NRRI Research Bulletin No. 11

Stagnant Flooding Tolerance in Rice: Endeavours and Achievement

R.K. Sarkar

NICRA
National Innovations in Climate Resilient Agriculture

भाकृअनुप-राष्ट्रीय चावल अनुसंधान संस्थान
(भारतीय कृषि अनुसंधान परिषद)
ICAR-National Rice Research Institute
(Indian Council of Agricultural Research)

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CORRECT CITATION
Sarkar RK. 2016. Stagnant Flooding Tolerance in Rice: Endeavours and Achievements. NRRI Research Bulletin No. 11. ICAR-National Rice Research Institute, Cuttack, Odisha-753006, India. pp 48.

Published By :
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ICAR - National Rice Research Institute
Cuttack-753006, Odisha, India

December, 2016

Printed At :
Print-Tech Offset Pvt. Ltd.
Bhubaneswar-751024, Odisha

Foreword

Rice is the main source of energy for more than half of the world population. To meet the demand of the ever-increasing global population, greater production of rice is needed. Rice is grown in different ecosystems i.e., irrigated and rainfed lowlands, upland, deep wateras well as drought and flood-prone ecosystems. According to the World Bank, flood affected areas have increased to 40 million hectares (Mha) from 19 Mha during the last decade in India. Flooding affects vast rainfed lowland rice areas (48.7 Mha) in Asia during the monsoon season. Flood prone area is already in a high-risk zone, which has become riskier due to climate change. Rice in these areas is the major crop providing food for millions of subsistence farming families. Improvement of rice productivity in flood-prone area is surely to give food security of the people live in this fragile ecosystem.

In deepwater and floating rice areas, water stagnates for longer duration, generally more than a month. Rice cultivars adapt to these conditions through shoot elongation to avoid complete inundation. Transient submergence up to two weeks can also occur in some areas at any time and mostly more than once during the growing season. The flood-prone rice ecosystem is subjected to uncontrolled flooding, for as long as five months at a stretch, with water depth of 0.5 to 4.0 m. Intermittent flooding with brackish water is also caused by tidal fluctuations in coastal areas. Only rice crop can be grown in this ecosystem.

National Rice Research Institute (formerly Central Rice Research Institute) at Cuttack, Odisha has made significant contributions to the characterization of germplasms, development of varieties and cultivation technologies for stagnant flooding tolerance in rice. The Institute started work on stagnant flooding tolerance in 1960's. With the discovery of SUB1 gene in 1990s, scientist in India and abroad gave less emphasis on stagnant flooding tolerance research. The scenario has changed now.

Stabilizing yield in submergence and stagnant flooding is important for rainfed, flood-prone ecosystem. I sincerely appreciate the efforts of the author in bringing out a comprehensive compilation of the research findings on various aspects of stagnant flooding tolerance in the present bulletin on 'Stagnant flooding tolerance in Rice: Endeavours and Achievements'. The publication identifies the research gaps and suggests future strategies for improving stagnant flooding tolerance in rice. I hope that this bulletin will be useful for the researchers, students, policy makers and others working in the area of flooding tolerance in rice.

(H. Pathak)

Acknowledgement

Author is grateful to all the scientists who contributed greatly on stagnant flooding tolerance in rice. My respect and gratitude are for the Directors and other staff members who helped in finalizing the programme on stagnant flooding tolerance. Indian Council of Agricultural Research, New Delhi supported the activity by granting fund through several schemes such as A. P. Cess Fund, NATP and NICRA.

CONTENTS

Summary

Flooding affects vast rainfed lowland rice areas in Asia during the monsoon season. In deepwater and floating rice areas, water stagnates for longer duration, commonly more than a month, and cultivars adapt to these conditions through shoot elongation to avoid complete inundation. Transient submergence for periods of up to two weeks can also occur in some areas, at any time and mostly more than once during the growing season caused by either heavy rain or outflow of nearby river. The flood-prone rice ecosystem is subjected to uncontrolled flooding, for as long as five months at a stretch with water depth of 0.5 to 4.0 m or more and even intermittent flooding with brackish water caused by tidal fluctuation. No other crops apart from rice can be grown in this ecosystem. Rice is the energy source of the more than half of the world population. To meet the demand of the ever increasing global population, greater production of rice is needed from this flood prone ecosystem. Flood prone area is already in a high risk zone, which become now more at risk due to climate change. Rice in these areas is the major crop providing food for millions of subsistence farming families. Improvement of rice productivity in flood-prone area is indeed an uphill task. National Rice Research Institute (formerly Central Rice Research Institute), Cuttack, India is probably the oldest research Institute started their work on stagnant flooding even when most of the Institute in the world did not think about it. Identification of tolerant stagnant flooding rice germplasm initiated in this Institute probablyin nineteen hundred sixties. Besides, germplasm identification management of rice cultivation under stagnant flooding got attention from the Scientists of NRRI long before. Physiological and biochemical basis of stagnant flooding tolerance were also worked out by the Scientists of this premiere Institute. Depending on the depth of stagnation of water on the rice field rainfed lowland is divided into six categories. Medium (25-50 cm) to semi-deep (up to 70 cm) water depth occupy a major part (about 6 million ha) in India and therefore the research at NRRI got attention to develop technologies suitable for these ecosystem. Varietal to cultivation technology are being develop at NRRI. Attempt has been made to develop scientific knowledge which could be applied in future development. Dozens of publication in national and international referred journals were done by the scientists of NRRI. Stagnant flooding tolerance is sticky. Unlike other abiotic stress tolerance where mortality is the sole criteria for screening here a numbers of traits related to yield and yield attributes are to be considered in identifying the tolerant genotypes. In the present research bulletin an overall improvement of yield under medium depth to semi-deep conditions are being presented.

1. INTRODUCTION

Flooding affects vast rainfed lowland rice areas in Asia during the monsoon season. In deepwater and floating rice areas, water stagnates for longer duration, commonly more than a month, and cultivars adapt to these conditions through shoot elongation to avoid complete inundation. Transient submergence for periods of up to two weeks can also occur in some areas, at any time and mostly more than once during the growing season because of flash floods caused by either heavy rains or outflow of nearby rivers. The flood-prone rice ecosystem is subjected to uncontrolled flooding, for as long as five months at a stretch with water depth of 0.5 to 4.0 m or more, and even intermittent flooding with brackish water caused by tidal fluctuations in coastal areas. No other crops apart from rice can be grown in this ecosystem. Rice is the energy source of the more than half of the world population. To meet the demand of the ever increasing global population, greater production of rice is needed from this flood prone ecosystem. According to the estimate of World Bank flood affected areas increased to 40 million hectares from 19 million hectares within one decade in India. Flood prone area is already in a high risk zone, which became now more at risk due to climate change. Probability of flooding and sea level rise is greater, with adverse impacts on crop yield and farm income. Rice in these areas is the major crop providing food for millions of subsistence farming families. Improvement of rice productivity in flood-prone area is indeed an uphill task.

Rice plants that exhibit limited or no elongation during submergence often show tolerance to flash flooding whereas under stagnant flooding plant adopts opposite strategy, exhibits elongation so that leaf tips come out above the water surface. These two opposite strategies i.e. quiescence and elongation are quite useful to counteract the adverse effect of flash flooding and stagnant flooding, respectively. We reported that introgression of submergence tolerance (*SUB1*) QTL into 'Swarna' greatly enhanced its survival under submergence and plant productivity under flash flood conditions through quiescence mechanism. Using the *SUB1* locus several submergence tolerant mega varieties of rice namely IR64-*Sub1*, SambaMahsuri-*Sub1*, Thadokkam1-*Sub1* and BR11-*Sub1* have been developed and are being released for commercial cultivation in Asia and Africa. The mega varieties with *SUB1* QTL survive flash flooding through quiescence strategy. The strategy is no longer useful if water stagnates more than 2-3 weeks. Under complete submergence photosynthesis impaired, plants exhausted the reserve carbohydrate and ultimately died. To continue life, exposure of leaf tips above the water surface is vital even for submergence tolerant varieties if submergence duration exceeds more than 2-3 weeks. In Southeast Asia about 20 million ha of land comes under medium-deep to deep and very deep ecology where stagnation of water after complete submergence is common. Here the ideal plant type would be that which survive complete submergence, yet possess some degree of elongation which in turn helps in surviving even under stagnation of water.

Adoption of modern rice varieties is less in flood prone areas and still farmers grow different types of traditional rice genotypes due to lack of proper high yielding variety which can tolerate heterogeneous flooding situations. Traditional rice genotypes are low yielder, however, it possess some adaptive traits require for the ecosystem for survival and plant productivity. Broadly, four major kinds of rice categories are found: medium deep water-logged rice where water accumulates and stagnates for 1-4 months because of impeded drainage. Water depth may vary from 25 to 50 cm; deepwater rice, which can survive water depths of 50-100 cm; floating rice, which can be found in water up to 300 cm deep; and tidal wetland rice, which can survive submergence, sometimes with salty water, for short period. Deepwater and floating rice escapes complete submergence by fast internodal elongation growth to keep up with the rising floodwater, and is commonly harvested after the water recedes. In medium depth water ecology first elongation does not require, however, main requisite is to water-logged tolerance with slow elongation so that plant can maintain appropriate yield and yield attributes characteristics for greater yield. Success of crop improvement especially for stressful environment depends on effective phenotyping approach base on greater understanding of plant functioning under stress. Targets that may aid in this objective include evaluating growth and physiological traits associated with SF tolerance in rice. Identification of new genetic resources would certainly broaden the scope of crop improvement provided basis of tolerance and proper phenotypic traits are known. Therefore, the goals of the present research bulletin are to identify new genetic resources and understanding the bases of waterlogging / stagnant flooding tolerance based on morpho-physiological traits.

2. PROBLEM OF FLOODING: AREAS AND DURATION

Rainfed lowlands in South and Southeast Asia mostly occur in the warm sub-humid and humid tropics. Throughout the rainfed rice ecosystems, the amount and seasonal distribution of water supply are considered the most important determinant of productivity. Water supply conditions vary greatly within the rainfed lowland ecosystem, ranging from drought to excess water stress and can occur during different stages of crop development. However, predominant dryland conditions are usually associated with upland rice while prolonged deepwater conditions (> 50 cm water depths) are associated with deepwater and floating rice. India by far has the largest area under rainfed lowlands and flood-prone ecosystems in South and Southeast Asia.

Based on hydrology, rainfed lowlands are broadly classified into six categories (Sarkar *et al.* **2009)**

- Shallow and favorable rainfed lowlands : Rainfall and water control are more or less adequate. Short period of drought stress or mild submergence may occur, but are not a serious constraint. Supplementary irrigation may be available.
- Shallow and drought prone rainfed lowlands : Growing conditions range from upland to lowland, the rainy period is about 90-110 days and water deficit may occur at any growth stage. Crops generally are not subjected to submergence. Soils vary from neutral to alkaline.
- Shallow, drought and submergence-prone rainfed lowlands : Complete submergence usually takes place due to heavy rains and overflow from adjacent rivers and streams. There also may be extended period of no rain and water deficit during the growing season. Soils generally have light texture and low fertility.
- Shallow, submergence-prone rainfed lowlands : Depth of flood water is usually shallow but complete submergence for up to 10 days or more may occur during periods of heavy rainfall.

- Medium deep, water-logged rainfed lowland rice areas: Water accumulates and stagnates for 1-4 months because of impeded drainage. Water depth may vary from 25 to 50 cm.
- Semi-deep, like medium deep, however water depth may reach up to 70 cm.

Table 1. Estimated rice area in rainfed lowland and flood-prone/deep water ecosystem ('000 ha).

Country	Shallow (0-25 cm)				Medium-deep (25-50 cm)	Deep-water (<50 cm)	Total rainfed lowland + Deepwater	Total of all cultural types
	Favorable	Drought-prone	Drought and Submergence	Submergence prone				
India[1]	1100	5800	2600	1100	3000	4000	17600	43500
Bangladesh	847	837	1001	1608	747	3066	8106	12306
Thailand	513	3166	1437	723	200	500	6539	8677
Myanmar	1224	283	0	784	699	557	3547	6488
Vietnam	663	332	0	554	195	870	2614	5573
Cambodia	72	275	762	0	623	85	1817	2104
Laos	116	116	116	0	0	0	348	695
Indonesia	811	231	0	261	320	4916	6539	12391
Philippines	765	241	60	141	303	45	1555	3515
South and Southeast Asia Total	6111	11281	5976	5171	6087	14039	48665	95249
Percentage*	6.4	11.8	6.3	5.4	6.4	14.7	51.0	100

Adopted from Sarkar *et al.* (2009); *Percentage of land compared to the total land.

It is assumed that rice is flooding tolerant compared to other cereal crops yet greater genotypic variations exist among rice cultivars. Besides complete submergence, waterlogging tolerance is another constraint which restricts rice production in east and south-east Asian countries. Submergence tolerant QTL *'SUB1'* identified from FR13A, a local cultivar of Odisha, India paid dividend in developing submergence tolerant high yielding commercial rice cultivars. Publications on submergence tolerance in rice are rich. However, publication on waterlogging / stagnant flooding tolerance in rice is comparatively less. During the last two decades attention was paid mainly on submergence tolerance rather than stagnant flooding. To improve the rice yield in fragile ecology besides submergence tolerance, stagnant flooding is now getting attention from researchers. Rice genotype tolerant to submergence already paid dividend. And we hope it would be true in the case of waterlogging / stagnant flooding tolerance also. New interest has been developed on rice community to work on waterlogging tolerance after greater success on flash flood tolerance with the discovery of *'SUB1'* and efficient use of it. National Rice Research Institute is a pioneer research organization started work in 1970's on waterlogging tolerance in rice. Due to the discovery of *SUB1* which is associated with flash flood tolerance through quiescence mechanism, the opposite of which is another strategy which rice plant adopt under waterlogging condition. The survival and productivity depends on the elongation of plant. In exemplifying the term 'flash flood tolerance', here in subsequent writing we shall write 'stagnant flooding tolerance (SF)' in stead of waterlogging tolerance.

Medium deep and semi deep is very commonly intermingles and depth of water mainly varies from 40 to 60 cm in large part of the rainfed lowland areas. In the present research bulletin we are mainly focusing on medium deep to semi-deep stagnant flooding.

