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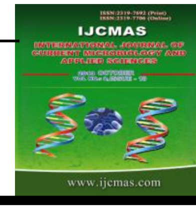

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Original Research Article

Root Physiology of Rice Genotypes as Influenced by Cultivation Systems and Planting Dates in the Coastal Plains of Orissa, India

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A B S T R A C T

Field experiments were conducted in *Kharif* of 2009 and 2010 in the East and South East Coastal Plain zone of Odisha to study the morphophysiological and phonological effects of dates of sowing and systems of cultivation of rice genotypes. The experimental site in particular was located at 86^0 22' E longitude, 20^0 17' N latitude, 14 m above the mean sea level, and at a 25.6 km air distance from the Bay of Bengal in the East. The location of the experiment is characterized by a warm and moist climate with a hot and humid summer and normal cold winter. The experiment was carried out in a split-split plot design with 18 treatment combinations and three replications. The treatments consisting of three dates of sowing viz. 20 June (early), 5 July (normal) and 20 July (delayed) were assigned to the main plots, three systems of cultivation such as best management practice (BMP), the system of rice intensification (SRI) and modified SRI (MSRI) were allotted to 3 subplots and two medium duration rice genotypes viz. high yielding variety Tapaswini and hybrid Ajay were grown in sub-subplots. Early sowing of rice by 20 June resulted in vigorous root growth with the maximum root volume per unit area, and depth and the maximum xylem exudates at 50% flowering and the maximum force at the panicle initiation stage were required for uprooting of the rice plants. Among the systems of cultivation, MSRI and among the genotypes hybrid Ajay could exhibit the best root parameters per unit area as mentioned above. The average perimeter of tillers was also the maximum in early sown rice, SRI and hybrid Ajay. Whereas delayed sowing by 20 July, the BMP and HYV Tapaswini lagged behind in manifesting superior rice root morphophysiology and also in root pulling resistance. Hence, early sowing of hybrid rice Ajay under MSRI could be recommended to the farming community in the coastal Orissa for achieving the best morphophysiological response of rice that could also be reflected in terms of superior plant growth and grain yield.

Keywords

Root exudates, system of rice intensification, sowing date, hybrid Ajay.

Introduction

Rice, a semi-aquatic annual cereal crop is the most important staple food for about half of the human race (Hawksworth, 1985 and David, 1989). The current level of annual rice production of around 545 million (M) t needs to be increased to about 700 M t to feed an additional 650 M rice eaters by 2025 using less water and less land is indeed a great challenge in Asia (Dawe, 2003). In Asia, irrigated agriculture accounts for 90% of total diverted fresh water and more than 50% of it is used to irrigate rice (Barker *et al.*, 1998). Flooded rice requires 900 to 2,250 mm (average 1,500 mm) of water depending on water management and soil and climatic factors. Almost 90% of global rice is produced under inundated conditions during the major part of the growing season but recently, inundated rice has come under pressure due to declining availability of water and labour, increasing demand for rice and other food items, increasing claims on limited land resources and increasing concern for environmental pollution. These changes in ecological, social and economic conditions call for transformation in rice cultivation to comply with current and future developments.

Rice plants are known to be capable of growing under both flooded and non-flooded conditions (Teare and Peet, 1983) and irrigation methods can vary from continuous submergence to intermittent flooding (Ustimenko-Bakumovsky, 1983). Efforts are being made in many countries to reduce the water requirements for growing rice. Concerns about sustainability and, the social and technical shortcomings of the green revolution have triggered a number of alternative crop production strategies like the “System of Rice Intensification”, popularly known as “SRI”. The use of hybrids and water-saving approach like SRI may help in increasing rice productivity. The use of young seedlings, single plant plantation, wider spacing in square geometry, use of organic manure, limited irrigation instead of flood irrigation and mechanical weeding as followed in SRI needed to be compared with the best-recommended management practices.

