.13	27.98	4.83	18.75	13.63
Ae-RIL-B-158	14.61	9.46	5.18	4.66	20.91	7.62	13.78	13.10
Ae-RIL-B-171	9.81	7.56	1.89	1.53	24.10	7.11	20.14	12.75
Ae-RIL-B-173	8.97	4.34	3.77	1.91	27.64	8.18	21.01	13.41
Ae-RIL-B-191	16.74	5.58	7.51	2.12	47.71	8.55	23.24	16.73
Parents								
PR120	6.82	2.59	2.33	1.08	37.19	13.72	25.62	14.27
UPLRi7	13.92	18.70	7.69	4.45	29.50	16.61	21.11	14.56
Checks								
APO	3.75	1.87	1.80	0.94	45.69	13.61	27.09	16.08
Bas370	18.42	9.52	6.53	2.29	31.50	7.40	19.40	11.80
IR64	3.81	3.98	2.28	0.69	26.62	8.59	18.11	12.38
GA2	9.25	18.03	6.10	1.54	28.76	5.80	18.50	15.70

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Table 4: Effect of sowing methods (direct-seeded aerobic and conventional transplanted) on canopy height and leaf area at vegetative (40DAS) and reproductive (50%anthesis) stage in a recombinant inbred line (RIL) population of rice (2012).

RILs	Canopy height(cm)				Leaf area(cm ²)			
	Aerobic		Transplanted		Aerobic		Transplanted	
	Vegetative	Reproductive	Vegetative	Reproductive	Vegetative	Reproductive	Vegetative	Reproductive
Ae-RIL-B-7	35.10def	73.00	46.00	110.20	9.88	23.25	14.37	178.40
Ae-RIL-B-27	41.80a-e	73.20	34.00	101.80	18.42	41.49	25.35	743.55
Ae-RIL-B-42	47.00abc	112.00	53.00	133.40	364.29	28.26	26.21	47.74
Ae-RIL-B-44	50.30a	11.20	44.00	145.20	14.39	37.28	17.05	167.95
Ae-RIL-B-82	49.80a	94.00	50.00	143.50	14.65	41.94	35.83	42.44
Ae-RIL-B-92	46.00abc	118.80	51.00	147.20	23.51	64.89	28.06	63.10
Ae-RIL-B-100	39.60b-e	68.00	42.00	90.00	11.83	40.60	11.32	59.78
Ae-RIL-B-112	40.20a-e	99.00	43.00	118.40	9.10	36.64	20.51	51.22
Ae-RIL-B-116	42.50a-d	110.00	41.00	120.10	17.20	57.25	22.18	64.64
Ae-RIL-B-117	46.10abc	89.00	50.00	136.50	17.32	38.70	21.70	51.96
Ae-RIL-B-126	41.60a-e	87.50	54.00	106.40	12.48	39.68	17.72	40.62
Ae-RIL-B-129	44.50a-d	117.00	47.00	122.40	17.21	55.33	24.92	44.21
Ae-RIL-B-132	39.40b-e	104.00	49.00	127.80	12.59	22.57	21.79	51.00
Ae-RIL-B-135	40.90a-e	103.00	49.00	145.00	16.72	42.20	24.75	50.70
Ae-RIL-B-142	46.70abc	96.00	42.00	115.10	13.34	45.05	21.93	56.63
Ae-RIL-B-155	27.10f	79.80	36.00	115.80	13.33	39.07	17.60	51.85
Ae-RIL-B-158	43.20a-d	127.00	45.00	135.40	16.31	40.35	20.60	49.20
Ae-RIL-B-171	31.80ef	78.80	42.00	133.30	9.77	52.95	23.93	51.52
Ae-RIL-B-173	38.50def	108.20	42.00	130.10	13.71	57.98	15.92	65.81
Ae-RIL-B-191	43.50a-d	105.10	35.00	139.60	18.10	79.50	19.80	46.83
Parents								
PR120	39.60b-e	92.00	50.00	101.40	9.71	69.08	24.63	50.19
UPLRi7	49.40ab	108.00	46.00	116.20	20.01	70.88	16.83	75.28
Checks								
APO	42.30a-d	110.00	44.00	148.00	23.94	45.60	21.78	893.70
Bas370	41.60a-e	117.00	49.00	124.00	18.02	46.25	26.00	52.69
IR64	28.30f	60.00	43.00	121.30	9.76	39.78	24.05	38.85
GA2	43.60a-d	103.20	36.00	85.00	14.49	54.66	31.83	52.48

Similar subscript denotes non-significant differences at 5% probability level according to Duncan's multiple range test.

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Table 5: Effect of sowing methods (direct-seeded aerobic and conventional transplanted) on membrane integrity and chlorophyll at vegetative (40DAS) and reproductive (50%anthesis) stage in a recombinant inbred line (RIL) population of rice (2012).

RILs	Membrane integrity				Chlorophyll			
	Aerobic		Transplanted		Aerobic		Transplanted	
	Vegetative	Reproductive	Vegetative	Reproductive	Vegetative	Reproductive	Vegetative	Reproductive
Ae-RIL-B-7	75.37	92.92	372.68	235.48	40.50	22.20	59.50	19.80
Ae-RIL-B-27	73.89	200.00	261.29	100.20	37.35	24.70	84.00	3.40
Ae-RIL-B-42	90.89	185.09	326.94	15.91	46.65	13.00	73.70	1.50
Ae-RIL-B-44	57.30	233.89	390.04	13.33	36.15	14.40	84.50	2.00
Ae-RIL-B-82	102.27	101.30	169.38	389.01	31.40	5.50	62.00	1.40
Ae-RIL-B-92	91.38	240.59	401.00	12.63	34.05	3.90	85.50	2.30
Ae-RIL-B-100	110.85	96.24	369.55	235.50	34.90	4.60	60.40	2.00
Ae-RIL-B-112	55.51	91.76	191.78	16.02	18.85	1.90	63.50	1.90
Ae-RIL-B-116	100.20	107.88	264.08	17.65	34.15	4.70	72.50	15.20
Ae-RIL-B-117	111.48	64.26	243.19	102.66	34.15	1.00	65.00	19.10
Ae-RIL-B-126	114.41	71.90	379.32	111.61	9.55	1.70	75.60	6.10
Ae-RIL-B-129	128.54	15.05	483.51	18.47	31.20	16.10	69.80	2.70
Ae-RIL-B-132	79.58	98.55	474.04	263.66	33.40	1.20	89.20	2.80
Ae-RIL-B-135	53.34	87.90	322.72	342.11	32.65	16.20	18.20	15.80
Ae-RIL-B-142	141.41	111.99	381.58	78.05	33.55	12.40	80.30	11.40
Ae-RIL-B-155	149.89	500.00	595.08	125.05	34.85	2.50	87.90	2.10
Ae-RIL-B-158	163.90	129.39	365.04	16.28	58.85	6.20	22.40	22.30
Ae-RIL-B-171	114.42	402.00	450.76	17.21	40.05	17.10	61.40	7.40
Ae-RIL-B-173	67.52	88.99	286.56	110.93	32.55	3.80	67.00	24.00
Ae-RIL-B-191	50.58	96.26	520.92	89.47	30.90	14.80	53.10	3.50
Parents								
PR120	133.16	92.70	256.02	437.32	41.80	25.60	63.60	4.40
UPLRi7	44.64	155.63	203.96	491.98	32.50	22.60	61.80	21.70
Checks								
APO	99.67	209.33	168.09	575.00	36.50	2.90	70.20	6.90
Bas370	186.55	17.09	496.22	19.65	31.05	7.20	62.20	5.00
IR64	74.60	257.99	220.25	99.81	39.90	3.40	61.60	10.30
GA2	60.35	320.51	600.00	462.91	28.25	9.50	60.30	5.00