3. IMPACT OF WATER DEPTH ON YIELD AND YIELD ATTRIBUTES

Contributors: DP Bhattacharjee, AK Singh, N Samal, G. Ramakrishnayya, BB Reddy, BC Ghosh, RSV Rai and KS Murty

Large numbers of experiment was conducted under different depths of water stagnation i.e. control-standing water 5 cm, shallow rainfed lowland-standing water 35 cm and medium depth lowland-standing water 50 cm. In most of the studies a few yield contributing parameters and grain yield production was noted. In one study 20 cultures were taken. It was observed that average grain yield production decreased with increase of water depth (Fig. 1). In all the genotypes grain yield production decreased under medium depth stagnant flooding, however, under shallow depth stagnant flooding greater grain yield was obtained compared to the control in certain rice varieties (Fig. 2). Mahsuri produced greater grain yield under all water regime compared to other cultivars. Jagannath a high yielding semi-dwarf rice varieties produced more yield under shallow stagnant flooding compared to control.

In an another experiment reported in the **Annual Report of CRRI, page 142-143** eight rice cultivars were transplanted at the age of 30 day for evaluation of yield reduction under different depth of water stagnation. After 25 days of planting water stagnation of the depth of 55-65 cm was imposed till dough stage. Under stagnant flooding CN540 was found to be the highest grain yielder (4 t ha^{-1}). Susceptible cultivar Jagannath produced only 2.26 t ha^{-1} though under normal condition Jagannath was the highest grain yielder (Fig. 3).

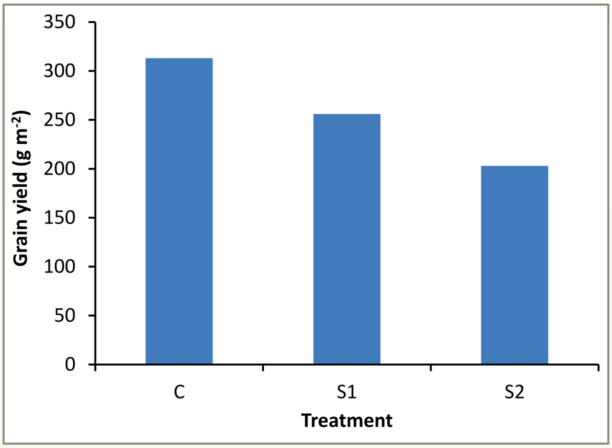

Fig. 1. Influenced of water depth on grain yield production (C-control, standing water 5 cm; S1-shallow depth (35 cm) standing water; S2-medium depth (50 cm) standing water)

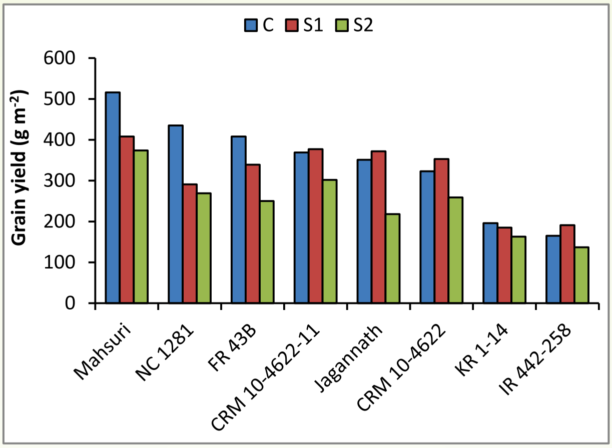

Fig. 2.Influenced of water depth on grain yield production of different varieties of rice (C-control, standing water 5 cm; S1-shallow depth (35 cm) standing water; S2-medium depth (50 cm) standing water)

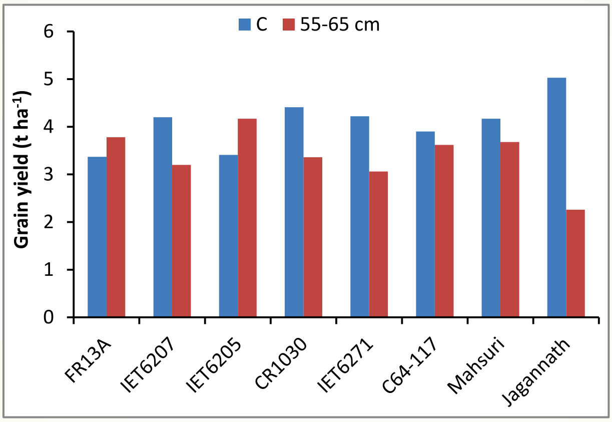

Fig. 3. Effect of stagnant flooding (55-65 cm depth) on grain yield of in different rice cultivars. C, normal

There was greater reduction of productive tillers in all the cultivars with increase of depth of water (Fig. 4). The height of plant increased with increase of the depth of water (Fig. 5). Increase of plant height under stagnant flooding was an adaptive trait to counter act the adverse effect of SF for survival. Probably under SF, the less developed tiller died out and thus number of tiller per unit area decreased. Like increase of plant height and number of grain panicle^{-1} increased with increase in depth of water (Fig. 5). Increase of grain number panicle^{-1} might compensate to some extent the greater reduction of productive tillers under SF. In another experiment it was reported that with progress increase of water depth from 25 to 50 cm increased the plant height, decreased the panicle numbers and grain yield (CRRI Annual Repot 1979, page 68). The reduction was greater in semi-dwarf varieties (e.g. CR 1016, CR 1009, CR 1002, CR 260-147, CR 260-100, CR 1018 and Jagannath) compared to the tall varieties (e.g. CR 1030 and CR 260-30).

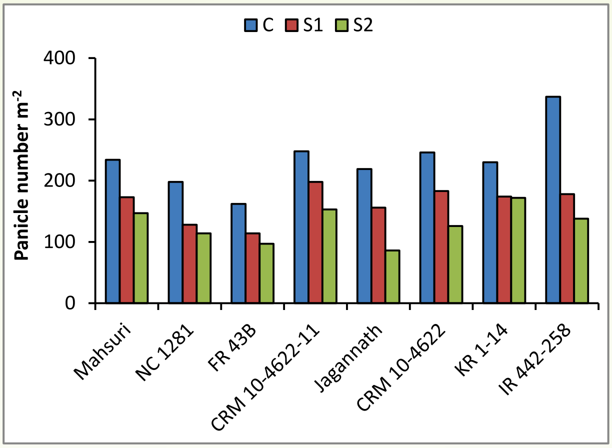

Fig. 4. Influenced of water depth on panicle number of different varieties of rice (C-control, standing water 5 cm; S1-shallow depth (35 cm) standing water; S2-medium depth (50 cm) standing water)

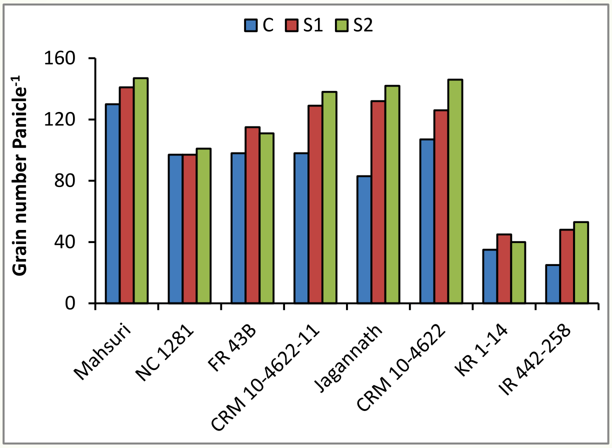

Fig. 5. Influenced of water depth on grain number panicle-1of different varieties of rice (C-control, standing water 5 cm; S1-shallow depth (35 cm) standing water; S2-medium depth (50 cm) standing water)

Plant height found to be an important criterion in getting more yield under medium depth stagnant flooding. An ingenious experiment was conducted to prove the hypothesis i.e. grain yield vs. height of tiller by Bhattacharjee (CRRI Annual Report 1983, page 68-71). He measured the length of the tiller before onset of the imposition of the treatment (60 cm standing water) and 15 days after the treatment. In semi-dwarf variety Jagannath the length of the 50% of tiller was below 50 cm while the length of the rest 50% of tiller was between 50 and 70 cm. On the other hand in tolerant cultivar CR 1030 the length of the most of the tillers (61%) was between 70 and 90 cm, 39% was between 50 and 70 cm length. None of the tiller was below 50 cm in length (Table 2). After 15 days of the imposition of the treatment the length of the some of the tillers in FR 13A and CR 1030 were more than 100 cm in length. Stagnant flooding decreased the number of the panicles as much as 50% in Jagannath while in CR 1030 and FR 13A the reduction in panicle number m^{-2} was 3 and 12%, respectively. In CN 540, however, no reduction of panicle number was noticed. Grain weight $panicle^{-1}$ was more in tiller of higher length compared to the tiller of lower length (Table 3).

Table 2: Variation in the length of the tiller before stagnant flooding (60 cm water depth).

Variety	Tiller number (m^{-2})	Percentage of tillers in different length range		
		70-90 cm	50-70 cm	< 50 cm
FR 13A	425	55	41	4
CN 540	353	32	54	14
CR 1030	646	61	39	Nil
Jagannath	607	Nil	50	50

(*Source*: CRRI Annual Report 1983, page 70).

Table 3: Grain weight (g) panicle^{-1} at different ear bearing tillers of a range of length.

Variety	Different ear bearing tillers of a range of length (cm)						
	170-190	150-169	130-149	110-129	90-109	70-89	< 70
A. Control							
FR 13A	–	–	1.95	1.27	0.42	–	–
CN 540	–	–	2.50	1.66	0.73	–	–
CR 1030	–	–	2.31	1.29	0.62	0.31	–
Jagannath	–	–	–	–	2.53	1.28	0.42
B. Water depth (55-65 cm)							
FR 13A	–	1.81	1.34	0.56	–	–	–
CN 540	–	2.58	1.57	0.77	–	–	–
CR 1030	1.62	2.07	1.20	0.70	–	–	–
Jagannath	–	–	1.55	1.79	1.24	0.77	–

(*Source*: CRRI Annual Report 1983, page 70).

4. PHYSIOLOGICAL BASIS OF TOLERANCE

1. Internodal elongation under medium depth stagnant flooding

Contributors: DP Srivastava and RN De

The experiment was conducted with 22 cultivars to study the intermodal elongation under 40-50 cm of water depth. Under normal condition, the internodes were shorter towards base whereas under stagnant flooding some of the lower internodes were longer than successive upper ones. The phenomenon was more distinct when each culm was considered separately. Due to excessive elongation of internodes at early growth stages, the stem became week and tended to show lodging otherwise they are non-lodging type under normal condition (CRRI Annual Report 1981, page 15).

2. Impact of stagnant flooding on elongation in relation to plant hormone and anti-oxidant enzymes

Contributors: T Pullaiah, B Das, SV Ambudkar, SB Lodh and DP Bhattacharjee

Anaerobiosis of submerged soil leads to the formation of toxic levels of hydrogen sulphide, organic acids and other chemicals, which restrict growth and productivity of the crops. Rice in general is tolerant to such conditions. Due to self degeneration of aerenchymatous cells passage of air to the root zone through stem occurred in rice and rice can survive the stagnant flooding even up to the level more than 3 m depth of water keeping the leaf tip always above the water surface. It needs energy. In general with increasing water depth the main penalty is the yield. However, at a specified water depth certain cultivars surpass the yield compared to the others. The tolerant cultivar is identified for agricultural purposes. Soil submergence impairs the absorption of metallic ions. Thus to study haem containing enzymes catalase and peroxidase as well as cupper containing enzyme ascorbic acid oxidase in relation to stagnant flooding tolerance is important. A lot of work was done in this direction at CRRI (Annual Report 1979, page 154-155; Annual Report 1980, page 169; Annual Report 1981, page 104). Role of IAA oxidase and IAA and GA content were also studied in relation to adaptation or rice under intermediate stagnant flooding condition with stagnant flooding susceptible (e.g. Jagannath and CR1009) and tolerant cultivars (e.g. IET6206). Due to the imposition of stagnant flooding the activities of IAA oxidase increased with the increase of water depth. IAA oxidase activities increased even up to 20 days of stagnant flooding in susceptible cultivars Jagannath and CR1009 whereas the opposite trend was observed in resistant type (IET6206). Differential behavior of anti-oxidant enzymes such as catalase, peroxidase and ascorbic acid oxidase were observed in rice roots submerged at different depths of water. Catalase activity either increased or decreased with increasing water depthin different cultivars irrespective of tolerant to stagnant flooding or not. Peroxidase activity increased with increasing water depth in all types of cultivars. Ascorbic acid oxidase activity followed the same trend. Concentration of IAA was greater in panicle at flowering stage at water depth of 55-60 cm. Increase in water depth increased IAA content in internodes at maximum tillering stage whereas at flowering stage IAA content decreased in internodes with increase in water level.Auxin content of the stem under stagnant flooding was similar between Jagannath (susceptible type) and IET6205 (tolerant type) whereas GA content was greater in susceptible cultivar Jagannath compared to tolerant cultivar IET6205 (CRRI Annual Report 1982, page 143).

3. Air space, cell wall degrading enzyme, tiller growth and oxygen liberating power of the root system

Contributors: DP Bhattacharjee, S Singh, SB Lodh and DP Singh

Along with rapid stem elongation under stagnant flooding situations, air-space generally increased, making the stem more congenial to move air. Determination of air-space was done by drawing air of the holes on the stem by means of suction and determining the volume by expressing quantity of water that occupied air space in ml (CRRI Annual Report 1981, page 100). The results indicated highest volume of air-space in the susceptible cultivar Jagannath. Among the tolerant type air-space was greater in FR13A followed by CR1030. The volume of air-space was the lowest in tolerant high yielding cultivar IET6205. Jagannath, FR13A and CR1030 were more vulnerable to lodging compared to IET6205 with greater air-space volume.

The activity of cell-wall degrading enzyme pectinmethyl esterase (PME) was greater in all plant parts (e.g. leaf blade, leaf sheath and culm) in susceptible cultivar Jagannath at the initial stage of stagnant flooding compared to tolerant cultivar CN540. The trend remained same with respect to leaf sheath and culm with growth in susceptible cultivar while the activity of PME in leaf blade was greater in the tolerant cultivar CN540 (CRRI Annual Report 1981, page 100).