Although, the benefits of SRI in and around Orissa compared to the continuously flooded traditional farmers’ practices are well established, studies on the effect of the “Best Management Practices” (BMP) and “Modified System of Rice Intensification” (MSRI) on the physiological effects on rice genotypes such as hybrid Ajay and ruling cultivar Tapaswini sown at different dates during *Kharif* need through evaluation in coastal Orissa.

Materials and Methods

Experimental site

The experiments were conducted during *Kharif* of 2009 and 2010 in the Agro-climatic zone of ‘East and South East Coastal Plain’ at a 25.6 km air distance from the Bay of Bengal in the East. The experiment site in particular was located at 86^0 22’ E longitude, 20^0 17’ N latitude and 14 m above the mean sea level. The soil parameters were tested and are depicted in Table 1. The location of the experiment is characterized by a warm and moist climate with a hot and humid summer and normal cold winter. Broadly, the climate falls in the ‘moist hot’ group (Lenka, 1976). The mean annual rainfall is 1,333.9 mm and nearly 62% of rainfall is received between June and October (827 mm). The monsoon usually sets in around mid-June and recedes by the first week of October. July and August are the wettest months, while December is the driest one during the cropping season. The range of maximum (36.38 ^{0}C) and minimum (14.96 ^{0}C) temperatures during the experimental cropping years were more or less the same as the long-term average. The daily mean sunshine hours during the period of investigation was more or less the same as the long-term average and ranged from 1.82 to 7.84 hours.

Experimental details

The experiment was carried out in a split-split plot design with 18 treatment combinations replicated thrice (R_1, R_2 and R_3).

The treatments consisting of three dates of sowing (D_1, D_2 and D_3) were assigned to the main plots, three systems of cultivation of rice (S_1, S_2 and S_3) were allotted to 3 subplots and two rice genotypes, one medium duration high yielding variety (G_1) and one medium duration hybrid (G_2) were grown in sub-subplots. The details of the treatments are in Table 2 and the aerial view of the experimental unit is depicted in Fig. 1.

Description of genotypes

Tapaswini (IET 12168)

It is a semi-dwarf medium duration (135-140 days) High Yielding Variety (HYV) with medium slender grains favourable for cultivation in irrigated ecosystem developed at Central Rice Research Institute (CRRI), Cuttack through hybridization of Jagannath x Mahsuri followed by selection in the segregating generations. It was released by the Orissa State Variety Release Committee (OSVRC) in 1996 and notified by the Govt. of India in 1997. It is tolerant to white-backed plant hopper, bacterial leaf blight, moderately tolerant to leaf folder and gall midge having a yield potential of 5.5 t ha^{-1}.

Ajay (CRHR-7, IET 18166)

It is a semi-dwarf (110 cm), non-lodging and medium duration (135 days) hybrid with moderate tillering habit and high spikelet fertility (>85%) developed at the Central Rice Research Institute, Cuttack and subsequently released by the OSVRC and notified in 2005. This is an F1 hybrid developed through a three-line system of hybrid rice breeding from the cross CRMS 31A X IR 42266-29-3R. The yield potential of this hybrid is 6.5 t ha^{-1} when cultivated in *Kharif* and 7.5 t ha^{-1} in *Rabi*.

Agronomic practices of rice crop

For each date of sowing under BMP (S_1), three beds of 5 m X 1 m were prepared by raising the nursery bed 15 cm above the ground level and the beds were separated by channels in-between. In each bed, 15 kg of FYM, 50 g of MOP and 100 g of SSP were applied at the time of final land preparation. In each bed, 0.75 kg of sprouted seeds of Tapaswini and Ajay were sown separately. After 15 days of sowing, 50 g of urea was applied to each bed.

For each date of sowing under SRI (S_2) and MSRI (S_3) cultivation three beds of 2.5 m X 1 m for each genotype were prepared through the mixing of 1 part sand, 1 part well decomposed FYM and 2 parts of topsoil in between two parallel bamboos separated at 1 m width. In each bed, 50 g of MOP and 100 g of SSP were applied at the time of final bed preparation before sowing. The bed top was levelled and 0.25 kg of sprouted seeds of Tapaswini and Ajay were sown separately and duly labelled for easy identification. The seeds were covered with a soil mixture of 1 cm thickness and irrigated by sprinkling water over it. For transplanting under S_1, seedlings from the raised nursery beds were uprooted at 25 days old stage.

