Vol. 13, No. 2, pp. 116-125 (2013)
Journal of Agricultural Physics
ISSN 0973-032X
http://www.agrophysics.in

Research Article

Rainfall-Flooding Depth Relationship Analysis and Soil Characterization for Development of Coastal Waterlogged Areas

GOURANGA KAR* AND ASHWANI KUMAR

Directorate of Water Management, Bhubaneswar – 751023, Odisha

ABSTRACT

By virtue of its geographical position and varied terrain and climatic zones, a rich diversity of inland and coastal waterlogged and wetlands are available in India. The saucer shaped landform, high rainfall due to southwest monsoon (June-September) and poor drainage condition make certain parts of east coast of India susceptible to waterlogging during rainy season. On the other hand, after receding flood the land remains dry from January to May. As a case study, development and management strategies of seasonal waterelogged coastal areas of Puri district of Odisha were developed through deep water rice cultivation, pond based farming and multiple use of water. Based on the rainfall-runoff relationship, it was observed that flooding was highly dependent on rainfall in the catchments and rice yield production was highly influenced by time of flooding. Among 3 years (2005, 2006, 2007), no yield was obtained in 2006 due to occurrence of early flood (1st week of July). Performance of improved deep water rice varieties (Hangseswari, Sabita, Ambika, Saraswati) was compared with that of two local varieties (Bankui and Dhalakaritk) under 3 flooding depths. The net water productivity was enhanced from Rs. 1.22 m^{-3} through sole rice to Rs. 6.26 m^{-3} through integrated rice-fish pond based farming.

Key words: Pond based farming, Rainfall, Flood, Wetlands, Coastal region, Deep water rice

Introduction

Traditionally, local farmers of coastal waterlogged areas of eastern region plough the agricultural field twice or thrice before June with the help of pre-monsoon shower and broadcast dry seeds of local rice varieties of long duration (150 days) in the first week of June. But chances of profitable crop production depend upon the time and depth of flooding/waterlogging. Waterlogging during rainy season for most part of the crop growth reduces tillering and growth of the normal rice genotype. Sometimes flash flood inundates the standing crop for 8-10 days at a stretch, resulting in heavy mortality. The crop is damaged completely if this situation occurs in early vegetative period (Sahoo *et al.*, 2005; Baruah *et al.*, 2006). Thus, submergence caused by flooding ranks next only to drought as the most serious abiotic constraint to rice production in the region (Kar *et al.*, 2007). There is no alternative other than to grow rice on such lowlands where surface water accumulation of 0.5-2.0 m occurs during rainy season. Water-logging-tolerant rice varieties (deep water or floating) can be grown to make the waterlogged land productive during rainy season (Rose-John and Kende, 1984**;** Ambumozhi *et al.*, 1998; Zeng *et al.*, 2003; Khakwani *et al.*, 2005; Sahoo *et al.*, 2005; Roy Chowdhury *et al.*, 2006; Kar *et al.*,

*Corresponding author,
Email: kar_wtcer@yahoo.com

2007; Kotera and Nawata, 2007). Therefore, performance evaluation of deep water rice (DWR) varieties with better yield potential in coastal waterlogged areas is one of the critical needs for sustainable rice production in this ecology (Das and Uchimiya, 2002; Baruah *et al*., 2006). Although precise data on flooding patterns are of fundamental value for DWR cultivation, there is a surprising paucity of long-term water records on daily basis from actual DWR fields. In this investigation, rainfall-flooding depth relationship was also studied and probability of successful crop production in relation to time and depth of waterlogging has been investigated based on historical flood data of 34 years in the region. Performance of 4 improved DWR varieties (Hangseswari, Sabita, Ambika, Saraswati) was compared with that of local varieties (Bankui, Dhalakartik) at 3 water depths [shallow (0.6-0.8 m), medium (0.8-1.2 m) and deep (>1.2 m) flooded]. Pond based farming was designed and implemented to enhance and stabilize net returns of seasonal waterlogged areas through multiple use of harvested water (fisheries+on-dyke horticulture + field crops).

Materials and Methods

General climate of the study area

The waterlogged region of Puri district of Odisha was selected for the study. On an average, the region receives 1500 mm annual rainfall, 65-80% of which occurs during rainy season (June-September). The mean date of onset of effective monsoon is 16th June, which generally ends on 29th September. The open pan evaporation values vary from 8.1 mm in May-June to 3.5-5 mm in December-January. In the region, mean maximum temperature ranges from 33 to 37 ^{0}C during pre-flood period (January-June). During the main flooding period (July-September), the monsoon cloud cover lowers the maximum temperature within narrow range of 31-32 ^{0}C. In November and December, maximum and minimum temperatures drop to 24-27 and 9-10 ^{0}C, respectively. Generally water accumulation starts from the month of July after onset of monsoon. The first rise of accumulated water depth in the region depends entirely on rainfall in the catchment areas. Flood recession phase is more consistent, which occurs from November onwards and the land remains dry from January-May. The general trends of pre-flood, flood, and post-flood periods of the study area are given in Fig. 1.