It is assumed as the water table increase supply of oxygen to root zone decrease. The cultivars are able to supply more oxygen to the root zones are supposed to survive better and could produce greater yield. Root oxidase activity, an indirect method to measure oxygen liberating power of the root system was always greater in tolerant cultivars compared to the susceptible cultivars under different depth of stagnant flooding (CRRI Annual Report 1981, page 101). The tillers which were productive and survived the onslaught of stagnant flooding in both tolerant and susceptible cultivars showed greater activities of root oxidase compared to non-performing week tillers (Table 4). Primary tillers which accumulated greater quantities of dry matter before the on set of stagnant flooding survived better compared to secondary tillers. Increased water depth also decreased leaf area and dry matter accumulation in secondary tillers. Both Chlorophyll a and b content was greater in primary tillers compared to the week secondary tillers.

Table 4. Physiological behavior of the tillers of different ranks under stagnant flooding (mean of four weekly observations up to flowering).

Cultivars	Tiller ranks	Percent tiller survival		In comparison to normal condition			
		S1	S2	Percent reduction of root oxidase acitivity		Percent reduction of dry matter	
				S2	S2	S1	S2
CR1030	1	100	100	22.4	29.8	20.4	40.1
	2	88	73	21.4	31.3	15.2	46.5
	3	0	0	---	---	---	---
IET6205	1	100	100	22.8	32.9	15.7	34.2
	2	86	71	40.5	51.2	19.2	43.8
	3	10	10	37.8	52.7	32.1	60.8
IET6271	1	100	86	28.4	50.2	24.2	47.8
	2	76	62	40.0	50.5	42.2	62.8
	3	16	12	46.2	60.8	48.8	72.9
Jagannath	1	100	75	34.1	52.1	17.1	52.7
	2	58	31	33.5	53.9	20.1	48.8
	3	44	11	51.1	69.6	51.7	87.5

Tiller rank: 1, mother tiller; 2, primary tiller; 3, secondary tiller; S1 and S2 stagnant flooding with 45-50 cm and 55-60 cm depth of water respectively.

4. Leaf sheath elongation and depletion of carbohydrate

Contributor: RK Sarkar

The experiment was conducted with three rice cultivars such as Tulasi (susceptible type), CR625-18-1 (intermediate type) and Hatipanjari (tolerant type). Hatipanjari exhibited greater elongation of leaf sheath compared to other two cultivars (Table 5). Total non-structural carbohydrate (NSC) content was greater in Hatipanjari. The level of NSC decreased fast in Hatipanjari compared to Tulasi and CR625-18-1. Likewise, amylase activity was also greater in Hatipanjari (Fig. 6). The results indicated that elongation of leaf sheath in tolerant cultivar was possible due to more consumption of stored carbohydrate (CRRI Annual Report 1992-93, page 151-152).

Table 5. Plant height, leaf sheath elongation and carbohydrate content under semi-deep stagnant flooding (65-75 cm water depth).

Cultivar	Plant height (cm)			Leaf sheath length (cm)			Carbohydrate (mg g^{-1} DW)		
	BS	5 DAS	10 DAS	BS	5 DAS	10 DAS	BS	5 DAS	10 DAS
Tulasi	29.8	52.6	53.0	9.5	26.1	26.2	242.4	83.5	73.6
CR625-18-1	33.9	59.4	67.5	11.2	28.2	29.5	339.6	120.1	98.1
Hatipanjari	38.4	79.3	85.5	11.5	40.5	42.0	365.4	85.5	99.4
LSD$_{*p<0.05}$	4.5	4.6	6.5	NS	2.3	2.2	8.6	10.4	4.2

BS, before submergence; DAS, days after submergence; NS, non-significant.

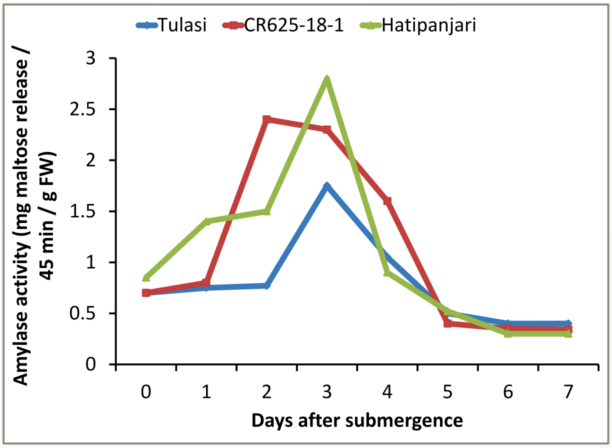

Fig. 6. Changes of the activity of total amylases due to stagnant flooding

5. Association of certain physiological traits in relation to stagnant flooding tolerance in rice

Contributor: SR Kuanar and RK Sarkar

The local landraces adapted to extremes in water availability could be the sources of new gene/(s) which would be utilized to improve the adaptability of rice to SF with high yield. Sixteen rice genotypes were selected after initial screening of more than four hundred rice genotypes which were collected from eastern states of India. The rate of increase of plant height was greater under SF compared to control whereas no such trend was observed in the case of the increment rate of upper ground total dry weight and stem dry weight (Fig. 7). Numbers of gas spaces hill^{-1} and root oxidase activity decreased due to SF (Fig. 8, 9). The reduction of numbers of gas spaces hill^{-1}, root oxidase activity, leaf area and leaf dry weight was greater in susceptible cultivar under SF compared to control (Fig. 10).

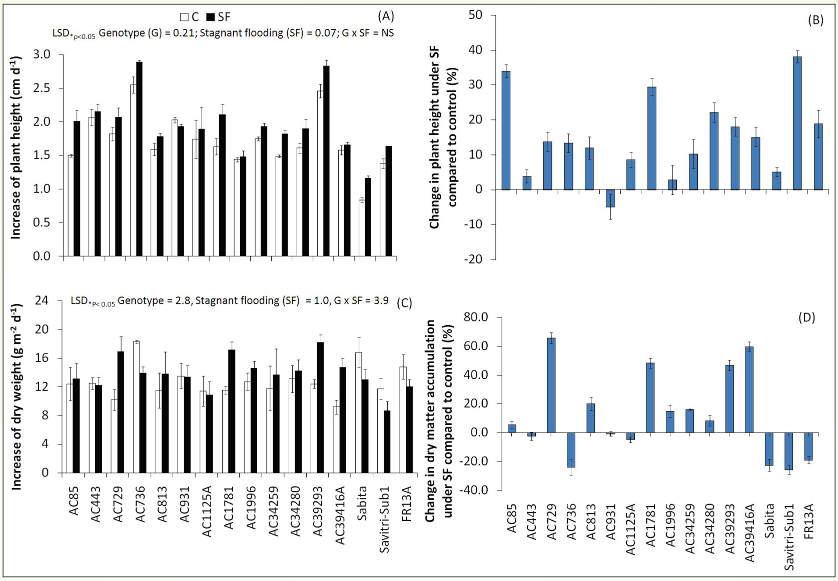

Fig. 7. Elongation and crop growth rate during the initial 30 days of stagnant flooding (A, C) and change in height and dry biomass accumulation in percentage under SF compared to control (B, D) of sixteen rice genotypes. Replication, 3; C, control; SF, stagnant flooding. (Adopted from Kuanar *et al.* 2016. Rice Science)

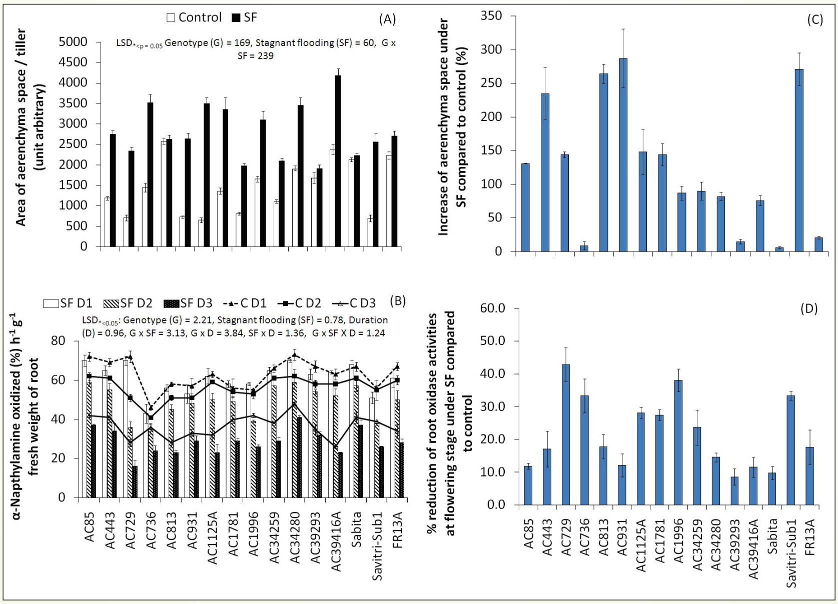

Fig. 8. Number of aerenchyma gas spaces hill^{-1} after 30 days of stagnant flooding (A) and root oxidase activity after 30 and 60 days of SF and at flowering stage (B). Reduction in number of aerenchyma gas spaces and root oxidase in percentage (C, D) under stagnant flooding compared to control. Replication, 3; C, control; SF, stagnant flooding. D1, D2 and D3 respectively after 30 and 60 days of SF and at flowering. (Adopted from Kuanar *et al.* 2016. Rice Science)

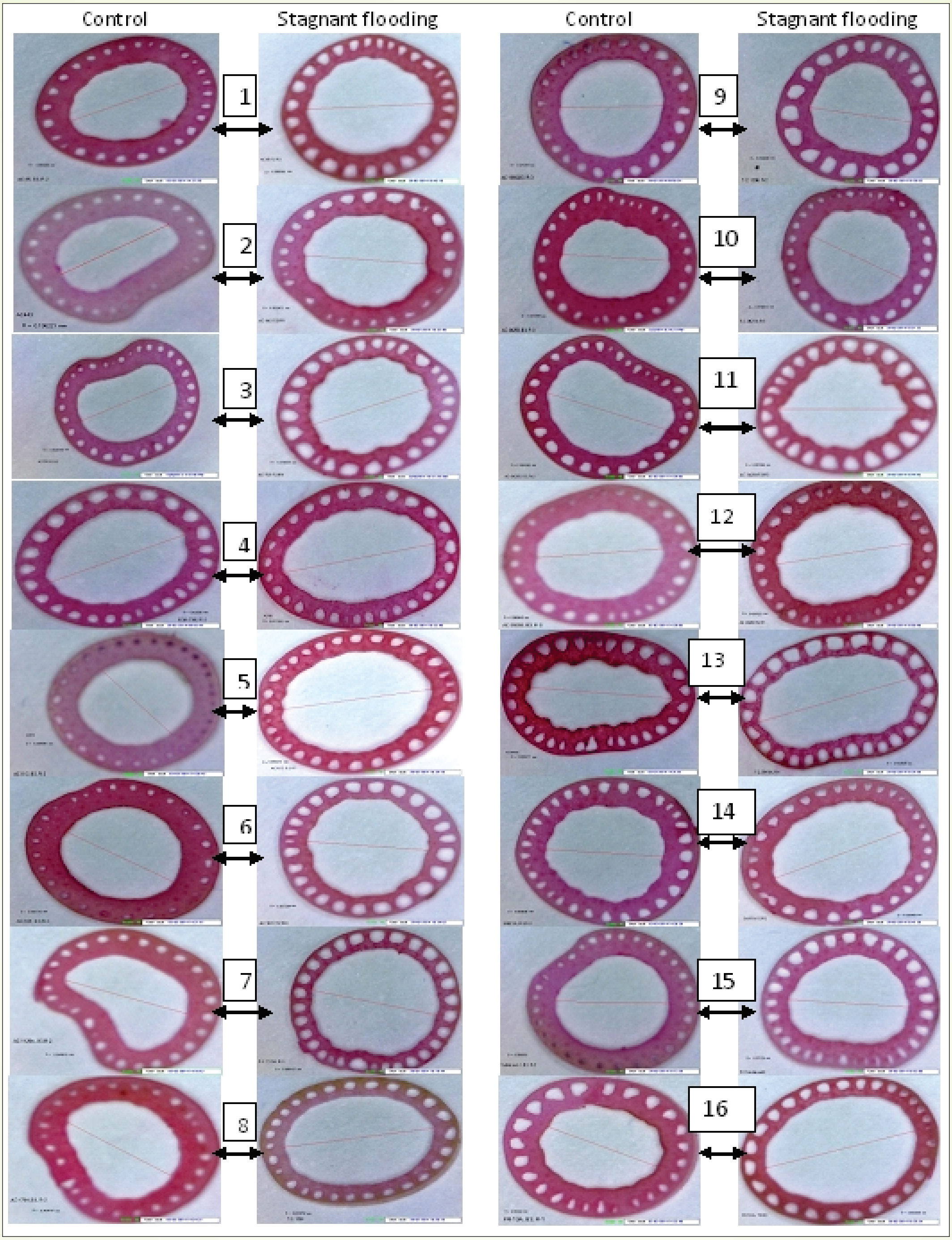

Fig. 9. Cross section of main stem shows the aerenchyma gas spaces of sixteen rice genotypes under control and stagnant flooding after 30 days of stagnant flooding. 1- AC85, 2- AC443, 3- AC729, 4-AC736, 5- AC813, 6- AC931, 7-AC1125A, 8-AC1781, 9-AC1996, 10-AC34259, 11-AC34280, 12-AC39293, 13- AC39416A, 14- Sabita, 15- Savitri- *Sub1* and 16- FR13A. (Adopted from Kuanar *et al.* 2016. Rice Science)

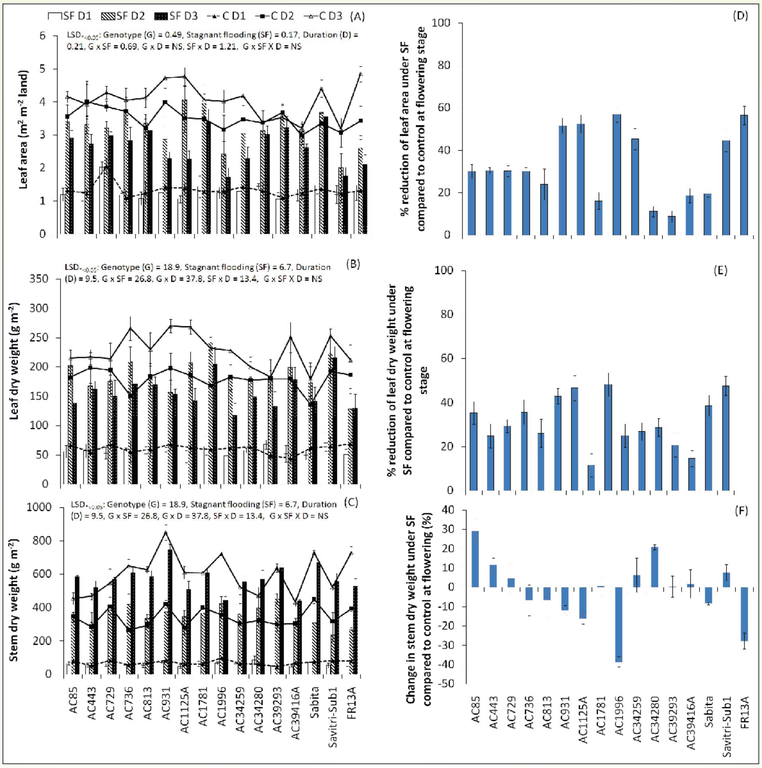

Fig. 10. Leaf area index (LAI in m^2 m^{-2}, A), dry mass of leaf (g m^{-2}, B) and stem (g m^{-2}, C) after 30 and 60 days of SF and at flowering stage. Reduction of leaf area, leaf dry mass and stem dry mass in percentage (D, E, F) under stagnant flooding compared to control. Replication, 3; C, control; SF, stagnant flooding. D1, D2 and D3 respectively after 30 and 60 days of SF and at flowering. (Adopted from Kuanar *et al.* 2016. Rice Science)

Stability index (values under waterlogged condition / values at normal condition) for different yield and yield attributes revealed that the impact of SF differed among different genotypes (Table 6, 7). Correlation coefficient studies among different parameters taking SI values showedsignificant association with SI values of grain yield (Table 8). Based on the findings it was concluded that maintenance of equivalent panicle weight and panicle number, plant height and harvest index at maturity, leaf area, leaf and stem dry weight, root oxidase activity and tiller numbers at flowering under SF compared to control help the plant to counteract the adverse effects of SF.