The beds were irrigated before uprooting for smooth lifting of the seedlings. Two seedlings hill^{-1} were transplanted in the main field at 25 cm X 12.5 cm spacing in lines. For transplanting under S_2 and S_3, seedlings from the raised bamboo beds were uprooted at 10 days by scooping the seedlings in bulk at 2 to 3 cm below the nursery bed surface along with the moist mother soil.

Due care was taken up to reduce damage to the root system of the seedlings during uprooting. The seedlings were then carried away to the main field by trays without much delay and the transplanting was carried out preferably within half an hour of uprooting. Single seedlings hill^{-1} in S_2 and two seedlings hill^{-1} in S_3 were then transplanted in lines in the main field at 25 cm X 25 cm and 25 cm X 12.5 cm spacing, respectively.

After laying out the main field, well decomposed FYM of calculated mass was applied to different plots. In S_1 subplots FYM @ 5 t ha^{-1} along with total phosphorous and 1/3rd of the total recommended dose (100:50:50 kg ha^{-1} of $N:P_2O_5:K_2O$) of the nitrogenous and potassic fertilizers was applied before final puddling. Rest of the nitrogenous and potassic fertilizers were applied in two equal halves i.e.1/3rd at maximum tillering (40 DAS) and 1/3rd at the PI stage (70 DAS). However, in S_2 and S_3 systems of plantings, FYM @ 15 t ha^{-1} along with total phosphorous and 1/4th of the total (50:50:50 kg ha^{-1} of $N:P_2O_5:K_2O$) nitrogenous and potassic fertilizers were applied before final puddling. The rest of the nitrogenous and potassic fertilizers were applied in three equal splits i.e. 1/4th each at 25, 40 and 70 DAS. The share of the nitrogenous fertilizer from the chemical source has been reduced to half of the recommended dose keeping in view its availability from the 10 t extra FYM applied to the field at the time of final land preparation.

In S_2 and S_3 systems of cultivation, four weeding operations at 20, 30, 40 and 50 DAS were carried out by using a conoweeder. In $S_{2,}$ the weeder was operated in a criss-cross manner and the weeds were incorporated into the soil. However, in S_3, the weeder was run in an east-west direction only. In the S_1 system of cultivation, three hand weeding operations at 40, 55 and 70 DAS were carried out incorporating the weeds *in situ*.

In the S_1 system of cultivation, water was allowed to stand in the plots since planting of the seedlings by irrigating on alternate days so as to maintain a layer of 5 to 8 cm depth of water during the entire crop period till 15 days before harvest.

In S_2 and S_3 systems of cultivation, water was not allowed to stand in the plots and special care was taken to avoid submergence of 10 days' old tiny seedlings just after transplanting in the main field.

The soil was kept moist above the field capacity by irrigating the sub-sub-plots as per requirement till the PI was attained. These plots were first irrigated 5 days after transplanting to moisten the field without ponding. Second irrigation was given on the evening of the 9^{th} day after planting at a ponding depth of 2 to 5 cm and the next morning first weeding was performed by using a cono-weeder. Thereafter alternate wetting and drying method of irrigation was practised and subsequent irrigation was applied 3 days after the disappearance of the ponded water or immediately after the development of hair cracks on the soil surface. However, after the PI stage, the plots were allowed to hold standing water of 5 cm height up to two weeks before harvest.

Methods of recording observations

The root depth (cm) and volume (ml m^{-2}) were measured from the destructive plant samples taken at 40, 55, 70, 85 and 100 DAS. Circles with appropriate diameters were determined after observing the horizontal spread of root systems of the demarcated roots in BMP, SRI and MSRI.

The plants were then removed carefully by digging a trench around them without damage to the root system and thereafter cleaned in flowing water. The length of the longest root from the mesocotyl was measured for ascertaining its vertical depth in the soil. However, its volume was measured by following the water displacement method.