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Table 6: Effect of sowing methods (direct-seeded aerobic and conventional transplanted) on radiation use efficiency (RUE) at vegetative (40DAS) and reproductive (50%anthesis) stage in a recombinant inbred line (RIL) population of rice (2012).

RILs	Aerobic				Transplanted			
	Vegetative		Reproductive		Vegetative		Reproductive	
	RUE(upper)	RUE(lower)	RUE(upper)	RUE(lower)	RUE(upper)	RUE(lower)	RUE(upper)	RUE(lower)
Ae-RIL-B-7	854a	368c	152	17	706	485	83	5
Ae-RIL-B-27	814cd	299hi	136	30	673	462	83	5
Ae-RIL-B-42	801de	227nm	155	21	648	436	67	7
Ae-RIL-B-44	809cde	205op	147	11	619	471	58	4
Ae-RIL-B-82	777fgh	367c	142	14	599	479	47	3
Ae-RIL-B-92	802de	480a	146	19	603	432	67	5
Ae-RIL-B-100	755h-k	244kl	111	11	647	365	57	6
Ae-RIL-B-112	735klm	418b	137	15	658	328	48	10
Ae-RIL-B-116	774ghi	263j	131	13	594	265	62	2
Ae-RIL-B-117	744jkl	339ef	129	17	991	483	59	8
Ae-RIL-B-126	787efg	295i	109	23	722	344	98	8
Ae-RIL-B-129	728ml	344ef	123	14	714	452	95	7
Ae-RIL-B-132	775f-i	226mn	122	17	679	437	67	4
Ae-RIL-B-135	755h-k	360cd	122	15	661	434	66	2
Ae-RIL-B-142	764hij	256jk	121	12	636	527	73	7
Ae-RIL-B-155	754ijk	308gh	104	23	623	5.4	74	2
Ae-RIL-B-158	725ml	236lm	116	13	602	453	79	7
Ae-RIL-B-171	721m	350de	95	18	606	308	93	9
Ae-RIL-B-173	733klm	365c	115	8	602	434	91	9
Ae-RIL-B-191	753ijk	334f	113	11	627	412	76	2
Parents								
PR120	837ab	341ef	165	36	711	323	109	9
UPLRi7	825bc	312g	158	38	683	582	100	10
Checks								
APO	797def	259j	152	9	612	396	59	9
Bas370	753ijk	194d	123	11	681	515	92	7
IR64	741klm	241l	88	16	680	344	59	5
GA2	746jkl	216no	106	14	683	566	67	10

Similar subscript denotes non-significant differences at 5% probability level according to Duncan's multiple range test.

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Table 7: Yield and yield contributing parameters at harvest stage as affected by sowing methods (direct-seeded aerobic and conventional transplanted) in a recombinant inbred line (RIL) population of rice (2012).

RILs	Aerobic				Transplanted			
	Above ground biomass(g)	Total no. of tillers/ 0.5m row	Spikelets per panicle	Sterile grains per panicle	Above ground biomass(g)	Total no. of tillers/0.5m row	Spikelets per panicle	Sterile grains per panicle
Ae-RIL-B-7	175	58	8	80	350	67	10	165
Ae-RIL-B-27	200	80	10	60	225	54	12	94
Ae-RIL-B-42	250	70	10	65	600	57	10	96
Ae-RIL-B-44	225	60	9	42	350	46	11	42
Ae-RIL-B-82	225	38	9	75	300	52	10	20
Ae-RIL-B-92	200	32	11	103	225	35	10	92
Ae-RIL-B-100	175	55	10	107	225	52	9	55
Ae-RIL-B-112	175	54	11	92	200	35	13	105
Ae-RIL-B-116	200	43	10	95	275	60	10	20
Ae-RIL-B-117	225	37	8	116	225	43	13	48
Ae-RIL-B-126	150	43	11	154	225	46	13	37
Ae-RIL-B-129	300	41	10	125	350	38	12	130
Ae-RIL-B-132	200	42	7	40	300	38	10	30
Ae-RIL-B-135	175	38	8	127	450	41	11	62
Ae-RIL-B-142	300	52	10	102	300	48	13	45
Ae-RIL-B-155	175	57	11	46	225	48	12	70
Ae-RIL-B-158	350	53	10	45	250	35	10	76
Ae-RIL-B-171	175	43	10	149	375	43	10	78
Ae-RIL-B-173	300	43	11	240	275	42	10	97
Ae-RIL-B-191	250	55	11	135	475	56	9	135
Parents								
PR120	175	43	11	145	375	46	13	150
UPLRi7	275	51	11	160	350	45	14	233
Checks								
APO	175	43	9	110	350	37	12	42
Bas370	275	94	8	473	350	55	10	79
IR64	175	55	6	30	275	27	10	69
GA2	225	49	12	293	250	56	14	160

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Table 8: Yield and yield contributing parameters at harvest stage as affected by sowing methods (direct-seeded aerobic and conventional transplanted) in a recombinant inbred line (RIL) population of rice (2012).