Incidences of stagnant flooding will increase in future due to unusual rainfall patterns under the influence of climate change, especially in delta regions. Rice genotype tolerant to SF can help in developing improved SF-tolerant rice variety. The present investigation has identified some new SF tolerant genotypes, which could be utilized as donors in rice breeding programme and also for identification of additional genes / QTLs. To summarize, we conclude that the ability of rice to acclimate to a long period of stagnant flooding depends on a combination of morphological and physiological adaptation. Anatomical adjustments such as slow formation of aerenchyma gas spaces along with greater maintenance of root oxidase activity could increase the rate of oxygen diffusion from aerated parts to the root, which is essential for maintaining survival of tillers and growth. Medium elongation is vital for greater plant productivity under SF. Stabilization of vital plant characteristics under SF even after long-term exposure to stagnant flooding is more beneficial for plant productivity.

Table 6. Yield and yield attributing parameters under control and medium depth (˜ 50 cm) stagnant flooding.

Name of the genotypes	Tiller number (m^{-2})			Panicle length (cm)			Panicle number (m^{-2})			Panicle weight (g m^{-2})			Grain Yield (g m^{-2})		
	C	SF	SF/C	C	SF	SF/C	C	SF	SF/C	C	SF	SF/C	C	SF	SF/C
AC 85	189	160	0.85	22.5	21.5	0.95	179	149	0.83	423	400	0.94	325	315	0.97
AC 443	219	164	0.75	24.2	23.9	0.99	184	155	0.84	530	431	0.81	451	367	0.82
AC 729	192	127	0.66	25.7	23.6	0.92	187	118	0.63	482	270	0.56	360	216	0.60
AC 736	162	135	0.83	24.4	23.7	0.97	154	115	0.75	331	253	0.76	234	195	0.83
AC 813	191	167	0.87	22.0	20.2	0.92	183	165	0.90	536	351	0.65	479	274	0.57
AC 931	180	131	0.73	24.8	23.7	0.95	168	123	0.73	459	329	0.72	394	285	0.72
AC 1125A	213	171	0.80	21.2	19.5	0.92	213	170	0.73	417	300	0.72	386	245	0.63
AC 1781	194	177	0.91	24.1	23.3	0.97	187	168	0.90	468	380	0.81	393	303	0.77
AC 1996	187	145	0.78	23.4	21.2	0.90	185	143	0.77	444	323	0.73	381	260	0.68
AC 34259	217	167	0.77	23.6	22.0	0.93	212	170	0.80	481	377	0.78	366	259	0.71
AC 34280	172	146	0.85	24.9	23.7	0.95	171	139	0.81	514	456	0.89	412	373	0.90
AC 39293	179	155	0.87	27.7	24.0	0.87	179	146	0.81	483	334	0.69	383	270	0.70
AC 39416A	174	155	0.89	24.4	23.0	0.94	161	145	0.90	278	276	0.99	214	213	0.99
Sabita	168	149	0.89	25.3	23.1	0.91	166	138	0.83	413	339	0.82	306	269	0.88
Savitri-*Sub1*	198	120	0.61	23.1	22.3	0.96	193	114	0.59	511	336	0.66	448	285	0.64
FR13A	202	129	0.64	23.1	21.5	0.93	194	127	0.65	555	413	0.74	452	331	0.73
LSD$_{*p = <0.05}$															
Genotype (G)	25		~	1.3		~	26		~	80		~	68		~
Treatment (T)	9		~	0.5		~	9		~	28		~	24		~
G x T	ns		~	ns		~	37		~	ns		~	ns		~

C, no flooding; SF, stagnant flooding; ns, non-significant

Table 7. Changes of some yield attributing parameters due to medium depth (~ 50 cm) stagnant flooding.

Name of the genotypes	Plant height (cm)			Fertile spikelet (%)			Single panicle weight (g)			Harvest Index		
	C	SF	SF/C	C	SF	SF/C	C	SF	SF/C	C	SF	SF/C
AC 85	171	199	1.16	74	75	1.01	2.35	2.68	1.14	0.33	0.28	0.85
AC 443	172	190	1.10	75	78	1.04	2.86	2.77	0.97	0.41	0.31	0.76
AC 729	179	184	1.03	73	70	0.96	2.55	2.28	0.89	0.30	0.23	0.77
AC 736	186	200	1.07	71	66	0.92	2.16	2.19	1.01	0.23	0.20	0.87
AC 813	173	196	1.13	88	68	0.77	2.93	2.11	0.72	0.36	0.26	0.72
AC 931	179	200	1.12	85	79	0.93	2.73	2.69	0.98	0.29	0.25	0.86
AC 1125A	151	174	1.15	73	71	0.97	1.93	1.78	0.92	0.30	0.25	0.83
AC 1781	170	186	1.09	76	73	0.96	2.49	2.26	0.91	0.33	0.27	0.82
AC 1996	158	162	1.02	76	64	0.84	2.33	2.28	0.98	0.34	0.32	0.94
AC 34259	170	186	1.09	68	68	1.00	2.26	2.20	0.97	0.31	0.26	0.84
AC 34280	173	204	1.18	78	78	1.00	2.99	3.26	1.09	0.37	0.29	0.78
AC 39293	177	187	1.06	75	71	0.95	2.68	2.32	0.86	0.33	0.26	0.79
AC 39416A	170	208	1.22	69	65	0.94	1.72	1.96	1.14	0.23	0.25	1.09
Sabita	167	188	1.12	63	64	1.01	2.50	2.47	0.99	0.26	0.24	0.92
Savitri-*Sub1*	123	132	1.07	85	76	0.89	2.65	2.98	1.12	0.37	0.31	0.84
FR13A	151	171	1.13	80	81	1.01	2.85	3.20	1.12	0.32	0.30	0.94
$LSD_{*p = <0.05}$												
Genotype (G)	6		—	3		—	0.28		—	0.02		—
Treatment (T)	2		—	1		—	ns		—	0.01		—
G x T	9		—	4		—	0.43		—	0.03		—

C, no flooding; SF, stagnant flooding; ns, non-significant

Table 8. Correlation coefficients (r values) among different parameters based on stability index (values at SF / values at control).

Parameters	DWI	PH	LAI	LDW	SDW	TN	NGS	RO	FS	SPDW	PL	PN	PDW	HI	GY
PHI, increase of height (cm d^{-1})	0.053	0.110	0.289	0.138	**0.522**	-0.032	0.117	-0.070	0.070	0.373	0.219	-0.098	0.169	-0.086	0.166
DWI, increase of dry weight (g m^{-2} d^{-1})	~	-0.039	**0.449**	0.305	0.040	0.298	0.311	0.118	-0.132	-0.333	-0.286	0.335	-0.001	-0.015	-0.044
PH, plant height (cm)		~	0.236	0.207	0.351	0.382	**0.429**	**0.616**	0.242	0.395	0.220	**0.452**	**0.720**	0.323	**0.599**
LAI, leaf area index (m^{2} m^{-2} land)			~	**0.802**	**0.580**	**0.676**	**0.523**	0.402	0.104	-0.175	-0.012	**0.593**	0.326	-0.205	**0.426**
LDW, leaf dry weight (g m ^{2})				~	**0.495**	**0.655**	0.420	0.299	0.173	-0.171	0.211	**0.703**	0.402	-0.065	**0.429**
SDW, stem dry weight (g m $^{-2}$)					~	0.262	0.255	0.277	0.369	0.261	**0.486**	0.290	**0.462**	-0.313	**0.520**
TN, tiller number (m^{-2})						~	**0.764**	0.352	-0.054	-0.240	-0.133	**0.876**	**0.550**	0.075	**0.481**
NGS, numbers of gas spaces hill^{-1}							~	0.381	0.001	-0.296	-0.027	**0.804**	0.417	-0.132	0.279
RO, root oxidase activities								~	0.345	0.087	-0.184	**0.477**	**0.450**	0.069	**0.431**
FS, fertile spikelets % panicle^{-1}									~	**0.444**	0.253	-0.044	0.415	0.048	**0.502**
SPDW, single panicle weight (g)										~	0.369	-0.270	**0.606**	**0.613**	**0.655**
Panicle length (cm)											~	0.043	0.330	-0.080	0.349
PN, panicle numbers (m^{-2})												~	**0.579**	0.016	**0.446**
PDW, panicle weight (g m $^{-2}$)													~	**0.509**	**0.931**
HI, harvest index														~	**0.490**
GY, grain yield (g m ^{2})															~

Significance at $p<0.1$ (0.426), $p<0.05$ (0.497), $p<.01$ (0.623) and $p<0.001$ (0.742) at fourteen degrees of freedom. Bold letters show significant correlation among different parameters.

5. IDENTIFICATION OF NEW GENETIC RESOURCES TOLERANCE TO STAGNANT FLOODING

Contributors : DP Bhattacharjee, RN De, DP Srivastava, AK Singh, BB Reddy, BC Ghosh, G Sahu, T Pullaiah, B Das, SV Ambudkar, RSV Rai, KS Murty, SB Lodh, S Patnaik and RK Sarkar

Due to the heterogeneity in flood-prone ecosystem many different types of traditional rice cultivars are being grown by farmers. These cultivars are low yielder but possess one or more of the adaptive traits required for this ecosystem. Identification of new genetic resources always broadens research activities. It helps to know the basis of tolerance, identification of new genes / QTLs and as parent in on going crop improvement programme. During 70's the work on SF in identification of tolerant cultivars was mainly confined with fixed breeding lines nominated under All India Coordinated Rice Improvement Programme and important best known rice cultivars grown in rainfed lowland areas. On the process several cultivars were identified and were nominated for commercial cultivation. Comparison of grain yield production under normal and medium depth stagnant flooding with two rates of nitrogen application revealed that cultivar NC 1281 was highly tolerant under SF compared to other cultivars (Table 9). SF stability factor index was 96.3 to 97.0 % in NC 1281 and 79.7 to 82.8 % in Jagannath.

Table 9: Grain yield (t ha^{-1}) under normal (0-5 cm) and shallow depth (0-35 cm) stagnant flooding with different doses of nitrogen application.

Cultivars	Normal (N)		Stagnant flooding (SF)		SF/N*100	
	N1	N2	N1	N2	N1	N2
IR 8	4.34	5.08	2.97	2.86	68.4	56.3
Jaya	4.89	4.43	2.82	2.63	57.6	59.2
Vijaya	5.48	5.60	3.77	3.91	68.7	69.7
Jagannath	5.10	5.37	4.23	4.28	82.8	79.7
Manoharsali	5.38	4.83	3.42	3.13	63.5	64.7
T 141	4.51	3.29	2.87	2.51	63.7	76.3
NC 1281	5.39	5.38	5.20	5.22	96.3	97.0
Prasadbhog	4.11	2.97	2.62	2.27	63.6	76.4

(Source: Annual Report 1972, CRRI), N1 and N2, 30 and 60 Kg N ha^{-1}, respectively.

Probably, All India Coordinated Rice Improvement Programme on stagnant flooding was initiated in the year 1976 with 22 high yielding rice cultures under shallow water depth condition (Annexure I). A few cultures were identified. The cultures were NC1281, CR1001, CR1009, IET5656 and Mahsuri. These cultures did not shown any yield loss under SF compared to normal condition. A new initiative was taken under AICRIP in conducting the trial for stagnant flooding conditions. In addition of shallow water depth another treatment of medium depth (45-50 cm) stagnant flooding was also imposed in the year 1977. Intan, a Malayasian variety recorded the highest grain yield of 3.7 t ha^{-1} even at the medium depth SF. Other two promising cultures were NC1281 and CRM 10-4622. Through AICRIP and Institute research activities several high yielding fixed breeding lines were tested. A few cultures, which gave more than 3 t ha^{-1} grain yields under medium depth stagnant flooding, were identified. The cultures were IET 6206 (RAU 38-12-3-1), CR 1030, CRM 10-4817-65-111, CR 1017, CN 540 (Purnendu), IET 6205, CN 643, IET 6237, IET 6206, CR292, FR13A, Mahsuri, IET 6271, C 64-117, IET 6207, CN 492, CR 320-9.

In general fixed breeding lines or the cultures recommended for AICRIP trails were tested for SF tolerance. However, in the year an attempt was made to screen 120 rice cultures along with some germplasm lines received from RRS, Chinsurah, West Bengal for stagnant flooding tolerance under the water depth of 50-60 cm. NC 488-77 was the only culture which gave more than 3 t ha^{-1} grain yield. Other promising cultures were CN 689-1, CN 505-12-5-6 and Achra 1081 (Grain yield was 2-2.4 t ha^{-1}). The above promising cultures were found to be characterized by high survival of the hills and greater number of panicles per unit land basis (CRRI Annual Report 1981, page 98).