Root uprooting force **(**RUF) evaluates root growth and rooting density in a summary way by measuring the amount of force that is required to uproot a single plant or set of plants on a hill (Ekanayake *et al.*, 1986).

While measurements of RUF, which evaluates the combined, cumulative effect of respective crop management practices, can be affected by differences in soil conditions (structure and moisture), RUF is a meaningful indicator if such conditions are kept reasonably similar and if the differences observed are large. To minimize the effects of variability in soil characteristics, the soil for all the samples evaluated was kept at the same moisture level for a week before the plants were pulled up to assess RUF. For determining RUF, samples of 3 hills $plot^{-1}$ were taken at random.

A spring balance was attached to the rope at the base of each hill to be uprooted and the force (in kg) required to pull up the plant was recorded at the moment of uprooting.

The xylem exudation rate at the flowering stage of stems was measured by taking three hills with an average number of panicles selected randomly from each plot. Each stem was cut at 10 cm from the soil surface and pre-weighed absorbent cotton packed in polythene bag was attached to the cut-end of each stem with a tape.

After 24 hrs, each bag was detached, sealed and weighed and the weight of the root exudates was calculated by subtracting the weight of the bag and pre-weighed cotton wool. The perimeter of the tillers of the demarcated hills at 10 cm above the ground surface was measured at the early ripening stage and the average was calculated in cm.

Statistical analysis

All the biometrical data collected in the pre-harvest and post-harvest studies were arranged in appropriate tables and analysed statistically by applying the analysis of variance technique (ANOVA) laid down by Panse and Sukhatme (1978); Cochran and Cox (1977); Fisher (1925) and Gomez and Gomez (1984).

Results and Discussion

Root depth

Data on root depth of plant rice recorded at fortnight intervals from 40-100 DAS indicated the longest roots at 70 DAS irrespective of dates of sowing and thereafter it gradually decreased (Table 2). Early sowing by 20 June had the deepest roots. This was followed by normal sowing by 5 July and late sowing by 20 July, respectively. The root depth of plants under SRI recorded significantly the highest values at all dates of observation and had the maximum depth at 70 DAS (29.25 cm). The MSRI had root depth of second order and having significantly deeper than BMP at 40, 55, 85 and 100 DAS while at 70 DAS it remained at par with that of the latter one. Hybrid Ajay had significantly deeper roots at 40, 70, 85 and 100 DAS while at 55 DAS this was at par with that of the variety Tapaswini. The rate of root depth increased to 70 DAS after which the rate gradually declined with the ageing of genotypes.

Root volume

The root volume of rice recorded at fortnight intervals from 40 to 100 DAS indicated its steady increase up to 85 DAS and thereafter decreased marginally at the next date of observation irrespective of dates of sowing (Table 2). The root volume in all three sowing dates varied significantly from each other at all dates of observation except at 40 DAS. Early sowing resulted in the highest root volume followed by normal sowing and late sowing, respectively at 55, 70, 85 and 100 DAS. However, at 40 DAS normal sowing surpassed early and late sowing of rice in this regard. The superiority of early sowing could be due to the better availability of growth functions in adequate quantities and also in suitable proportions. Diminishing root configuration in the latter dates of sowing could be due to a decrease in sunshine hours, the decline in mean diurnal temperature and the reduction in crop duration. The present results are in accordance with the report of Thakur *et al.,* (2011). The root volume under MSRI was consistently top ranking with significantly higher values at all growth stages and also had a maximum volume at 85 DAS (1,271.73 cm^3 m^{-2}). The SRI had root volume second in the order and had significantly more volume than BMP at all the growth stages (Fig 2). Higher volume and deeper roots in the hills of SRI probably be due to favourable soil physicochemical properties, balanced soil air and moisture, availability of adequate soil volume and greater light interception by open rice canopy. Such result in SRI was the cumulative effects and thus reflected in enhanced root proliferation $hill^{-1}$. However, the present trend of the superiority of MSRI in recording higher root morphology m^{-2} could be due to crop geometry accommodating more plants per unit area. This result was in accordance with the report of Thakur *et al.,* (2011). Studies on the effect of genotypes on root volume indicated the superiority of Ajay at all dates of observation compared to Tapaswini. The rate of increase in root volume in both genotypes continued till 85 DAS and thereafter declined with ageing. This could be due to the reason that after panicle initiation and heading, the lower leaves of those contributing assimilates towards roots would have died gradually (Tanaka, 1958). Root uprooting force $hill^{-1}$ at the PI stage was significantly higher in Ajay (40.1 kg) compared to Tapaswini (33.85 kg) possibly due to more proliferation and anchorage of its roots.