RILs	Aerobic				Transplanted			
	Grain filling %age	Grain yield per 0.5m row(g)	Harvest index	1000 Grain weight(g)	Grain filling %age	Grain yield per 0.5m row(g)	Harvest index	1000 Grain weight(g)
Ae-RIL-B-7	62.26	7.05k	0.04	6.42o	76.89	72.54hi	0.21	23.12o
Ae-RIL-B-27	78.42	26.57gh	0.13	15.42n	87.14	74.48ghi	0.33	20.26s
Ae-RIL-B-42	87.87	88.92b	0.36	23.32b	86.46	128.45a	0.21	28.16c
Ae-RIL-B-44	91.27	47.25c	0.21	18.42i	94.98	120.67b	0.34	20.42r
Ae-RIL-B-82	80.00	29.41g	0.13	22.32c	96.44	88.29d	0.29	27.54d
Ae-RIL-B-92	84.72	20.29ij	0.10	17.24k	85.91	67.03jk	0.30	24.56k
Ae-RIL-B-100	76.84	29.59gf	0.17	20.58ed	88.32	39.86r	0.18	22.52pmn
Ae-RIL-B-112	84.46	18.70j	0.11	19.02h	82.82	65.99jkl	0.33	23.78g
Ae-RIL-B-116	77.05	33.88ef	0.17	25.06a	93.98	77.92gf	0.28	26.28k
Ae-RIL-B-117	68.39	19.73j	0.09	18.22i	93.44	57.07nop	0.25	24.60b
Ae-RIL-B-126	61.69	20.01ij	0.13	16.74l	93.39	63.95mlk	0.28	29.40f
Ae-RIL-B-129	82.59	37.38ed	0.12	23.18b	82.24	79.05efg	0.23	27.04g
Ae-RIL-B-132	92.35	40.43d	0.20	22.32c	95.16	82.85e	0.28	26.36n
Ae-RIL-B-135	70.67	26.82gh	0.15	20.74d	90.59	106.03c	0.24	23.64q
Ae-RIL-B-142	82.50	61.35b	0.20	16.38m	93.68	70.61ij	0.24	22.36m
Ae-RIL-B-155	88.14	40.00d	0.23	17.00kl	86.08	47.15q	0.21	23.84c
Ae-RIL-B-158	91.09	59.95b	0.17	25.26a	89.14	59.45mno	0.24	28.24v
Ae-RIL-B-171	66.21	19.77j	0.11	17.00g	89.40	61.40nml	0.16	11.52hi
Ae-RIL-B-173	60.66	37.79ed	0.13	15.38n	76.74	72.81ij	0.26	25.90i
Ae-RIL-B-191	66.75	27.64gh	0.11	19.90f	81.20	126.24a	0.27	25.82
Parents								
PR120	70.71	20.78ij	0.12	19.96f	80.67	103.37c	0.28	26.02h
UPLRi7	66.60	40.91d	0.15	17.58j	71.38	79.22efg	0.23	27.36e
Checks								
APO	75.82	62.04b	0.35	25.20a	94.72	82.00ef	0.23	31.60a
Bas370	11.26	1.01l	0.00	0.00p	81.32	57.92nop	0.17	18.22u
IR64	84.21	17.98j	0.10	19.80gf	83.69	53.95p	0.20	25.40j
GA2	63.60	24.17ih	0.11	20.40e	80.46	55.66op	0.22	24.30l

Similar subscript denotes non-significant differences at 5% probability level according to Duncan's multiple range test.

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Table 9. Correlation analyses between grain yield and various morphological traits in a recombinant inbred line (RIL) population of rice raised under direct-seeded aerobic conditions (2012).

	Plant height	Leaf area	MTS	Chlorophyll	CGR	RGR	Yield
Plant height	1.000						
Leaf area	0.324*	1.000					
MTS	-0.281*	-0.009	1.000				
Chlorophyll	-0.151*	0.284*	-0.044	1.000			
CGR	0.056	0.057	-0.138*	0.336*	1.000		
RGR	-0.100*	-0.0123*	-0.143*	0.427*	0.834*	1.000	
Yield	0.251*	0.074	0.205*	0.084	0.203*	0.000	1.000

*significant at 5%

Table 10. Correlation analyses between grain yield and various morphological traits in a recombinant inbred line (RIL) population of rice raised under conventional transplanted conditions (2012).

	Plant height	Leaf area	MTS	Chlorophyll	CGR	RGR	Yield
Plant height	1.000						
Leaf area	0.097	1.000					
MTS	-0.004	0.130*	1.000				
Chlorophyll	0.031	0.006	0.065	1.000			
CGR	-0.061	0.172*	0.222*	0.080	1.000		
RGR	-0.500*	0.187*	0.095	0.060	0.675*	1.000	
Yield	0.189*	0.209*	0.209*	-0.042	0.173*	0.040	1.000

*significant at 5%

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Table 11: Effect of sowing methods (direct-seeded aerobic and conventional transplanted) on total soluble sugars and total starch at vegetative (40DAS) and reproductive (50%anthesis) stage in a recombinant inbred line (RIL) population of rice.