Though stagnant flooding tolerance screening at CRRI started in 1970's, systematic evaluation of germplasm screening was started in 1990s. In earlier occasion mainly elite lines were tested for SF tolerance. Stagnant flooding with 45 to 55 cm standing water was imposed after 60 days of germination till dough stage (CRRI Annual Report 1993-94, page 134). Out of 54 genotypes tested for submergence tolerance were also tested for SF tolerance. Only 13 genotypes showed superiority above the tolerant checks (Table 10).Genotype AC 1020 (T 535) was tolerant to submergence and also produced more grain compared to FR13A, Hatipanjari and Jagannath (Table 10) under SF. Two genotypes such as AC 2386 (679 g m^{-2}) and AC 1922 (577 g m^{-2}) produced greater yield among all the genotypes due to greater filled grain %, panicles number per unit area, panicle weight and harvest index.

Table 10. Effect of stagnant flooding ($\approx$ 50 cm water depth) on grain yield and yield attributes of different rice genotypes.

Genotypes	Grain yield (g m^{-2})	Spikelet fertility (%)*	Panicles number (m^{-2})	Panicle weight (g)	Harvest Index
FR13A	230	3	133	201	0.22
Hatipanjari	370	2	159	3.3	0.22
Jagannath	184	3	139	1.9	0.22
AC 19 (CH 19)	525	3	145	3.9	0.23
AC 231 (CD 15)	362	2	105	3.0	0.26
AC 878 (T 343)	358	3	140	2.0	0.20
AC 1020 (T 535)	420	3	145	2.5	0.23
AC 1604 (T 1437)	414	2	290	1.6	0.17
AC 1728 (T 1651/1)	447	3	265	2.1	0.19
AC 1784 (T 1734)	489	3	260	2.3	0.17
AC 1824 (T 1299)	390	3	270	1.6	0.22
AC 1919 (T 1925)	405	2	215	2.2	0.29
AC 1922 (T 1931)	577	1	170	3.9	0.32
AC 2296 (Doc Phung 3470)	478	3	180	3.2	0.19
AC 2386 (Kattuvaman)	679	2	240	3.3	0.25
AC 3260 (KarangSerang 55)	401	2	185	2.1	0.18

*1 = >80% fertility, 2 = >70% fertility up to 80%, 3 = >60% fertility up to 70%. (Adapted from CRRI Annual Report 1993-94, page 136).

Fifty two rice cultivars suitable for rainfed lowland were collected from diverse locations were grown under medium depth SF ($\approx$ 50 cm) conditions (Table 11). The data were analyzed for genetic variability, trait association and D^2 statistics (CRRI Annual Report 1995-96, page 126). Spikelets per panicle, sterility % and straw yield had greater Genetic Coefficient of Variation (GCV) with high heritability and genetic advance. Ear bearing tiller (EBT) per plant and per unit area, plant height, spikelet per panicle and 1000-grain weight exhibited significant positive association with grain yield per plant. EBT per plant, straw yield and spikeltes per panicle showed remarkable direct effect on grain yieldof which EBT per plant and straw yield acted indirectly through other traits in achieving greater yield under SF. The cultivars were grouped into eight clusters (Table 11). Cluster VII and VIII were identified as genetically most divergent from the remaining six clusters. Cluster V showed comparatively greater mean value for spikelets per panicle and grain yield per plant while cluster IV scored the greater value of EBT per plant and panicle length (Table 12).

Table 11. Clustering pattern of 52 cultivars and their place of acclimatization.

Cluster	Number of cultivars	Constituent of population	Place of acclimatization
I	8	TTB 101-11, TTB-106-26-1, TTB-106-29-3, CR626-7-3, NC1281, CR626-7-3, CR260-77, Jogen.	Assam, Odisha.
II	12	SwarnaMahsuri, Rashpanjar, UtkalPrabha, Champeisali, BogaBardhan, Akisali, Monoharsali, Mansarovar, Salivahana, IR575-39-5-27, IR387-84-15-19, Pehkuh.	Odisha, West Bengal, Andhra Pradesh, Philippines.
III	15	Mugai Bombay, CR5800-17-1, CR627-18-1, CR383-10,Lunishree, CR626-16-1, BoitalPakhia, Ravan, FR13A, Biraj, Jaladhi, Sabita, Tilkachari, Ketan Nanga, Pankaj.	Assam, Andhra Pradesh, Philippines, Indonesia, West Bengal, Odisha.
IV	4	Gayatri, CR1006, Tulasi, Savitri.	Odisha.
V	6	TCA48, Champa, Sarumuli, Sudha, Hatipanjari, BaokJavanica.	Assam, Odisha, West Bengal, Indonesia.
VI	5	CR1014, Padmini, Banskathi, Pratap, Mas Javanica	Odisha, West Bengal, Andhra Pradesh, Indonesia.
VII	1	IET7251	Andhra Pradesh
VIII	1	IntanJavanica	Indonesia

(Source: CRRI Annual Report 1995-96, page 127).

Table 12.Cluster means of 10 important quantitative characteristics.

Cluster	Flowering (days)	EBT per plant	EBT (m^{-2})	Height (cm)	Panicle length (cm)	Spikelets per panicle	Sterility (%)	1000-grain wt. (g)	Yield per plant (g)	
									Straw	Grain
I	124	7.7	264	108	21.7	140	13.8	20.2	27.4	14.2
II	109	8.9	269	125	24.1	137	12.6	24.8	34.1	19.2
III	124	7.4	239	142	24.2	147	17.4	25.8	45.9	17.3
IV	147	8.2	256	97	21.9	123	13.5	23.8	30.0	12.7
V	118	9.4	211	149	25.1	183	19.7	27.2	44.4	24.3
VI	101	11.8	295	130	28.1	144	12.5	15.5	43.6	18.0
VII	133	5.9	196	122	28.0	180	15.4	16.8	16.8	9.4
VIII	78	7.5	246	121	24.7	86	16.1	25.3	27.0	15.1

(Source: CRRI Annual Report 1995-96, page 128).

6. ALTERATION OF MORPHO-PHYSIOLOGICAL PARAMETERS UNDER MEDIUM TO SEMI-DEEP WATER DEPTH CONDITIONS

Contributors: DP Bhattacharjee, RSV Rai and KS Murty

Stagnant flooding decreased the tiller number per unit area and increased the plant height. However, for other yield attributing parameters the changes due to stagnant flooding were not so linear. Varietal x Treatment interactions played a vital role and other different parameters changed in different directions. Rai and Murty (CRRI annual Report 1973, page 95) found reduction of panicle number and grain number panicle^{-1} as a result of high spikelet sterility. Several other workers observed increase of grain number vis-à-vis reduction of tiller number (Fig. 4). Bhattacharjee and his colleagues (CRRI Annual Report 1976, pag3 152-154) observed that stagnant flooding with 35-40 cm water depth either at vegetative stage or reproductive stage decreased grain yield, panicle number panicle^{-1}, dry matter production at harvest, however, increased height, panicle length and grain numbers panicle^{-1} (Fig. 11). Under normal condition dry matter at flowering and harvest showed significant association with grain yield (r= 0.88 and 0.90, respectively), whereas under SF grain number panicle^{-1} and grain number m^{-2} showed significant association with grain yield (r=0.86 and 0.88, respectively). Bhattacharjee in another experiment reported survival of tall stature tillers (> 50 cm length) at the time of stagnant flooding with 55-65 cm depth of water. Greater grain number panicle^{-1} and increase of test weight also occurred in tolerant varieties compared to the susceptible varieties (CRRI Annual Report 1982, page 143).

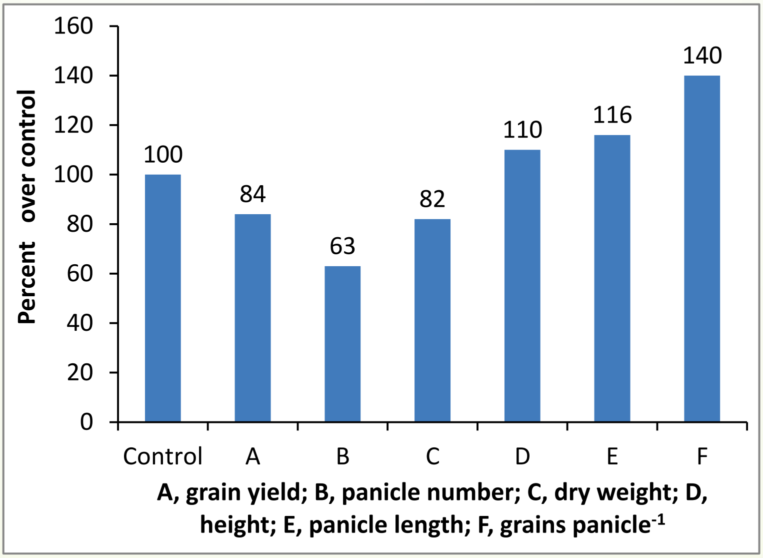

Fig. 11. Effect of stagnant flooding on yield and yield attributing parameters as % over control.

7. POSSIBILITY OF IMPROVEMENT OF TILLER / PANICLE NUMBER PER UNIT LAND UNDER MEDIUM TO SEMI-DEEP WATER DEPTH CONDITIONS

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Transplanting condition

It is now an established fact that mortality of tillers decreases the yield under SF. Several experiments were conducted to check the mortality of the tiller so that number of panicles per unit land area increased which in turn could produce greater yield under SF. The experiment was conducted with two rice varieties such as Mahsuri and Jagannath (CRRI Annual Report 1978, page 27). The experiment was conducted under different spacing i.e. 15 x 20, 15 x 15 and 15 x 10 cm. The approximate numbers of hill m^{-2} were 33, 44 and 67, respectively. Close spacing increased the grain yield production mainly in Mahsuri (Table 13). It was concluded that yield could be augmented under SF condition by increasing the number of plants in certain variety like Mahsuri.

Table 13: Effect of spacing on yield and number of panicle under stagnant flooding.

Spacing (cm)	Hills (m^{-2})	Grain yield (t ha^{-1})			Panicle number (m^{-2})		
		Mahsuri	Jagannath	Mean	Mahsuri	Jagannath	Mean
15 x 20	33	4.21	3.00	3.60	174	137	156
15 x 15	44	4.47	2.96	3.71	197	149	173
15 x 10	67	4.84	3.22	4.03	204	182	193
Mean		4.51	3.06	3.78	192	156	174
LSD*<p = 0.05							
Spacing		299			19		
Variety		244			16		

(Source: CRRI Annual Report 1978, page 27)

In 1978 several other experiments were also conducted taking different varieties under different fertilizers management, methods of crop raising and under different plant density. In one experiment six photosensitive cultures namely CR 1018, CR 1017, CR 98-7223, CR 98-7270, CRM 10-4748-9-63 and one local check Udyog was taken. The experiment was conducted under three water regimes i.e. 25 + 5 cm, 35 + 5 cm and 45 + 5 cm with 5 and 10 seedlings $hill^{-1}$. N, P, and K were applied as basal @ 40, 20 and 20 kg ha^{-1}. Greater number of grain per panicle and greater test weight found to be associated with greater grain yield under

SF (CRRI Annual Report 1978, page 141). The study indicated the advantage of heavy panicle weight type variety over heavy tillering type variety under SF. The study further concluded that increasing number of seedling hill^{-1} did not improve the yielding capacity under stagnant flooding.

To improve the tiller growth and inhibit tiller mortality another experiment was also conducted with three rice varieties namely CR 1009, CR 1017 and CR 1018 (CRRI Annual Report 1978, page 140-141). Three cultural practices were employed, 1) spacing (15 x 15 cm and 20 x 15 cm), 2) seedling number (3, 6, and 9 hill^{-1}) and 3) age of seedlings (35 and 50 days old). It was concluded that closer spacing (15 x 15 cm) gave greater yield (2.5 t ha^{-1}) compared to the wider spacing (20 x 15 cm). In wider spacing the grain yield was 2 t ha^{-1}.Increase the number of seedlings hill^{-1} did not improve the yield. Younger seedling gave more yields under shallow water depth. Greater seedling age did not improve the grain yield production under medium depth condition. However, placement of urea briquettes in moist soil resulted in higher crop yield compared to sulphur coated urea, urea briquettes in shallow water (20-30 cm water depth) and prilled urea drilled behind the plough (CRRI Annual Report 1979, page 60). Foliar application of urea did not prove effective under medium depth SF due to prevalence of less foliage above water. Application of N @ 40 kg ha^{-1} as basal found more effective under stagnant flooding of medium depth condition.

An ingenious experiment was conducted with cultivar CR1030 during the wet season of 1980 and 1981 (CRRI Annual Report 1980, page 79-80; CRRI Annual Report 1981, page 44-45). Varying plant densities (150, 200 and 250 seedlings m^{-2}) were achieved through changing the spacing as well as numbers of seedlings per hill. At active tillering stage the number of tillers or plant m^{-2} was greater under close spacing where numbers of seedlings were greater at the time of planting. As the crop growth advanced, mortality of tillers was high in closer planting that resulted in no appreciable difference in panicle bearing tillers and grain yield. Increase in initial population at the time of planting did not affect the number of ear bearing tillers and yield (Table 14). With new cultivar (test cultivar IET 6206) increase of yield was observed under medium depth stagnant flooding condition with close planting with greater number seedlings hill^{-1}(CRRI Annual Report 1980, page 160-161). Close spacing of 15 x 10 cm with 6 seedlings hill^{-1} increased grain yield by 70 % over that of wider spacing (15 x 20 cm) with 6 seedlings hill^{-1} (Table 2). The panicle number and dray matter content per unit land area at harvest and leaf area index at flowering increased under dense planting. The findings indicated that close spacing (15 x 10 cm) with 6 seedlings hill^{-1} was optimum to get greater yield under medium depth stagnant flooding condition. It is appearing two opposite observation that cultivar x spacing determine the yield potential under stagnant flooding. Some cultivars are responsive with spacing under stagnant flooding, others are not. Several experiments were conducted to find out the optimum seedling density under intermediate stagnant flooding condition. In an experiment (CRRI Annual Report 1982, page 27) two cultivars namely CR1018 (Semi-dwarf) and CN540 (medium tall) were used under different spacing and seedlings hill^{-1}. Tiller number was recorded at 15d intervals till maturity. It was observed that the rate of tiller formation was greater at low seedling density condition compared to high seedling density condition. However, at maturity there was no significant difference in panicle bearing tillers among different seedling densities conditions. Summarizing all the experiments conducted during 1970s and 1980s it was observed that except one experiment (Table 15) in other experiments increasing planting density did not improve the grain yield production. It was probably due to the variation of the age of the seedlings, application of stress days after transplanting and of course depending on the severity of stress. In the experiment where beneficial aspects of dense planting observed stagnant flooding was imposed after 25 days of planting till dough stage with 55-60 cm depth of water. Plant did not get time to produce sufficient tillers before which stagnant flooding imposed. However, in this experiment tiller growth with time was not studied.