Table.1 Physico-chemical properties of the experimental soil

Year	pH	Sand (%)	Silt (%)	Clay (%)	Organic Carbon (%)	EC (ds m^{-1})	Available N (kg ha^{-1})	Available P_2O_5 (kg ha^{-1})	Available K_2O (kg ha^{-1})
2008-09	5.6	42.8	28.7	28.5	0.79	0.96	457.5	22.6	192.8
2009-10	5.5				0.87	0.98	488.8	24.3	200.2
Methods followed	Beckman pH meter method (Jackson, 1958)	Bouyoucos Hydrometer method (Bouyoucos, 1951)			Volumetric method (Walkley and Black, 1947)	Digital electrical conductivity Bridge method (Jackson, 1973)	Alkaline permanganate method (Subbiah and Asiha, 1956)	Brays'method No.1 (Bray and Kurtz, 1945)	Flame photometer method (Muhr *et al.*, 1965)

Table.2 Details of treatment and symbols used

Treatments	Symbols used
The main plot (Dates of sowing)	
20 June (early)	D_1
5 July (normal)	D_2
20 July (late)	D_3
Subplot (Systems of planting)	
Best management practice (BMP)	S_1
System of Rice Intensification (SRI)	S_2
Modified System of Rice Intensification (MSRI)	S_3
Sub-subplots (Genotypes)	
HYV Tapaswini	G_1
Hybrid Ajay	G_2

Table.3 Effect of treatments on root depth (cm) at different growth stages of rice (pooled over *Kharif* of 2009 and 2010)

Treatments	Days after sowing									
	Root depth (cm)					Root volume (cm^3 m^{-2})				
	40	55	70	85	100	40	55	70	85	100
Dates of sowing										
20 June	21.25a	26.63a	29.17a	25.97a	24.77a	295.76b*	739.25a	1082.91a	1202.45a	1166.00a
5 July	19.02b	23.56b	27.71b	23.83b	21.86b	324.27a	679.37b	977.38b	1076.81b	1040.51b
20 July	16.17c	22.59c	23.59c	21.76c	19.21c	261.12b	605.25c	861.39c	964.48c	899.42c
S.Em (±)	0.18	0.26	0.34	0.33	0.16	8.45	6.85	17.07	13.94	9.43
C.D. (0.05)	0.59	0.84	1.10	1.06	0.52	27.55	22.35	55.65	45.46	30.76
C.V. (%)	5.78	6.36	7.56	8.21	4.39	17.26	6.10	10.51	7.73	5.47
Systems of cultivation										
BMP	14.15c	21.96c	25.16b*	21.89c	19.89c	140.72c	478.84c	712.23c	892.92c	850.85c
SRI	21.94a	27.09a	29.25a	26.47a	23.88a	321.24b	709.61b	1022.26b	1079.09b	1045.96b
MSRI	20.34b	23.73b	26.07b	23.19b	22.07b	419.17a	835.42a	1187.19a	1271.73a	1209.12a
S.Em (±)	0.32	0.43	0.46	0.25	0.31	5.60	9.18	17.25	14.59	14.64
C.D. (0.05)	0.95	1.26	1.33	0.73	0.91	16.34	26.79	50.34	42.59	42.72
C.V. (%)	10.33	10.70	10.18	6.26	8.52	11.43	8.16	10.62	8.10	8.48
Genotypes										
Tapaswini	18.21b	23.86	25.90b	23.35b	21.08b	274.24b	622.33b	899.13b	1001.08b	946.09b
Ajay	19.41a	24.66	27.75a	24.35a	22.81a	313.18a	726.92a	1048.66a	1161.41a	1124.53a
S.Em (±)	0.10	0.28	0.30	0.28	0.18	2.23	5.38	6.12	5.75	6.89
C.D. (0.05)	0.30	NS	0.87	0.81	0.52	6.39	15.43	17.55	16.49	19.77
C.V. (%)	4.05	8.61	8.31	8.67	6.12	5.57	5.86	4.61	3.90	4.89