RILs	Total soluble sugar (mg/gFW)				Total starch (mg/gFW)			
	Vegetative stage(40DAS)		Reproductive stage(50%anthesis)		Vegetative stage(40DAS)		Reproductive stage(50%anthesis)	
	Aerobic	Transplanted	Aerobic	Transplanted	Aerobic	Transplanted	Aerobic	Transplanted
Ae-RIL-B-7	25.94cd*	21.02n*	21.47g	20.50kl	11.94cd*	6.02n*	12.44cd*	6.52o*
Ae-RIL-B-27	26.37b	29.91a	23.81c	23.04e	12.37b	14.91a	12.87b	15.41a
Ae-RIL-B-42	25.44ef	23.46h	24.99a	23.40d	11.44ef	8.46h	11.94ef	8.96i
Ae-RIL-B-44	25.70de*	20.41o*	20.71hi	20.01n	11.70de*	5.41o*	12.20de*	5.91p*
Ae-RIL-B-82	26.20cb	24.64d	21.86f	20.26m	12.20cb	9.64d	12.70bc	10.14e
Ae-RIL-B-92	24.54gh	22.74j	23.72c	22.24f	10.54gh	7.74j	11.04gh	8.24k
Ae-RIL-B-100	22.86l	25.58b	20.60hij*	25.51a*	8.86l	10.58b	9.36l	11.08b
Ae-RIL-B-112	25.98cd*	20.94n*	25.01a	20.68j	11.98cd*	5.94n*	12.48cd*	6.44o*
Ae-RIL-B-116	24.21i	20.12p	23.01d	20.02n	10.21i	5.12p	10.71i*	5.62q*
Ae-RIL-B-117	23.41k	25.37c	20.32lk	23.27d	9.41k	10.37c	9.91k	10.87c
Ae-RIL-B-126	25.27f	24.11f	24.37b	23.42d	11.27f	9.11f	11.77f	9.61g
Ae-RIL-B-129	25.95cd	23.81g	20.63hi	22.00g	11.95cd	8.81g	12.45cd	9.31h
Ae-RIL-B-132	20.72n	23.06i	20.69hi	20.34m	6.72n	8.06i	7.22n	8.56j
Ae-RIL-B-135	25.18f	21.27m	24.61b	21.03i	11.18f*	6.27m*	11.68f*	6.77n*
Ae-RIL-B-142	25.78d	21.56l	21.92f	21.24h	11.78d*	6.56l*	12.28d*	7.06m*
Ae-RIL-B-155	24.12ij	24.25f	21.34g	21.92g	10.12ij	9.25f	10.62ij	9.75g
Ae-RIL-B-158	26.74a	24.70d	25.04a*	20.02n*	12.74a	9.70d	13.24a	10.20e
Ae-RIL-B-171	24.78g	24.25f	20.66hi	20.02n	10.78g	9.25f	11.28g	9.75g
Ae-RIL-B-173	24.37hi	20.95n	20.15hi	20.38ml	10.37hi	5.95n	10.87ih	6.45o
Ae-RIL-B-191	23.91j	25.61b	21.52lk	25.25b	9.91j	10.61b	10.41j	11.11b
Parents								
PR120	23.14kl	25.67b	23.12d	20.70j	9.14kl	10.67b	9.64kl	11.17b
UPLRi7	23.01l	22.24k	22.37e	20.59jk	9.01l	7.24k	9.51l	7.74l
Checks								
APO	21.17m	24.48e	20.81h	23.01e	7.17m	9.48e	7.67m	9.98f
IR64	23.07l	22.23k	20.03l	21.23h	9.07l	7.23k	9.57l	7.73l
CT-6510-24-1-2	25.35f	24.10f	25.05a	21.97g	11.35f	9.10f	11.85f	10.60d

LSD(0.05) = 4.57

*significant interaction among RILs under two sowing conditions (p-value<0.05%)

Similar subscript denotes non-significant differences at 5% probability level according to Duncan's multiple range test.

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Table 12a: Analysis of variance for total soluble Sugar in leaves at Vegetative stage (40 DAS) in a recombinant inbred line (RIL) population of rice.

Source	DF	Type III SS	Mean Square	F Value	Pr > F	Significant
Sowing conditions(2)	1	33.62	33.61	14.73	0.0002	*
RILs+parents+ checks(26)	25	254.41	10.17	4.46	<.0001	*
RILs(20)	19	217.27	11.43	5.01	<.0001	*
Parents+checks(6)	5	28.77	5.75	2.52	0.0326	*
RILs vs (parents+check)	1	8.37	8.37	3.67	0.0577	NS
Error	129	294.46	2.28	.	.	
Corrected Total	155	582.48	.	.	.	
* - Significant at 5%, NS - Non Significant						
p-Value < 0.05 - Significant at 5%, p-Value < 0.01 - Significant at 1%						

Table 12b: Analysis of variance for total soluble Sugar in leaves at reproductive stage (50% anthesis) in a recombinant inbred line (RIL) population of rice.

Source	DF	Type III SS	Mean Square	F Value	Pr > F	Significant
Sowing conditions(2)	1	8.51	8.51	4.62	0.0335	*
RILs+parents+ checks(26)	25	205.56	8.22	4.46	<.0001	*
RILs(20)	19	178.32	9.38	5.09	<.0001	*
Parents+checks(6)	5	27.11	5.42	2.94	0.0151	*
RILs vs (parents+check)	1	0.13	0.13	0.07	0.7906	NS
Error	129	237.90	1.84	.	.	
Corrected Total	155	451.98	.	.	.	
* - Significant at 5%, NS - Non Significant						
p-Value < 0.05 - Significant at 5%, p-Value < 0.01 - Significant at 1%						

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Table 13a: Analysis of variance for total starch in leaves at Vegetative stage (40 DAS) in a recombinant inbred line (RIL) population of rice.

Source	DF	Type III SS	Mean Square	F Value	Pr > F	Significant
Sowing conditions(2)	1	145.03	145.039	63.54	<.0001	*
RILs+parents+ checks(26)	25	254.41	10.17	4.46	<.0001	*
RILs(20)	19	217.27	11.43	5.01	<.0001	*
Parents+checks(6)	5	28.76	5.75	2.52	0.0326	*
RILs vs (parents+check)	1	8.37	8.37	3.67	0.0577	NS
Error	129	294.45	2.28	.	.	
Corrected Total	155	693.90	.	.	.	
* - Significant at 5% , NS - Non Significant p-Value < 0.05 - Significant at 5%, p-Value < 0.01 - Significant at 1%						

Table 13b: Analysis of variance for total starch in leaves at reproductive stage (50% anthesis) in a recombinant inbred line (RIL) population of rice.

Source	DF	Type III SS	Mean Square	F Value	Pr > F	Significant
Sowing conditions(2)	1	139.31	139.30	60.93	<.0001	*
RILs+parents+ checks(26)	25	260.18	10.40	4.55	<.0001	*
RILs(20)	19	217.27	11.43	5.00	<.0001	*
Parents+checks(6)	5	36.88	7.37	3.23	0.0089	*
RILs vs (parents+check)	1	6.02	6.02	2.64	0.1069	NS
Error	129	294.93	2.28	.	.	
Corrected Total	155	694.42	.	.	.	
* - Significant at 5% , NS - Non Significant p-Value < 0.05 - Significant at 5%, p-Value < 0.01 - Significant at 1%						

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Table 14: Effect of sowing methods (direct-seeded aerobic and conventional transplanted) on proline content and nitrogen content at vegetative(40DAS) and reproductive(50%anthesis) stage in a recombinant inbred line (RIL) population of rice