Table 14. Tillering pattern, effective tillers and grain yield as influenced by varying plant densities under stagnant flooding condition (Cultivar CR1030).

Treatment		Tillers (m^{-2})				Panicle (m^{-2})	Grain yield ($t\ ha^{-1}$)
Spacing	Seedling $hill^{-1}$	30d	60d	90d	120d		
20 x 10 cm	3	150	307	225	201	193	2.27
	4	200	303	255	226	204	2.67
	5	250	310	281	242	206	2.47
Mean		200	307	254	223	201	2.47
20 x 15 cm	5	160	260	226	220	192	2.07
	6	200	309	254	233	207	2.17
	8	240	319	285	255	231	2.37
Mean		200	296	255	236	210	2.20
20 x 20 cm	6	150	250	200	200	159	2.15
	8	200	286	214	213	182	2.07
	10	250	290	238	224	210	2.10
Mean		200	275	217	212	184	2.10
20 x 25 cm	8	160	236	216	183	175	2.23
	10	200	276	243	222	196	2.37
	13	260	307	280	240	218	2.13
Mean		207	273	246	215	196	2.24

(Source: CRRI Annual Report 1980, page 80)

In an another experiment eight cultivars namely ARC7028, ARC7109, ARC7041, ARC7022, Tulasi, Lunishree, CR383-10 and Hatipanjari were studies at three different spacing such as 10 cm x 10 cm, 10 cm x 20 cm and 10 cm x 30 cm with three replications under medium depth (≈ 50 cm) stagnant flooding (CRRI Annual Report 1999–2000, page 69–70). Three seedlings per hill were planted. Means of various parameters under different spacing showed that total above ground dry matter accumulation at flowering was greater under close spacing (10 cm x 10 cm). Differences of various parameters are given in Table 16. Spacing had great effects on different growth and yield contributing characteristics. Among the different cultivars, Hatipanjari gave maximum grain yield (416 g m^{-2}), followed by CR383-10 (382 g m^{-2}) and Lunishree (361 g m^{-2}). The correlation studies revealed that most important parameters contributed greater yield under medium-deep stagnant flooding were harvest index and single panicle weight, which showed highly significant positive association with grain yield. Unfilled grain percentage had highly significant negative association with grain yield, harvest index and single panicle weight. High-density grain percentage did not vary much in lowland cultivars, which generally gave flower after 20th October. Single tiller weight at flowering had greater influence on single panicle weight at harvest. It showed highly significant association (r = 0.648**).

Table 15. Effect of spacing and seedlings $hill^{-1}$ on yield and yield attributes under stagnant flooding (water depth 55 - 60 cm, Cultivar IET6206).

Number of seedlings $hill^{-1}$	Spacing			Mean
	15 x 10 cm	15 x 15 cm	15 x 20 cm	
Gran yield (g m^{-2})				
2	74.4	36.8	35.0	48.4
4	251.7	203.9	169.4	208.3
6	306.1	244.3	179.8	243.4
Mean	210.7	161.3	128.1	--
Panicle (number m^{-2})				
2	57	23	16	32
4	162	122	92	125
6	218	151	106	157
Mean	146	99	71	--
Panicle length (cm)				
2	16.7	17.0	18.6	17.4
4	17.7	17.8	19.7	18.4

6	16.6	17.1	18.9	17.5
Mean	17.0	17.3	19.1	–
Grains panicle^{-1}				
2	82	87	116	95
4	84	90	100	91
6	78	89	95	87
Mean	81	89	104	–
LSD$_{*p<0.05}$	Spacing	Seedlings (number hill^{-1})		Interaction
Grain yield	64.0	64.0		NS
Panicle (number m^{-2})	31	31		52
Panicle length (cm)	1.8	NS		NS
Grains panicle^{-1}	10.3	10.3		17.9

NS, non-significant.

Table 16. Varietal means of different parameters under medium depth SF at flowering and at harvest.

Cultivars	Parameters at flowering				Parameters at harvest				
	Flowering date	Tiller weight (g)	LDW (g m^{-2})	TDM (g m^{-2})	Panicle (number m^{-2})	Panicle weight (g)	Sterility (%)	Harvest Index	Grain yield (g m^{-2})
ARC7028	27 Oct	5.9	286	1,316	209	2.01	36.9	0.22	294
ARC7109	26 Oct	5.7	250	1,161	203	1.92	38.7	0.20	283
ARC7041	26 Oct	7.0	203	987	151	2.46	50.0	0.21	258
ARC7022	21 Oct	8.8	246	1,162	119	2.73	39.6	0.17	204
Tulasi	26 Oct	6.6	280	1,594	184	1.95	59.2	0.16	236
Lunishree	26 Oct	7.4	209	1,094	182	2.75	37.0	0.26	361
CR383-10	08 Nov	8.5	319	1,648	142	3.25	28.0	0.24	382
Hatipanjari	27 Oct	7.3	245	1,318	177	3.09	35.0	0.28	416
LSD $_{*p<0.05}$	–	1.4	46	365	33	0.50	10.0	0.03	60
CV (%)	–	12	10.9	13.2	11.7	12	15	9.4	12

(Source: CRRI Annual Report 1999-2000, page 69)

Direct Seeding

The experiment was conducted with four rice cultivars namely CR1009, CR1016, CR1030 and Mahsuri with four seed rates i.e. 60, 80, 100 and 120 kg ha^{-1} (CRRI Annual Report 1979, page 64-68). Greater seed rate increased the numbers of ear bearing tillers but the same was not reflected in yield particularly with semi-dwarf cultivars like Mahsuri, CR1009 and CR106. The cultivars showed inverse relation between ear bearing tillers and spikelet number panicle^{-1}. It was concluded that increase of panicle numbers more than 250 m^{-2} appeared to be difficult under waterlogged condition with 40 kg N ha^{-1}.

The experiment was conducted with three rice cultivars namely CR1018, CR1030 and CR260-30 with four seed rates i.e. 200, 300, 400 and 500 seeds m^{-2} under intermediate depth waterlogged condition. Data on tillering pattern indicated that varying seed rates influenced the initial seedling count and tillers. However, the similar trend was not noticed during the harvest. Tiller mortality was greater in thickly sown crop (400 and 500 seeds m^{-2}). Three hundred seeds m^{-2} found to be optimum to get maximum yield (CRRI Annual Report 1981, page 44). In another experiment it was concluded that two to three hundred seed m^{-2} would be optimum to get the maximum benefit. Increasing the seed rate beyond 200-300 seed m^{-2} did not improve the yield in the test variety CR1018 (CRRI Annual Report 1984, page 20). In an another experiment it was observed that grain yield of direct-sown rice using 400 and 600 seeds m^{-2} gave comparable yield as the increase of panicle numbers m^{-2} at higher seed rate was associated with reduced panicle-weight (CRRI Annual Report 1992-93, page 146; CRRI Annual Report 1993-94, page 149). Direct sown with different seed rate (200, 400, 600, 800 and 1000 seeds m^{-2}) with 0, 40 and 60 kg of N ha^{-1}did not improve the grain yield even in a tall variety Nalini under seed rate beyond 400 seeds m^{-2}. Basal application of 40-60 kg N ha^{-1} was necessary to get maximum yield under semi-deep stagnant flooding condition (CRRI Annual Report 1992-93, page 165). The crop raised from clonal tillers, which collected from direct seeded plants gave greater grain yield followed by that from fertilized and unfertilized nursery seedlings (CRRI Annual Report 1993-94, page 138-140). The yield of direct sown crop from which the clonal tillers were removed for planting did not decrease because the reduction of panicle number was compensated for by increased panicle weight. Planting with clonal tillers produced significantly more grain yield than that of nursery seedlings irrespective of the time of planting and variety.

Direct seeding and transplanting

Thirty days old seedlings were transplanted with three seeds per hill. The level of water above the soil surface varied from 30 to 50 cm for most of the growing season (Fig. 12). Comparison of grain yield and growth parameters under direct seeding and transplanting conditions revealed that compared to transplanting, the crops from direct seeding had more plant height and above ground dry matter, less chlorophyll and specific leaf weight, and more panicles per unit leaf area and sterile spikelets under medium depth water stagnation (Tables 17A, B).

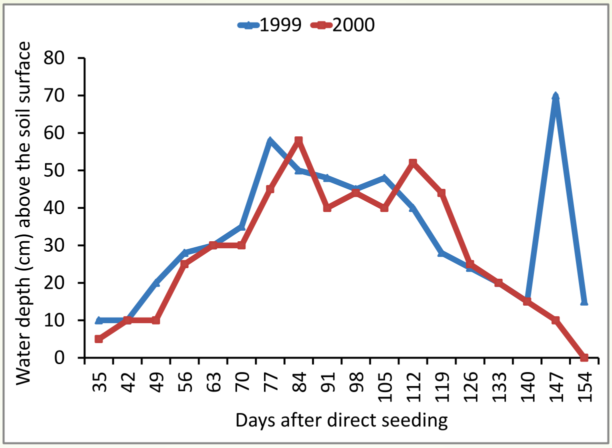

Fig. 12. Stagnation of water in rice field with crop growth.

Table 17. Growth parameters under direct seeding compared to transplanting at medium depth stagnant flooding (30–50 cm water depth).

A.

Parameters	Year	Tualsi	FR13A	T1471	Sabita	Kolasali	CH19
Plant height (cm)							
Direct seeding	1999	159^{b}	156^{b}	169^{a}	165^{a}	147^{c}	169^{a}
	2000	165^{b}	159^{c}	169^{ab}	167^{ab}	146^{d}	172^{a}
Transplanting	1999	146^{b}	145^{b}	156^{a}	155^{a}	142^{b}	161^{a}
	2000	157^{bc}	152^{c}	158^{b}	157^{bc}	137^{d}	165^{a}
Tiller weight (g)							
Direct seeding	1999	5.33^{b}	4.56^{cd}	4.22^{cd}	6.67^{a}	4.08^{d}	4.65^{c}
	2000	4.53^{bc}	3.66^{c}	4.22^{bc}	6.35^{a}	4.39^{bc}	4.86^{b}
Transplanting	1999	5.33^{a}	3.71^{c}	3.85^{c}	5.71^{a}	3.58^{c}	4.75^{b}
	2000	6.50^{a}	5.42^{bc}	5.07^{c}	6.23^{ab}	4.77^{c}	6.21^{ab}
Total above ground dry matter (g m^{-2})							
Direct seeding	1999	1516^{a}	1469^{a}	1259^{b}	1580^{a}	1337^{b}	1232^{b}
	2000	1194^{c}	909^{d}	1710^{a}	1455^{b}	789^{c}	1669^{a}
Transplanting	1999	1019^{bc}	1206^{a}	1097^{b}	927^{c}	774^{d}	1302^{a}
	2000	889^{c}	776^{d}	1100^{b}	1046^{b}	626^{c}	1265^{a}
Leaf dry weight (g m^{-2})							
Direct seeding	1999	311^{a}	281^{b}	241^{c}	314^{a}	297^{ab}	226^{c}
	2000	232^{cd}	196^{dc}	369^{a}	261^{c}	168^{c}	315^{b}
Transplanting	1999	204^{bc}	240^{a}	208^{bc}	197^{c}	171^{d}	226^{ab}
	2000	184^{ab}	140^{bc}	224^{a}	180^{ab}	120^{c}	215^{a}

B.

Chlorophyll (SPAD value)						
Direct seeding	1999	30.7^{bc}	30.2^{b}	33.3^{ab}	$32.4a^{bc}$	34.3^{a}
	2000	26.7^{cd}	28.5^{bc}	28.5^{bc}	28.8^{b}	32.9^{a}
Transplanting	1999	33.6^{b}	33.4^{b}	33.4^{b}	34.3^{b}	38.4^{a}
	2000	27.5^{b}	30.2^{a}	30.7^{a}	31.8^{a}	31.6^{a}
Panicle weight (g)						
Direct seeding	1999	1.80^{d}	2.18^{bc}	1.83^{d}	2.71^{a}	2.33^{b}
	2000	1.68^{bc}	1.72^{bc}	1.62^{c}	2.46^{a}	2.06^{b}
Transplanting	1999	2.16^{d}	2.24^{cd}	2.47^{bc}	3.43^{a}	2.55^{b}
	2000	2.64^{b}	2.30^{b}	2.30^{b}	3.15^{a}	2.28^{b}
Effective panicle (number m^{-2})						
Direct seeding	1999	247a	241a	252a	220a	227a
	2000	312a	242b	288ab	262b	242b
Transplanting	1999	235a	203b	235a	176b	202b
	2000	191b	164b	267a	178b	157b

Means in row with a common letter are not significantly different at the 5% level (Source: Sarkar and Das, 2003)

With direct seeding there were more sterile grains than with transplanting, apart from Kolasali (Table 18). In 1999, percentage of chalf was generally higher, presumably due to untimely flooding just before flowering. The harvest index was quite low, especially for direct seeding. Sabita gave the highest yield under both direct seeding and transplanting. Tulasi gave substantially lower yield with direct seeding, but for other cultivars the yield difference was not significant.

Table 18. Yield and yield attributing parameters under direct seeding compared to transplanting at medium depth stagnant flooding (30-50 cm water depth).