* Means followed by common letters did not differ significantly up to 5% level

Table.4 Effect of treatments on the uprooting force required (kg hill^{-1}) at the PI stage of rice

Treatments	2009	2010	Pooled
Dates of sowing			
20 June	39.46	43.34	41.40a*
5 July	35.17	39.40	37.29b
20 July	32.63	31.87	32.25c
S.Em (±)	0.65	0.48	0.40
C.D. (0.05)	2.54	1.87	1.31
C.V. (%)	7.68	5.28	6.52
Systems of cultivation			
BMP	26.42	22.98	24.70c
SRI	46.44	52.69	49.56a
MSRI	34.41	38.92	36.67b
S.Em (±)	0.99	1.22	0.79
C.D. (0.05)	3.05	3.77	2.30
C.V. (%)	11.75	13.57	12.76
Genotypes			
Tapaswini	31.75	35.95	33.85b
Ajay	39.76	40.45	40.10a
S.Em (±)	0.36	0.28	0.23
C.D. (0.05)	1.07	0.84	0.66
C.V. (%)	5.24	3.86	4.56

* Means followed by different letters differed significantly up to 5% level

Table.5 Effect of treatments on xylem exudates at 50% flowering and average perimeter of the stem (cm) at early ripening stage (100 DAS) of rice (pooled over *Kharif* of 2009 and 2010)

Treatments	Xylem exudates				Average perimeter of the stem (cm)
	g hill^{-1} hr^{-1}	g m^{-2} hr^{-1}	g hill^{-1} d^{-1}	g m^{-2} d^{-1}	
Dates of sowing					
20 June	0.314a*	7.593a	7.554a	182.519a	2.95a
5 July	0.280b	6.797b	6.736b	163.499b	2.65b
20 July	0.265c	6.397c	6.339c	153.750c	2.29c
S.Em (±)	0.003	0.071	0.070	1.739	0.03
C.D. (0.05)	0.011	0.230	0.227	5.670	0.11
C.V. (%)	6.83	6.11	6.07	6.26	7.78
Systems of cultivation					
BMP	0.188c	6.032c	4.531c	144.961c	1.99c
SRI	0.419a	6.709b	10.055a	161.383b	3.30a
MSRI	0.252b	8.047a	6.044b	193.425a	2.61b
S.Em (±)	0.005	0.086	0.104	2.039	0.05
C.D. (0.05)	0.013	0.250	0.302	5.950	0.14
C.V. (%)	9.36	7.41	9.03	7.34	10.87
Genotypes					
Tapaswini	0.274b	6.719b	6.572b	161.495b	2.46b
Ajay	0.299a	7.139a	7.181a	171.684a	2.80a
S.Em (±)	0.002	0.055	0.053	1.309	0.02
C.D. (0.05)	0.006	0.157	0.153	3.757	0.06
C.V. (%)	5.20	5.80	5.70	5.77	6.04

* Means followed by different letters differed significantly up to 5% level

Fig.1 Aerial view of the experimental field during *Kharif* 2010

Fig.2 Effect of treatments on root morphology of rice at the maximum vegetative growth stage

The uprooting force required at the PI

Root pulling resistance is a function of the type of soil, soil moisture content and crop growth stage (volume and depth of roots). The highest force for uprooting was required for early sowing by 20 June (41.4 kg hill^{-1}) followed by timely sowing by 5 July (37.29 kg hill^{-1}) and late sowing by 20 July (32.25 kg hill^{-1}) (Table 3). Reduction in uprooting force with delay in sowing time might be due to reduced root proliferation i.e. depth and volume. Root uprooting force hill^{-1} at the PI stage of rice was significantly the highest in SRI (49.56 kg hill^{-1}) and that declined in rice grown in MSRI (36.67 kg hill^{-1}) and BMP (24.7 kg hill^{-1}), respectively. Higher uprooting force requirement in SRI could be due to more volume and depth of roots. Conversely, the reduction in uprooting force requirement in BMP might be due to reduced root depth and volume. The observation of Thakur *et al.,* (2011) corroborated the present result.