RILs	Proline content ($\mu\text{mol/gFW}$)				Nitrogen content (mg/gFW)			
	Vegetative stage(40DAS)		Reproductive stage (50%anthesis)		Vegetative stage(40DAS)		Reproductive stage (50%anthesis)	
	Aerobic	Transplanted	Aerobic	Transplanted	Aerobic	Transplanted	Aerobic	Transplanted
Ae-RIL-B-7	0.067k	0.124pq	1.863a*	0.202f*	1.32g-k	1.57efg	0.61ij*	1.45a*
Ae-RIL-B-27	0.166fgh	0.25i	1.591d*	0.317c*	1.15ijk	1.74a-d	0.60j	1.12fgh
Ae-RIL-B-42	0.146hij*	0.473c*	1.62c*	0.113i*	1.76a-d	1.46ghi	0.63ij*	1.46a*
Ae-RIL-B-44	0.263d*	0.779a*	0.056o	0.023o	1.61b-f	1.16lmn	1.15d-h	0.89ij
Ae-RIL-B-82	0.157ghi	0.457d	0.284g	0.144g	1.67a-d	1.87a	0.57j	1.35a-d
Ae-RIL-B-92	0.07k	0.331f	0.063no	0.047mn	1.80abc	1.83ab	1.59a	1.19c-f
Ae-RIL-B-100	0.131ij	0.124pq	0.194i	0.094j	1.95a	1.66c-f	1.56ab	1.25b-f
Ae-RIL-B-112	0.369a	0.157mn	0.086mn	0.032no	1.59b-g	1.58d-g	1.47abc	1.39ab
Ae-RIL-B-116	0.175efg	0.25i	0.122kl	0.058lm	1.66b-e	1.29jkl	1.55ab	0.98hi
Ae-RIL-B-117	0.286cd	0.27h	0.103lm	0.065kl	1.08jk	1.61c-g	1.00gh	1.13fgh
Ae-RIL-B-126	0.155ghi	0.173kl	0.229h	0.121i	1.69a-d	1.40hij	1.38a-e	1.01ghi
Ae-RIL-B-129	0.14hij	0.308g	0.092m	0.293d	1.67a-d	1.46ghi	1.11e-h	1.19c-f
Ae-RIL-B-132	0.304bc	0.171lm	0.149jk	0.128hi	1.64b-f*	1.04n*	1.24c-g	0.89ij
Ae-RIL-B-135	0.124j*	0.491b*	0.155j	0.018o	1.69a-d*	1.05mn*	1.29b-f	0.60l
Ae-RIL-B-142	0.075k*	0.439e*	0.151j	0.029o	1.18ijk	1.30i-l	1.16d-h	1.17efg
Ae-RIL-B-155	0.286cd	0.074r	0.351f	0.079k	1.64b-f	1.20lmn	1.49abc	1.12fgh
Ae-RIL-B-158	0.329b	0.068r	0.092m	0.072kl	1.53c-g	1.23kl	1.43a-d	0.94ij
Ae-RIL-B-171	0.286cd	0.139op	0.166ij	0.02o	1.74a-d	1.38h-k	1.26c-g	1.36abc
Ae-RIL-B-173	0.133ij	0.063r	0.484e	0.22e	1.04k	1.21lm	0.89hi	0.78jk
Ae-RIL-B-191	0.072k	0.079r	0.5e	0.387b	1.50d-h	1.52fgh	0.89hi	1.22b-f
Parents								
PR120	0.292c	0.113q	1.834b	0.196f	1.22h-k	1.62c-g	1.01fgh	1.33a-e
UPLRi7	0.072k	0.247i	1.588d	0.034no	1.36f-j	1.28jkl	0.68ij	1.26b-f
Checks								
APO	0.191ef	0.252i	0.05o	0.031no	1.81abc	1.70b-e	0.48j	1.18def
IR64	0.203e	0.187jk	0.076mno	0.855a	1.38e-i	1.40hij	1.35a-e	1.36abc
CT6510-24-1-2	0.135ij	0.194j	0.328f	0.14gh	1.87ab	1.48gh	1.04fgh	1.25b-f

LSD(0.05) = 0.33(proline(v)); 1.02(proline(r)); 0.60(Nitrogen (v)); 0.81(Nitrogen (r))

*significant interaction among RILs under two sowing conditions (p-value<0.05%)

Similar subscript denotes non-significant differences at 5% probability level according to Duncan's multiple range test.

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Table 15a: Analysis of variance for proline content in leaves at Vegetative stage (40 DAS) in a recombinant inbred line (RIL) population of rice.

Source	DF	Type III SS	Mean Square	F Value	Pr > F	Significant
Sowing conditions(2)	1	0.16	0.16	13.79	0.0003	*
RILs+parents+ checks(26)	25	1.24	0.04	4.20	<.0001	*
RILs(20)	19	1.11	0.05	4.95	<.0001	*
Parents+checks(6)	5	0.05	0.01	0.99	0.4259	NS
RILs vs (parents+check)	1	0.07	0.07	5.97	0.0159	*
Error	129	1.53	0.01	.	.	
Corrected Total	155	2.94	.	.	.	
* - Significant at 5% , NS - Non Significant						
p-Value < 0.05 - Significant at 5%, p-Value < 0.01 - Significant at 1%						

Table 15b: Analysis of variance for proline content in leaves at reproductive stage (50% anthesis) in a recombinant inbred line (RIL) population of rice.

Source	DF	Type III SS	Mean Square	F Value	Pr > F	Significant
Sowing conditions(2)	1	4.25	4.25	37.07	<.0001	*
RILs+parents+ checks(26)	25	16.71	0.66	5.82	<.0001	*
RILs(20)	19	11.03	0.58	5.06	<.0001	*
Parents+checks(6)	5	4.90	0.98	8.54	<.0001	*
RILs vs (parents+check)	1	0.77	0.77	6.72	0.0106	*
Error	129	14.80	0.11	.	.	
Corrected Total	155	35.77	.	.	.	
* - Significant at 5% , NS - Non Significant						
p-Value < 0.05 - Significant at 5%, p-Value < 0.01 - Significant at 1%						

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Table 16: Effect of sowing methods (direct-seeded aerobic and conventional transplanted) on storage proteins and total free amino acid at maturity from harvested seeds in a recombinant inbred line (RIL) population of rice.