Parameters	Year	Tualsi	FR13A	T1471	Sabita	Kolasali	CH19
Spikelet sterility (%)							
Direct seeding	1999	50.1^{a}	29.6^{cd}	31.4^{cd}	33.8^{bc}	25.3^{d}	39.2^{b}
	2000	25.4^{b}	23.6^{b}	36.7^{a}	18.5^{c}	26.6^{b}	24.8^{b}
Transplanting	1999	42.3^{a}	28.8^{cd}	33.0^{bc}	23.5^{d}	25.5^{d}	37.8^{ab}
	2000	19.3^{b}	17.8^{b}	26.0^{a}	17.9^{b}	25.4^{a}	21.3^{ab}
Harvest index							
Direct seeding	1999	0.18c	0.23^{ab}	0.21^{bc}	0.22^{ab}	0.26^{a}	0.23^{ab}
	2000	0.19^{b}	0.22^{ab}	0.19^{b}	0.24^{a}	0.21^{ab}	0.16^{c}
Transplanting	1999	0.26^{b}	0.23^{b}	0.24^{b}	0.33^{a}	0.30^{a}	0.25^{b}
	2000	0.26^{b}	0.25^{b}	0.21^{c}	0.31^{a}	0.25^{bc}	0.21^{c}
Grain yield (t ha^{-1})							
Direct seeding	1999	3.06^{c}	3.69^{bc}	3.74^{bc}	4.64^{a}	4.20^{ab}	3.63^{bc}
	2000	3.94^{b}	3.24^{cd}	3.74^{bc}	5.04^{a}	4.17^{b}	2.99^{d}
Transplanting	1999	3.73^{bc}	3.70^{bc}	3.89^{bc}	4.86^{a}	4.27^{ab}	3.00^{c}
	2000	4.57^{b}	3.13^{d}	3.91^{c}	5.43^{a}	3.74^{cd}	3.15^{d}

Means in row with a common letter are not significantly different at the 5 % level (Source: Sarkar and Das, 2003)

Correlation studies showed that in both years only harvest index and panicle weight was positively and significantly associated with grain yield. In 1999, sterility showed significant negative association with yield, while specific leaf weight showed significant positive association with yield. In both years, the harvest index was negatively associated with height, total above ground matter content, leaf dry weight, sterility percentage and panicle number, but it showed a significant positive association with specific leaf weight, chlorophyll content and panicle weight. The negative association between panicle weight and number suggested that in the rain-fed lowland with medium depth stagnation flooding, higher yield depended on stronger and healthy panicle.

8. SEEDLING AGE AND NITROGEN MANAGEMENT TO INCREASE YIELD UNDER MEDIUM DEPTH STAGNANT FLOODING

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1. Seedling age and time of planting

The experiment was conducted with two cultivars such as CR1018, a semi-dwarf and CR1030, tall cultivar. Transplanting was done in two occasions i.e. normal (around 10th July) and delayed planting 20 days after the first planting. Thirty, forty five and sixty days old seedlings were transplanted in all the years. Crop received a uniform dose of fertilizer @ 40, 20 and 20 kg N, P_2O_5 and K_2O ha^{-1}. Grain yield data of two years are presented in Table 19. Early planting gave greater yield compared to the late planting. Both the cultivars performed well at early planting compared to the delayed planting. It was reported (CRRI Annual Report 1982, page 7-9) that the cultivar CR1018 attained a height of 90-95 cm under normal condition whereas under medium depth stagnant flooding the height reached to 120 to 125 cm. This helps in producing good yield at normal condition and at the same time it helps in sustaining the production under medium depth stagnant flooding condition. Seedling age did not appear to alter the yields conspicuously when planted early. Under late planting, however, use of 45 days old seedlings appeared to be quite desirable.

Table 19. Effect of seedling age and time of planting on grain yield (t ha^{-1}) of two rice cultivar under medium depth stagnant flooding; Early planting, 10th July; Late planting, 30th July.

Cultivar	Planting	1981 Seedling age			Mean	1982 Seedling age			Mean
		30d	45d	60d		30d	45d	60d	
CR1018	Early	1.97	2.19	1.96	2.04	3.18	3.51	3.67	3.45
	Late	2.22	1.86	1.71	1.71	0.01	0.61	0.93	0.51
CR1030	Early	1.88	2.03	2.02	1.98	3.52	3.32	3.68	3.50
	Late	1.03	1.29	0.54	0.5	0.88	2.03	1.45	1.45

LSD$_{*p<0.05}$		
Date of planting	0.54	0.66
Cultivars	0.17	0.36
Seedling age	0.21	0.12
Date x cultivar	0.25	0.51
Date x age	0.30	0.17
Cultivar x age	NS	NS
Date x cultivar x age	NS	NS

NS, non-significant (Source: CRRI Annual Report 1982, page 7-9)

2. N management under stagnant flooding under medium deep to semi-deep conditions

The experiment was conducted with four rice cultivars namely, FR43B, CN643, CR143-7 and OR1105 under four levels of N i.e. 0, 20, 40 and 60 Kg N ha^{-1} under direct seeded condition with the seed rate of 80 kg ha^{-1}. Phosphorous and potassium was applied as 20 kg ha^{-1} as basal in the form of P_2O_5 and K_2O, respectively. The water depth in the field ranged between 70 and 110 cm in most of the time. Heavy rain at the end of August resulted increase of water depth to the extent of 130 cm (CRRI Annual Report 1982, page 32-33). The crop fertilized with N was vigorous due to early growth which could enable them to tolerate the rise of water depth.

Application of N significantly increased the yield while cultivars and interaction between N and cultivar did not reach the level of significance. At zero level of N a meager of 0.80 t ha^{-1} grain yield was obtained whereas the yield level of 1.20 and 1.57 t ha^{-1} was obtained at 20 and 40 kg N ha^{-1}, respectively. The yield level between 40 and 60 kg ha^{-1} was however non-significant. Among the rice cultivars, OR143-7 produced greater yield (2.15 t ha^{-1}) compared to the other cultivars due to tallness and sturdy stem. In another experiment under medium depth (45-50 cm) condition with 20 and 40 kg N ha^{-1} Janaki and CR143-7 performed well and produced 2.49 to 2.43 t ha^{-1}, respectively (CRRI Annual Report 1984, page 26). These two cultivars due to their greater elongation capacity attained the height of more than 140 cm as early period of stagnant flooding and counter acted the deleterious effects of stagnant flooding of 140 cm water depth. The cultivar Janaki produced 54 and 115 % more yield at 20 and 40 kg N ha^{-1} over control (0.39 t ha^{-1}), while the percentage increase of grain yield in Jaladhi1 was 12 and 36 % over control (1.34 t ha^{-1}).The crop received N along with P and K attained considerable plant vigour which in turn helped them to withstand such excess water stress.

3. Method of stand establishment and N application on grain yield of rice:

Nitrogen application @ 40 kg ha^{-1} improved the performances of rice under medium depth to semi-deep condition (35 to 75 water depth). Among the tested cultivars such as CR1018 and NC1281 proved to be superior under direct seeding condition compared to transplanting. On the other hand, the performance of CN540 (Suresh) was comparable between direct seeded and transplanting conditions.

Direct sown crop found to be better compared to transplanting crop. This was probably due to better initial crop establishment and better seedlings vigour of direct-sown crop before the stagnation of water in the field (Annual Report 1994-95, page 155-156). The results showed that dry direct seeding with 400 seeds m^{-2} or transplanting with clonal tillers collected from 50-day-old seedlings with 600 seeds m^{-2} was beneficial. Under SF with 70-85 cm depth of water basal application of nitrogen @ 30 kg ha^{-1} improved the yield. Seed rate (400 seeds m^{-2}) found optimum in realizing better yield. Increase of seed rate more than 400 seeds m^{-2} did not improve yield, whereas seed rater below 400 seeds m^{-2} decreased the production (CRRI Annual Report 1994-95, page 156, 163-164). It was also observed that even under greater depth of water stagnation (90-110 cm) greater seed rate (600 seeds m^{-2}) did not produce greater yield compare to lower seed rate (400 seeds m^{-2}).

FUTURE PERSPECTIVE

Rice is tolerant to stagnant flooding compared to any other cereals grown in this universe. Still rice production is far less under stagnant flooding compared to irrigated conditions. Efforts have been made since the 1970s at Central Rice Research Institute, Cuttack-753 006, India to improve the production of rice under various levels of stagnant flooding. The success still date is exemplary; several varieties have been released for commercial cultivation that is suitable for different level of stagnant flooding. Plant type suitable for shallow rainfed lowland is not suitable for medium-depth to deep water rainfed lowland conditions. Now-a-days climate change is also impeding the normal production under different level of stagnant flooding. Excess or deficit rainfall with extreme event is common even in a specific growing season. In a deficit year shallow lowland rice may encounter drought while the crop grown in medium depth conditions may encounter less stress. Shifting of agriculture operation due to deficit rain in the month of June followed by excess water in the latter period of growth may induce both drought and submergence stresses in entire rainfed lowland rice. To get sustainable production from rainfed lowland multiple abiotic stress tolerant varieties are needed. Characterizing germplasms tolerant to multiple abiotic stresses and development of high yielding rice variety tolerant to multiple stresses by utilizing such genetic resources may stabilize the rice production in rainfed lowland. Shifting of agricultural operation from June to latter period of the year invites separate types of pests and diseases, which may affect production.

Rice is a short day plant. Farmers in eastern India generally grow photosensitive rice cultivars due to its capability to flower starting from 3rd week of October to 2nd week of November for various benefits. To get greater yield an optimum biomass is required. When time to produce greater biomass is reduced, efficient plant type with greater biomass production capability can solve the problem. Stagnation of water in the field is not a fixed entity. It may change year to year, time to time in the same field. Short stature (semi-dwarf) plant may be good under shallow rainfed lowland conditions, but this is not suited under higher depth of water. Plant with great plasticity in finalizing the plant height under different depth of water is the key. A switch off / on mechanism is required on elongation growth depending on the level of stagnant water. Plants adapt the stagnant flooding with alteration of different morpho-physiological characteristics. Some changes are so drastic which affect the yield. There are some adaptive changes, which do not affect the yield. Germplasms with such characteristics may contribute in developing high yielding variety for stagnant flooding. Anatomical adjustments such as slow formation of aerenchyma gas spaces along with greater maintenance of root oxidase activity could increase the rate of oxygen diffusion from aerial part to the root, which is essential for maintaining survival of tillers and growth. Medium elongation is vital for greater plant productivity under SF. In eastern India still the production of rice is very less. Improvement is only possible if the production of rainfed lowland may getaugmentation with proper variety and fertilizer management. Fertilizer application is problematic under stagnation of water. Slow release fertilizer or organic fertilizer may help in realizing greater yield. A newer mode of fertilizer application different from irrigated / favourable conditions can solve the problem.

Annexure I

Screening can be done is either under transplanting or direct seeding conditions

A. Under transplanting condition

One month old seedlings are transplanted @ 2 seedlings hill^{-1} in lines that are 25 cm apart and with 15 cm between hills. Chemical fertilizers as basal were added as N:P:K at 40:20:20 kg ha^{-1}, respectively. Seven to ten days before imposition of stagnant flooding treatment N at the rate of 20 Kg ha^{-1} is added. After one month of transplanting plants are partially submerged by maintaining 50 cm water depth up to the dough stage. The water level rose gradually and it took one week to reach the 50 cm depth. A control set is also maintained under normal (0 – 10 cm) water depth from transplanting to harvesting. Yield and yield attributes are taken. Stability analysis is done. Best cultivars are identified based on the stability analysis of different yield and yield contributing parameters.

B. Under direct seeding condition

The screening technique is like described under transplanting condition. Here direct seeding is done under dibbling conditions. After 20 days of sowing, weeding and thinning is done and two seedlings are maintained per hill. Completion of thinning is followed by Nitrogen application.

Note: Main impact of stagnant flooding is on yield and yield attributing parameters not on mortality like submergence tolerance.

Numbers of germplasms evaluated for stagnant flooding tolerance: More than 1,200.

Germplasm lines: Notable germplasm lines tolerant to stagnant flooding: AC85, AC 42103, AC 42220, AC 42243 and AC 42254.

Varieties released: Utkalprabha, CR 1014, Gayatri, Kalashree, Panidhan, Tulasi, Sarala, Durga Varshadhan, Hanseswari, CR Dhan 500, CR Dhan 501, Jayanthidhan, Jalmani, CR Dhan 505.

Annexure II

Elite materials tested for stagnant flooding tolerance under All India Coordinated Rice Improvement Programme.

Name of the Entry	Grain yield (g m^{-2})	Panicle (number m^{-2})	Spikelet (number per panicle)	1000-grain wt. (g)	Harvest Index
IET11901	403	209	107	25.0	0.21
IET11928	452	263	137	25.0	0.21
IET13006	563	213	91	25.0	0.24
IET13116	374	149	205	23.0	0.15
IET13117	467	216	180	19.4	0.20
IET13119	573	230	194	18.3	0.21
IET13120	346	216	126	27.3	0.21
IET13537	266	239	133	22.0	0.17
Sabita	478	226	158	24.0	0.21
Utkal Prabha	574	269	203	19.0	0.21
LSD$_{*p<0.05}$	110	45	38	1.9	0.07

(Source: CRRI Annual Report 1995-96, page 143)

Entry	Panicle (number m^{-2})	Grain yield (g m^{-2})
IET9751	328	351
IET9757	236	347
IET9760	349	264
IET9776	323	358
IET10270	306	287
IET9186	223	189
IET9747	289	238
IET9758	273	206
IET10300	287	242
IET10717	250	286
Salivahana	301	302
FR13A	246	260
IET10097	293	409
IET10115	221	380
IET10558	333	264
IET10563	267	341
IET11195	258	270
Utkal prabha	260	304
NC678	223	192
NC492	222	442
Badshabhog	279	228
Bhasmanik	343	270
Roupsali	156	237
LSD$_{*p<0.05}$	60	78

(Source: CRRI Annual report 1991-92, page 60); SF imposed with ≈50 cm depth of water from 40 days after planting to dough stage.

Name of the entry	**Panicle (no. m^{-2})**	**Grain (no. m^{-2})**	**1000-grain wt. (g)**	**Total dry matter at harvest (t ha^{-1})**	**Grain yield (t ha^{-1})**
IEt10016	239	17,300	20.6	17.6	4.2
IEt10019	241	19,300	25.1	23.0	5.0
IET10119	176	10,000	25.0	15.8	3.2
IET10115	221	15,500	26.0	14.5	3.0
IET10543	231	15,400	26.0	12.3	3.0
IET10563	203	14,000	24.2	17.4	3.0
IET11183	311	16,100	23.2	12.2	3.0
IET11187	186	14,200	26.0	13.6	3.0
IET11188	218	18,400	21.3	17.7	3.2
IET11189	143	12,000	20.0	10.0	3.0
IET11193	115	9,500	28.0	12.6	3.0
IET11195	145	14,000	33.0	14.6	3.5
IET11196	176	17,000	31.0	13.0	4.0
IET11198	237	21,000	25.2	24.6	4.3
IET11270	191	24,400	26.0	23.7	5.0
IET11271	192	21,500	27.1	10.9	3.0
IET11272	248	28,000	24.0	19.0	3.2
Sabita	176	10,500	31.0	12.1	2.5
Utkal Prabha	255	27,000	20.0	22.3	3.2
LSD$_{*p<0.05}$	43	3,620	1.5	–	0.8

(Source: CRRI Annual report 1991-92, page 61); SF imposed with ≈50 cm depth of water from 40 days after planting to dough stage.