Xylem exudates at 50% flowering

The values of xylem exudates for all dates of sowing were significantly different from each other (Table 4). The xylem exudates m^{-2} measured under early sowing was of the first ranking for both hourly (7.593 g m^{-2}) and daily (182.519 g m^{-2}) basis. This was followed by timely sowing (163.499 g m^{-2} d^{-1}) and late sowing (153.75 g m^{-2} d^{-1}) of rice. The higher exudates could be attributed to deeper and larger roots of plant rice in early sowing compared to late sowing. Longer roots could have exploited deeper soil zone and increased root volume that could help extract larger amounts of plant nutrients from the plant rhizosphere. The xylem exudates m^{-2} under MSRI was significantly superior (193.425 g m^{-2} d^{-1}) to SRI (161.383 g m^{-2} d^{-1}) and BMP (144.961 g m^{-2} d^{-1}). However, the highest xylem exudates hill^{-1} d^{-1} (10.055 g) and average perimeter of the stem (3.3 cm) at 50% flowering and early ripening respectively were in SRI compared to MSRI and BMP. This might be due to the vigorous growth of SRI plants under favourable environments and supportive underground root morphological configuration and physiological activities. The effect of BMP on xylem exudates m^{-2} in spite of the higher number of total tillers m^{-2} was not so influencing compared to SRI and the reasons thereof could be ascribed to poor structure and lesser activity of roots. The present result was in agreement with the findings of Thakur *et al.,* (2011). Ajay had significantly higher xylem exudates (171.684 g m^{-2} d^{-1}) than Tapaswini (161.495 g m^{-2} d^{-1}).

Significantly higher xylem exudates m^{-2} d^{-1} at 50% flowering stage (171.684 g) and average perimeter of stem at early ripening (2.8 cm) in Ajay compared to Tapaswini could be due to the vigorous growth of Ajay owing to supportive underground root morphology and its increased activity.

The average perimeter of the stem (cm) at the early ripening stage (100 DAS)

The average perimeter under early sowing by 20 June was of first order (2.95 cm) followed by the timely sowing by 5 July (2.65 cm) and late sowing by 20 July (2.29 cm) (Table 4). The average perimeter of the stem in SRI was significantly superior (3.3 cm) to MSRI (2.61 cm) and BMP (1.99 cm). The hybrid rice Ajay had a significantly higher average stem perimeter (2.8 cm) than the rice variety Tapaswini (2.46 cm). The longer perimeter could be attributed to deeper and larger roots of plant rice in early sowing compared to late sowing. Field experiments were conducted during *Kharif* 2009 and 2010 to study the root physiological effects of sowing dates and systems of cultivation on rice genotypes in the coastal plains of Orissa.

Early sowing of rice by 20 June resulted in vigorous root growth with the maximum root volume per unit area, and depth and the maximum xylem exudates at 50% flowering and the maximum force at the panicle initiation stage were required for uprooting of the rice plants. Among the systems of cultivation, MSRI and among the genotypes hybrid Ajay could exhibit the best root parameters per unit area as mentioned above.

The average perimeter of tillers was also the maximum in early sown rice, SRI and hybrid Ajay. Whereas delayed sowing by 20 July, the BMP and HYV Tapaswini lagged behind in manifesting superior rice root morphophysiology and also in root pulling resistance.

Hence, early sowing of hybrid rice Ajay under MSRI could be recommended to the farming community in the coastal Orissa for achieving the best morphophysiological response of rice that could also be reflected in terms of superior plant growth and grain yield.

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