RILs	Storage proteins (mg/gDW)		Total free amino acids (mg/gDW)	
	Aerobic	Transplanted	Aerobic	Transplanted
Ae-RIL-B-7	5.08l	5.91h	0.86abc	0.91a-d
Ae-RIL-B-27	6.08ij	5.62i	0.84abc	0.62fgh
Ae-RIL-B-42	6.08ij	5.99h	0.87ab	0.99a
Ae-RIL-B-44	5.92jk	5.96h	0.81a-d	0.96abc
Ae-RIL-B-82	7.99de*	6.17g*	0.53d	0.75d-g
Ae-RIL-B-92	8.67a*	6.79e*	0.81a-d	0.79c-f
Ae-RIL-B-100	8.50ab*	5.87h*	0.94a	0.87a-e
Ae-RIL-B-112	7.16g	6.37f	0.84abc	0.85a-e
Ae-RIL-B-116	5.92jk	7.58a	0.87ab	0.87a-e
Ae-RIL-B-117	5.96j	5.87h	0.85abc	0.87a-e
Ae-RIL-B-126	6.29i	5.38j	0.98a	0.38i
Ae-RIL-B-129	7.08g	5.97h	0.84abc	0.97ab
Ae-RIL-B-132	8.29bc	7.50a	0.90a	0.50hi
Ae-RIL-B-135	8.20cd	7.46ab	0.91a	0.76d-g
Ae-RIL-B-142	5.20l	5.99h	0.90a	0.99a
Ae-RIL-B-155	5.66k	6.45f	0.60bcd	0.79c-f
Ae-RIL-B-158	8.16cd	7.33bc	0.84abc	0.81b-e
Ae-RIL-B-171	6.62h	6.45f	0.92a	0.61gh
Ae-RIL-B-173	6.29i	7.04d	0.73a-d	0.72efg
Ae-RIL-B-191	7.99de	6.50f	0.75a-d	0.75d-g
Parents				
PR120	7.71ef	5.87h	0.83abc	0.87a-e
UPLRi7	8.71a	5.92h	0.84abc	0.92a-d
Checks				
APO	5.25l	5.45j	0.80a-d	0.45i
IR64	6.96g	7.25c	0.83abc	0.85a-e
CT6510-24-1-2	7.12g	6.66e	0.58cd	0.85a-e

LSD(0.05) =1.81(Storage proteins); 0.41(total free amino acids)

*significant interaction among RILs under two sowing conditions (p-value<0.05%)

Similar subscript denotes non-significant differences at5% probability level according to Duncan's multiple range test.

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Table 17: Analysis of variance for storage protein at maturity from harvested seeds in a recombinant inbred line (RIL) population of rice.

Source	DF	Type III SS	Mean Square	F Value	Pr > F	Significant
Sowing conditions(2)	1	11.09	11.09	30.97	<.0001	*
RILs+parents+ checks(26)	25	88.19	3.52	9.84	<.0001	*
RILs(20)	19	70.24	3.69	10.32	<.0001	*
Parents+checks(6)	5	17.07	3.41	9.53	<.0001	*
RILs vs (parents+check)	1	0.87	0.87	2.43	0.1215	NS
Error	129	46.22	0.35	.	.	
Corrected Total	155	145.52	.	.	.	
* - Significant at 5% , NS - Non Significant						
p-Value < 0.05 - Significant at 5%, p-Value < 0.01 - Significant at 1%						

Table 18: Analysis of variance for total free amino acid at maturity from harvested seeds in a recombinant inbred line (RIL) population of rice.

Source	DF	Type III SS	Mean Square	F Value	Pr > F	Significant
Sowing conditions(2)	1	0.04	0.04	2.24	0.1372	NS
RILs+parents+ checks(26)	25	1.26	0.05	2.75	0.0001	*
RILs(20)	19	0.96	0.05	2.76	0.0004	*
Parents+checks(6)	5	0.28	0.05	3.11	0.0111	*
RILs vs (parents+check)	1	0.01	0.01	0.74	0.3923	NS
Error	129	2.36	0.01	.	.	
Corrected Total	155	3.67	.	.	.	
* - Significant at 5% , NS - Non Significant						
p-Value < 0.05 - Significant at 5%, p-Value < 0.01 - Significant at 1%						

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Table 19. Correlation analyses between grain yield and various biochemical traits in a recombinant inbred line (RIL) population of rice raised under conventional direct-seeded aerobic conditions.

	1	2	3	4	5	6	7	8	9	10	11
Total soluble sugar(V)	1.000										
Total soluble sugar(R)	0.505*	1.000									
Total soluble starch(V)	1.000*	0.505*	1.000								
Total soluble starch(R)	1.000*	0.505*	1.000*	1.000							
Total soluble proline(V)	-0.038	0.063	-0.038	-0.038	1.000						
Total soluble proline(R)	0.105*	0.225*	-0.105*	0.105*	-0.201*	1.000					
Total soluble nitrogen(V)	-0.070	0.221*	-0.070	-0.070	-0.007	-0.387*	1.000				
Total soluble nitrogen(R)	-0.037	0.074	-0.037	-0.037	0.250*	-0.601*	0.316*	1.000			
Seed protein	-0.186*	0.170*	-0.186*	-0.186*	-0.066	-0.095	0.281*	0.276*	1.000		
Total free amino acid	-0.142*	0.015	-0.142*	-0.142*	0.000	0.038	-0.055	0.270*	-0.015	1.000	
Yield	0.054	0.169*	0.054	0.054	0.099	0.053	0.129*	-0.269*	-0.212*	0.003	1.000

*significant at 5%

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Table 20. Correlation analyses between grain yield and various biochemical traits in a recombinant inbred line (RIL) population of rice raised under conventional transplanted conditions.

	1	2	3	4	5	6	7	8	9	10	11
Total soluble sugar(V)	1.000										
Total soluble sugar(R)	0.554*	1.000									
Total soluble starch(V)	1.000*	0.554*	1.000								
Total soluble starch(R)	0.996*	0.553*	0.996*	1.000							
Total soluble proline(V)	-0.277*	-0.101*	-0.277*	-0.280*	1.000						
Total soluble proline(R)	0.067	-0.023	0.091	0.090	-0.180*	1.000					
Total soluble nitrogen(V)	0.523*	0.489*	0.523*	0.521*	-0.093	0.055	1.000				
Total soluble nitrogen(R)	0.113*	0.028*	0.113*	0.122*	-0.107*	0.261*	0.459*	1.000			
Seed protein	-0.355*	-0.381*	-0.355*	-0.345*	-0.167*	0.103*	-0.419*	-0.506*	1.000		
Total free amino acid	-0.321*	-0.118*	-0.321*	-0.311*	0.308*	0.053	-0.026	0.266*	0.031	1.000	
Yield	-0.251*	-0.291*	-0.251*	-0.267*	0.699*	-0.137*	-0.196*	-0.066	-0.112*	0.174*	1.000

*significant at 5%

Appendix -V

Table 21: Plant height and crop growth rate as affected by sowing methods (direct-seeded aerobic and conventional transplanting) in a recombinant inbred line (RIL) population of rice (pooled data across 2012 and 2013).