Name of the entry	Panicle (no. m^{-2})	Grain (no. m^{-2})	1000-grain wt. (g)	Grain yield (g m^{-2})
IET13119	114	18,991	18.6	354
IET11901	126	13,817	24.0	330
IET 11896	132	11,962	26.7	319
IET 11910	158	11,451	24.3	278
IET 13116	185	11,981	22.4	267
IET 11904	154	10,157	24.2	245
IET 11271	175	9,611	25.1	241
IET 11272	159	10,060	23.3	234
IET 13120	124	8,271	27.7	212
IET 11893	179	8,902	23.3	207
IET 13537	173	12,852	22.4	203
Sabita	130	13,426	24.4	327
Utkal Prabha	216	17,403	18.2	316
LSD$_{*p<0.05}$	33	–	1.3	60

(Source: CRRI Annual report 1994-95, page 143)

Annexure III

Published literature from NRRI on stagnant flooding

1971 : Rao MJBK and Gangadharan C. 1971. Breeding rice varieties for waterlogged areas. *Oryza.* **8**: 34-40.

1975 : Rai RSV and Murty KS. 1975. Path analysis of grain yield in rice under normal and water logged conditions. *Riso.* **24**: 279-84.

1976 : Rai RSV and Murty KS. 1976. Note of the effect of partial submergence of plant on growth and yield in early high yielding rice varieties. *Indian Journal of Agricultural Research.* **13**: 133-137.

1977 : Rai RSV and Murty KS. 1977. Effect of water logging on growth and yield components of rice. *Madras Agricultural Journal.* **64**: 433-436.

1979 : Rai RSV and Murty KS. 1979. Growth and yield in rice as influenced by higher nitrogen application under normal and water-logged conditions. *Indian Journal of Agricultural Research* **10.**

1980 : Paul DK and Bhattacharya DP. 1980. Simulation of waterlogged situation in normal filed for screening of varieties by engineering skill. *Oryza.* **17**: 251-253.

1981 : De RN, Panda A and Roy JK. 1981. Screening of rice germplasm for rapid elongation under early submergence. *Oryza.* **18**: 229-230.

1982 : Srvastava DP and De RN. 1982. Changes in internode pattern in rice under intermediate water depth. *Oryza.* **19**: 151-54.

1983 : De RN and Srivastava DP. 1983. Effect of submergence on germination and seedling vigour in rice. *Science and Culture.* **49**: 254-255.

Singh S, Bhattacharjee DP and Dash NB. 1983. High plant population as a possible means for increasing the production of waterlogged rice. *Indian Journal of Agricultural Science.* **53**: 659-663.

1984 : Ghosh BC and Reddy BB. 1984. Effect of seed rate and vaiety on growth and yield of rice under intermediate deep water situations. *Indian Journal of Agronomy.* **29**: 72-76.

Mohapatra PC, Reddy BB and Ghosh BC. 1984. Vareity and fertilizer management in flood prone and water-logged areas for higher rice production- A case study. *The Andhra Agricultural Journal.* **31**: 303-307.

Reddy BB and Ghosh BC. 1984. Effect of seedling and hill density on the performance of rice under intermediate deep water conditions (15-50 cm). *Oryza.* **21**: 233-237.

Reddy MD and Mitra BN. 1984. Efffect of time of planting, age and number of seedlings per hill on yield and yield components of rice varieties in flood prone situations. *Thai Journal of Agricultural Sciences.* **17**: 41-49.

Reddy MD and Mitra BN. 1984. Effect of age of seedlings and popular density on yield and yield components of rice in intermediate deep water situation (15-50 cm). *Thai Journal of Agricultural Sciences.* **17**: 89-95.

1985 : Reddy BB, Ghosh BC and Panda MM. 1985.Flood tolerance of rice at different crop growth stages as affected by fertilizer application. *Plant and Soil.* **83**: 255-263.

Reddy MD and Mitra BN. 1985. Response of rice to different forms of urea and phosphorous fertilization under different intermediate deepwater conditions. *Plant and Soil.* **84**: 431-435.

Reddy MD and Mitra BN. 1985. Effect of complete plant submergence at different growth stages on grain yield and nutrient content of rice. *Plant and Soil.* **86**: 379-386.

Reddy MD and Mitra BN 1985. Effect of complete submergence on vegetative growth, grain yield and biochemical changes in rice plants. *Plant and Soil.* **87**: 365-374.

1986 : Das B. 1986. Effect of intermediate and semi-deep water situation on morphology and chlorophyll content of rice. *Oryza.* **23**: 62-64.

De RN and Roy JK. 1986. Path analysis in rice under rainfed semi-deep situation. *Phytobreedon.* **2**: 69-71.

Reddy MD, Ghosh BC and Panda MM. 1986. Effect of seed rate and application of N fertilizer on grain yield and N uptake of rice under intermediate deep water conditions (15-50 cm). *Journal of Agricultural Science (Cambridge).* **107**: 61-67.

1987 : Ghosh BC, Reddy BB, Panda MM and Reddy MD. 1987. Response of direct seeded rice to nitrogen under intermediate deep water conditions. *Indian Journal of Agronomy.* **32**: 44-48.

Panda MM, Ghosh BC and sinhababu DP. 1987. Uptake of nutrients by rice under rice-cum-fish culture in intermediate deep water situation (up to 50 cm water depth). *Plant and Soil.* **102**: 131-132.

Reddy MD and Ghosh BC. 1987. Comparative efficiency of different planting methods in intermediate deepwater (15-50 cm) rice. *Journal of Agricultural Science (Cambridge).* **108**: 573-577.

Reddy BB, Ghosh BC and Reddy MD. 1987. Effect of transplanting date and seedling age on stand establishment and grain yield of rice in rainfed lowland (intermediate deepwater) conditions. *Experimental Agriculture.* **23**: 201-206.

Singh S and Bhattacharjee DP. 1987a. Effect of submergence on survival, growth and productivity of rice varieties. *Oryza.* **24**: 140-145.

Singh S and Bhattacharjee DP. 1987b. Effect of water logging on phosphorous and iron content in shoot tissues of rice. *Oryza.* **24**: 376-380.

Singh S and Bhattacharjee DP. 1987c. Effect of partial submergence on the levels of endogenous growth hormones in stem of rice cultivars. Indian Journal of Plant *Physiology.* **30**: 293-296.

1988 : Ghosh BC, Reddy MD and Reddy BB. 1988. Effect of seedling density on growth and yield of transplanted rice in intermediate deepwater situation. *Thai Journal of Agricultural Sciences.* **21**: 13-21.

Panda MM, Ghosh BC, Reddy MD and Reddy BB. 1988. Effect of form, method and time of urea nitrogen application on growth, yield and nitrogen uptake of direct sown and transplated rice under intermediate deep water (15-50) condition. *Journal of Agricultural Science (Cambridge).* **110**: 309-313.

Reddy MD and Panda MM. 1988. Effect of methods of stand establishment on grain yield of rice under intermediate deepwater conditions (15-50 cm). *Journal of Agricultural Science (Cambridge).* **110**: 47-51.

Reddy MD, Panda MM, Ghosh BC and Reddy BB. 1988. Effect of nitrogen fertilizer on yield and nitrogen concentration in grain and straw of rice under semi-deepwater conditions (51-100 cm). *Journal of Agricultural Science (Cambridge).* **110**: 53-59.

De RN and Suriya Rao AV. 1988. Genetic variability and correlation studies in rice under semi-deep waterlogged situation. *Oryza.* **25**: 360-364.

Singh S and Bhattacharjee DP. 1988. Effect of waterlogging on yield and yield attributes in late high yielding rice varieties. *Oryza.* **25**: 315-318.

1990 : Panda MM, Reddy MD and Sharma AR. 1990. Effect of fertilizer management on growth and yield of intermediate deep-water rice (*Oryza sativa*). *Indian Journal of Agricultural Science.* **60**: 201-203.

Reddy MD, Panda MM and Sharma AR. 1990. Cultural practices on crop stand and grain yield of rice under intermediate deepwater (15-50 cm) conditions. *Thai Journal of Agricultural Sciences.* **23**: 225-232.

Singh S and Bhattacharjee DP. 1990. Effect of waterlogging on the activity of roots and some oxidative enzymes in roots of different varieties. *Oryza.* **27**: 255-258.

1991 : Panda MM, Reddy MD and Sharma AR. 1991. Yield performance of rainfed lowland rice as affected by nursery fertilization under conditions of intermediate deep water (15-50 cm) and flash floods. *Plant and soil.* **132**: 65-71.

Reddy MD, Sharma AR and Panda MM. 1991. Flood tolerance of rice under intermediate deepwater conditions (15-50 cm) as affected by phosphorous fertilization. *Journal of Agricultural Science (Cambridge).* **117**: 319-324.

Sharma AR and Reddy MD. 1991. Mixed cropping of early- and late-duration rice (Oryza sativa) varities at varying fertilizer levels under intermediate deep water conditions. *Indian Journal of Agricultural Science.* **61**: 659-661.

Sharma AR and Reddy MD. 1991. Performance of different rice varieties grown under intermediate deep water conditions (15-50 cm). *Oryza.* **28**: 489-491.

Singh S and Bhattacharjee DP 1991. Anatomical changes in rice stem as influenced by waterlogging. *Oryza*. **28**: 41-43.

1992 : De RN. 1992. Behaviour of plant height and internode number in lowland rice under different situations. *Oryza*. **29**: 143-145.

Sharma AR. 1992. Effect of varying seed rate and transplanting clonal tillers on the performance of rice under intermediate deepwater conditions (0-80 cm). *Journal of Agricultural Science (Cambridge)*. **119**: 171-177.

Sharma AR. 1992. Efffect of nursery fertilization and age of seedling on flood tolerance and productivity of rainfed lowland rice (*Oryza sativa*). *Indian Journal of Agricultural Science*. **62**: 657-663.

Sharma AR and Reddy MD. 1992. Effect of method of sowing and weed control practice on performance of rice (*Oryza sativa*) under intermediate deepwater condition. *Indian Journal of Agricultural Science*. **62**: 24-28.

Sharma AR and Reddy MD. 1992. Optimum sowing date and nitrogen fertilizer rate for rice varieties under intermediate deepwater conditions (15-50 cm). *Journal of Agricultural Science (Cambridge)*. **118**: 179-183.

1993 : Jayasankar R and Ramakrishnayya G. 1993a. Effect of partial submergence on the growth of rice. *Journal of Ecobiology*. **5**: 105-109.

Jayasankar R and Ramakrishnayya G. 1993b. Effect of partial submergence on the leaf characteristics of rice cultivars. *Oryza*. **30**: 265-266.

Sharma AR. 1993. Nitrogen management in rainfed lowland rice under varying water regimes. *Oryza*. **30**: 78-81.

Sharma AR. 1993. Yield performance of different rice varieties under deepwater conditions. *Oryza*. **30**: 359-361.

Sharma AR and Reddy MD. 1993. Effect of variation in water depth and cultural practices on performance of rice (*Oryza sativa*) under deepwater conditions. *Indian Journal of Agricultural Science*. **63**: 292-295.

1994 : Sharma AR. 1994. Effect of tillage, weed-control practices and nitrogen fertilization on performance of rice (Oryza sativa) under intermediate deep-water condition. *Indian Journal of Agricultural Science*. **64**: 829-834.

Sharma AR. 1994. Effect of seed rate and row spacing on the performance of early and late maturing rice cultivars in mixed crop systems under intermediate deep water conditions (15-50 cm). *Journal of Agricultural Science (Cambridge)*. **122**: 201-205.

Sharma AR. 1994. Fertilizer management in rainfed lowland rice under excess water conditions. *Fertilizer News*. **39**: 35-44.

Sharma AR and Das KC. 1994. Effect of nitrogen fertilization on performance of rice (*Oryza sativa*) under intermediate deep-water condition (0-50 cm). *Indian Journal of Agronomy.* **39**: 548-552.

Sharma AR and Das KC. 1994. Effect of green manuring with dhaincha (*Sesbania aculeate)* on growth and yield of direct-sown and transplanted rice under intermediate deepwater conditions (0-50 cm). *Journal of Agricultural Science (Cambridge).* **122**: 359-364.

Sharma AR and De RN. 1994. Effect of foliage cutting on growth and yield of different rice cultivars under semi-deepwater conditions (0-80). *Journal of Agricultural Science (Cambridge).* **122**: 35-40.

Sharma AR. 1994. Effect of different methods and timings of stand establishment on performance of rainfed lowland rice under 0-50 cm water depth. *Journal of Agronomy and Crop Science.* **172**: 38-51.

1995 : Sharma AR. 1995. Effect of basal and post-flood nitrogen fertilization on performance of rice (Oryza sativa) under conditions of intermediate deep water and simulated flash-flooding. *Indian Journal of Agricultural Science.* **65**: 399-404.

Sharma AR. 1995. Direct seeding and transplanting for rice production under flood-prone lowland conditions. *Field Crops Research.* **44**: 121-127.

1997 : Reddy JN, De RN and Suriya Rao AV. 1997. Correlation and path analysis in low-land rice under intermediate (0-50 cm) water depth. *Oryza.* **34**: 187-190.

1998 : Sharma AR and Ghosh A. 1998. Optimum sed rate and nitrogen fertilizer requirement of rice under semi-deep water ecosystem. *Journal of Agronomy and Crop Science.* **181**: 167-172.

Sharma AR and Ghosh A. 1998. Performance of direct sown and clonally propagated rice (Oryza sativa) under semi deep water conditions. *Indian Journal of Agricultural Sciences* **68**: 347-351.

2009 : Sarkar RK, Reddy JN, Das KK, Ram PC, Singh PN, Mazid MA, Sommut W, Pane H, Sharma SG and Ismail AM. 2009. Biophysical constraints in flood-prone ecosystems: impacts and prospects for enhancing and sustaining productivity; In (eds. Haefele S M, Ismail A M), Natural resource management for poverty reduction and environmental sustainability in fragile rice-based systems. Limited Proceedings No. 15, Los Banos (Philippines): *International Rice Research Institute.* pp. 67-81.

2016 : Kuanar SR, Ray A, Sethi SK, Chattopadhyay K and Sarkar RK. 2016. Physiological basis of stagnant flooding tolerance in rice. *Rice Science.* (*in press*).

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