RILs	Plant height(cm)				CGR(g plant ⁻¹ day ⁻¹)			
	Aerobic		Transplanted		Aerobic		Transplanted	
	Vegetative	Reproductive	Vegetative	Reproductive	Vegetative	Reproductive	Vegetative	Reproductive
Ae-RIL-B-7	34.58	73.00	55.13	103.43	0.04*	0.81	1.32*	1.27
Ae-RIL-B-27	36.26	75.18	50.25	94.07	0.09	1.04	0.98	1.73
Ae-RIL-B-42	43.04	107.50	59.58	121.70	0.20	0.92	0.83	1.77
Ae-RIL-B-44	43.07	58.52*	50.50	125.10*	0.20*	0.93	1.40*	1.28
Ae-RIL-B-82	45.45	106.33	54.17	129.58	0.14*	0.89	1.36*	0.92
Ae-RIL-B-92	39.64	121.40	47.14	134.93	0.22*	0.88	1.26*	1.38
Ae-RIL-B-100	36.05	84.33	39.38	101.00	0.22	0.76	0.96	1.13
Ae-RIL-B-112	37.00	104.92	56.25	111.53	0.08	0.44	0.89	1.90
Ae-RIL-B-116	35.73	98.17	50.38	122.55	0.26	0.56	0.77	1.86
Ae-RIL-B-117	42.93	106.42	60.25	130.25	0.27	0.90	1.17	1.57
Ae-RIL-B-126	39.72*	85.42	261.50*	104.87	0.05*	0.92	1.19*	1.63
Ae-RIL-B-129	40.15	117.33	50.00	118.70	0.29*	1.12	1.34*	1.19
Ae-RIL-B-132	38.63	102.75	52.25	122.40	0.15*	0.95	1.28*	1.72
Ae-RIL-B-135	37.15	106.50	55.50	133.33	0.31*	0.90	1.62*	1.81
Ae-RIL-B-142	43.25	97.75	54.25	115.55	0.36*	0.87	1.73*	1.99
Ae-RIL-B-155	33.15	90.57	49.25	115.80	0.27	0.96	1.11	1.32
Ae-RIL-B-158	43.95	125.25	53.25	118.87	0.19*	0.72	1.36*	0.71
Ae-RIL-B-171	32.66	85.98	51.75	114.30	0.16*	0.64	1.12*	1.30
Ae-RIL-B-173	38.75	110.18	50.00	120.05	0.26	0.64	0.79	1.61
Ae-RIL-B-191	42.55	107.97	45.00	126.47	0.22	0.84	0.99	2.13
Parents								
PR120	35.81	99.83	55.13	103.70	0.11	0.48	1.49	1.61
UPLRi7	42.00	104.83	50.25	105.27	0.28	0.98	1.22	1.32
Checks								
APO	40.39	107.50	59.58	140.33	0.29	0.63	1.35	1.89
IR64	31.16	68.67	50.50	110.65	0.23	0.53	0.74	1.75
CT-6510-24-1-2	44.06	104.77	54.17	92.50	0.19	0.74	1.19	1.26

LSD(0.05)= 119.59(plant height (v)); 60.78 (plant height (r)); 0.93 (CGR(v)); NS(CGR(r))

*significant interaction among RILs under two sowing conditions (p-value = 0.05)

(CGR) Crop growth rate

Appendix -V

Table 22a: Analysis of variance for plant height at vegetative stage (40DAS) in a recombinant inbred line (RIL) population of rice.

Source	DF	Type III SS	Mean Square	F Value	Pr > F	Significant
Sowing conditions(2)	1	71.49	71.49	770.51	<.0001	*
RILs+parents+checks(26)	24	5.96	0.25	2.68	<.0001	*
RILs(20)	19	5.06	0.27	2.87	<.0001	*
Parents+checks(6)	4	0.88	0.22	2.38	0.05	NS
RILs vs (parents+check)	1	0.02	0.02	0.23	0.63	NS
Error	274	25.42	0.09			
Corrected Total	299	102.87				

* Significant at p= 0.05, NS - Non Significant

(DAS) Days after sowing, (RIL) Recombinant inbred line

Table 22b: Analysis of variance for plant height at reproductive stage (50% anthesis) in a recombinant inbred line (RIL) population of rice.

Source	DF	Type III SS	Mean Square	F Value	Pr > F	Significant
Sowing conditions(2)	1	23705.19	23705.19	59.69	<.0001	*
RILs+parents+checks(26)	24	68194.72	2841.45	7.16	<.0001	*
RILs(20)	19	60341.65	3175.88	8.00	<.0001	*
Parents+checks(6)	4	7644.70	1911.18	4.81	0.00	*
RILs vs (parents+check)	1	208.38	208.38	0.52	0.47	NS
Error	274	108807.60	397.11			
Corrected Total	299	200707.50				

* Significant at p= 0.05, NS - Non Significant

(DAS) Days after sowing, (RIL) Recombinant inbred line

Appendix -V

Table 23a: Analysis of variance for crop growth rate at vegetative stage (40DAS) in a recombinant inbred line (RIL) population of rice.

Source	DF	Type III SS	Mean Square	F Value	Pr > F	Significant
Sowing conditions(2)	1	71.49	71.49	770.51	<.0001	*
RILs+parents+checks(26)	24	5.96	0.25	2.68	<.0001	*
RILs(20)	19	5.06	0.27	2.87	<.0001	*
Parents+checks(6)	4	0.88	0.22	2.38	0.05	NS
RILs vs (parents+check)	1	0.02	0.02	0.23	0.63	NS
Error	274	25.42	0.09			
Corrected Total	299	102.87				

* Significant at p= 0.05, NS - Non Significant

(DAS) Days after sowing, (RIL) Recombinant inbred line

Table 23b: Analysis of variance for crop growth rate at reproductive stage (50%anthesis) in a recombinant inbred line (RIL) population of rice.

	DF	Type III SS	Mean Square	F Value	Pr > F	Significant
Sowing conditions(2)	1	38.88	38.88	151.48	<.0001	*
RILs+parents+checks(26)	24	9.22	0.38	1.5	0.07	NS
RILs(20)	19	8.58	0.45	1.76	0.03	*
Parents+checks(6)	4	0.51	0.13	0.5	0.74	NS
RILs vs (parents+check)	1	0.13	0.13	0.51	0.47	NS
Error	274	70.32	0.26			
Corrected Total	299	118.42				

* Significant at p= 0.05, NS - Non Significant

(DAS) Days after sowing, (RIL) Recombinant inbred line

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Table 24: Yield and yield contributing parameters at harvest stage as affected by sowing methods (direct-seeded aerobic and conventional transplanted) in a recombinant inbred line (RIL) population of rice (pooled data 2012 and 2013)

RILs	Aerobic			Transplanted		
	Above ground biomass(g)	Grain yield per 0.5m row(g)	Harvest index	Above ground biomass(g)	Grain yield per 0.5m row(g)	Harvest index
Ae-RIL-B-7	225.0	7.85*	0.04	375.0	71.32*	0.20
Ae-RIL-B-27	200.0	27.37	0.14	300.0	71.75	0.28
Ae-RIL-B-42	187.5	54.58	0.26	425.0	92.24	0.25
Ae-RIL-B-44	237.5	27.46*	0.12*	362.5	110.98*	0.33*
Ae-RIL-B-82	275.0	35.79	0.13	300.0	80.72	0.27
Ae-RIL-B-92	262.5	31.00	0.12	312.5	75.34	0.26
Ae-RIL-B-100	212.5	32.56	0.16	287.5	52.17	0.19
Ae-RIL-B-112	250.0	27.97	0.11	212.5	57.54	0.27
Ae-RIL-B-116	225.0	29.80	0.14	300.0	63.11	0.22
Ae-RIL-B-117	225.0	20.53*	0.09	362.5	79.21*	0.26
Ae-RIL-B-126	225.0	18.97*	0.10	300.0	68.59*	0.25
Ae-RIL-B-129	300.0	35.12	0.12	400.0	68.31	0.19
Ae-RIL-B-132	212.5	34.31*	0.17	387.5	90.00*	0.27
Ae-RIL-B-135	175.0*	27.62*	0.16	462.5*	92.60*	0.24
Ae-RIL-B-142	300.0	53.11	0.18	400.0	76.86	0.22
Ae-RIL-B-155	237.5	28.67	0.14	350.0	65.37	0.21
Ae-RIL-B-158	312.5	43.69	0.14	412.5	53.51	0.17
Ae-RIL-B-171	175.0	20.57	0.12	387.5	60.20	0.18
Ae-RIL-B-173	275.0	37.79	0.14	300.0	67.87	0.24
Ae-RIL-B-191	250.0	25.22*	0.10	412.5	89.86*	0.22
Parents						
PR120	200.0	20.92	0.11	337.5	88.45	0.27
UPLRi7	212.5	29.67	0.14	325.0	69.38	0.24
Checks						
APO	225.0	37.72	0.20	400.0	76.78	0.22
IR64	187.5	18.09	0.10	337.5	60.89	0.22
CT-6510-24-1-2	225.0	28.99	0.13	400.0	68.48	0.21

LSD(0.05)= 242.51(above ground biomass); 48.85(grain yield); 0.18(harvest index)

*significant interaction among RILs under two sowing conditions (p-value = 0.05)

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Table 25: Analysis of variance for above-ground biomass in a recombinant inbred line (RIL) population of rice.

Source	DF	Type III SS	Mean Square	F Value	Pr > F	Significant
Sowing conditions(2)	1	1107168.75	1107168.75	175.12	<.0001	*
RILs+parents+checks(26)	24	314925.00	13121.88	2.08	0.00	*
RILs(20)	19	279257.81	14697.78	2.32	0.00	*
Parents+checks(6)	4	30562.50	7640.63	1.21	0.31	NS
RILs vs (parents+check)	1	5104.69	5104.69	0.81	0.37	NS
Error	274	1732362.50	6322.49			
Corrected Total	299	3154456.25				

* Significant at p= 0.05, NS - Non Significant

(DAS) Days after sowing, (RIL) Recombinant inbred line

Table 26: Analysis of variance for harvest index in a recombinant inbred line (RIL) population of rice.

Source	DF	Type III SS	Mean Square	F Value	Pr > F	Significant
Sowing conditions(2)	1	0.76	0.76	211.92	<.0001	*
RILs+parents+checks(26)	24	0.23	0.01	2.69	<.0001	*
RILs(20)	19	0.21	0.01	3.05	<.0001	*
Parents+checks(6)	4	0.02	0.01	1.65	0.16	NS
RILs vs (parents+check)	1	0.00	0.00	0.13	0.72	NS
Error	274	0.99	0.00			
Corrected Total	299	1.98				

* Significant at p= 0.05, NS - Non Significant

(DAS) Days after sowing, (RIL) Recombinant inbred line

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Table 27: Analysis of variance for yield in a recombinant inbred line (RIL) population of rice.

Source	DF	Type III SS	Mean Square	F Value	Pr > F	Significant
Sowing conditions(2)	1	144183.41	144183.41	561.96	<.0001	*
RILs+parents+checks(26)	24	23813.90	992.25	3.87	<.0001	*
RILs(20)	19	21210.17	1116.33	4.35	<.0001	*
Parents+checks(6)	4	2240.58	560.15	2.18	0.07	NS
RILs vs (parents+check)	1	363.15	363.15	1.42	0.24	NS
Error	274	70300.41	256.57			
Corrected Total	299	238297.71				

* Significant at p= 0.05, NS - Non Significant

(DAS) Days after sowing, (RIL) Recombinant inbred line

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Table 28: Correlation analysis between grain yield and various morpho-physiological traits in a recombinant inbred line population raised under conventional transplanted and direct-seeded aerobic rice (in parenthesis).

S. No.	Traits	1	2	3	4	5	6	7
1	Grain yield	1.000						
2	Harvest index	0.0169 (0.842**)	1.000					
3	Above-ground biomass	0.196 (0.404)**	-0.500** (-0.072)	1.000				
4	CGR (50% anthesis)	-0.380 (0.073)	-0.077 (0.127)	-0.720** (-0.076)	1.000			
5	CGR (40DAS)	0.335 (0.492**)	-0.048 (0.388)	0.522** (0.212)	-0.376 (0.142)	1.000		
6	Plant height (50%anthesis)	-0.179 (0.509**)	.805** (0.209)	0.422 (0.536**)	0.149 (0.269)	0.187 (0.195)	1.000	
7	Plant height (40DAS)	0.402** (0.443**)	-0.076 (0.205)	0.072 (0.335)	-0.119 (-0.102)	0.079 (0.362)	0.297 (0.361)	1.000

Critical value of r at 5%= 0.4 and at 1%= 0.5

*,** Significant at 5% and 1% probability level, respectively.

CGR (Crop Growth Rate), DAS (Days after sowing)

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