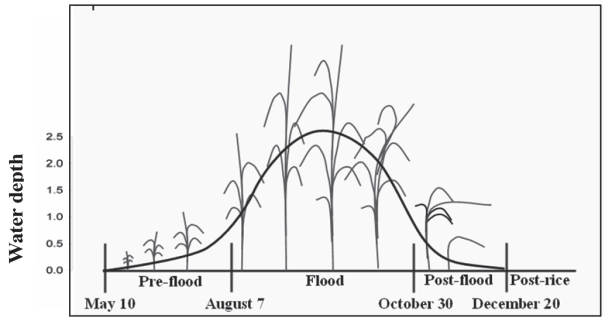

Fig. 1. General trend of pre-flood, flood and post-flood periods of the study area

Soils of the study area

The soil belongs to very fine, mixed, iso-hyperthermic, Vertic Endoaquepts with 0-1% slope, very slight erosion with normal relief. Before the experimental trials, soils of the study area were analysed in respect of major characteristics (Table 1). Soils were moderately acidic in reaction, non-saline with high organic carbon and potassium, but low in available nitrogen and phosphorus while presence of Mg superseded Ca. Some of the major physical characteristics of soils of deep (1-2.5 m) and moderately deep waterlogged areas (0.5-1 m are given in Tables 2 and 3, respectively. Soils were deep to very deep, find textured; the groundwater table was 1-2 m below ground level. These were poorly drained with very low permeability, and occurred in low-lying areas. Deep and wide cracks also appear during non-rainy periods.

Deep water rice (DWR) crop management and experimental procedure

Six DWR cultivars *viz*., Hangseswari (V_1), Saraswati (V_2) Sabita (V_3) Ambika (V_4), Bankui (V_5), and Dhalakartik (V_6), were sown in line (plant-to-plant 20 cm; row-to-row 25 cm) in three waterlogging depths *viz*., shallow (D_1), medium

Table 1. Chemical properties of soils of experimental sites

Sample	pH	EC ($dS\ m^{-1}$)	Org. C (%)	Av. N (%)	Available P	Available K	Ca	Mg
					ppm			
F1	5.6	0.3	1.8	0.20	Trace	5424	6.61	10.45
F2	4.9	1.0	1.1	0.08	2.32	5295	6.5	10.64
F3	5.4	0.0	1.7	0.13	2.95	4908	8.63	10.08
F4	4.9	0.9	1.6	0.15	6.32	3487	8.4	8.03
F5	5.3	0.4	2.0	0.18	1.47	4520	3.81	5.04
F6	5.1	0.9	1.5	0.17	3.93	3213	5.71	7.40

Table 2. Major soil physical properties of seasonal deep waterlogged (1-2.5 m) areas

Depth (cm)	Sand (2.0 - 0.05 mm)	Silt (0.05-0.002 mm)	Clay (<0.002 mm)	Texture	Bulk density ($Mg\ m^{-3}$)	Saturated hydraulic conductivity ($cm\ hr^{-1}$)
	%					
0-15	24.5	19.6	55.9	Clay	1.59	0.17
15-38	20.4	17.6	62.6	Clay	1.6	0.20
38-62	12.5	21.7	65.8	Clay	1.63	0.24
62-95	22.3	15.4	62.3	Clay	1.65	0.23
95-150	25.6	15.9	58.5	Clay	1.65	0.11

Table 3. Major soil physical properties of seasonal moderately deep waterlogged (0.5-1 m) areas

Depth (cm)	Sand (2.0 - 0.05 mm)	Silt (0.05-0.002 mm)	Clay (<0.002 mm)	Texture	Bulk density ($Mg\ m^{-3}$)	Saturated hydraulic conductivity ($cm\ hr^{-1}$)
	%					
0-15	25.6	36.9	37.5	Clay loam	1.53	0.17
15-30	41.0	37.6	21.4	Clay loam	1.55	0.20
30-60	15.0	42.6	42.4	Silty clay	1.60	0.24
60-90	41.1	36.3	22.6	Loam	1.62	0.23
90-150	24.6	39.9	35.6	Clay	1.62	0.11

(D_2) and deep flooded (D_3) with 3 replications. Similar fertilizer dose (N:P:K 40:20:20 kg ha^{-1}) and management practices were applied in all the land ecologies. Entire quantity of fertilizers was applied as basal because it was very difficult to apply top-dressing after flooding.

Different crop growth parameters and yield attributes (crop height, tillers m^{-2}, leaf area index, panicles m^{-2}), and grain and straw yields were recorded. Results of average of five plants at different water depths are presented. Throughout the rainy season, accumulated water depth was recorded at periodic interval and its interrelationship with rainfall was also studied.

Design of pond for harvesting excess rain water

To harvest the excess rain water in the seasonal waterlogged areas, rainwater harvesting pond was designed (Fig. 2). Four ponds with average areas of 0.553, 0.623, 0.623 and 0.720 ha were constructed. The pond was constructed in inverted trapezoidal shape with sufficient width to resist the vertical and horizontal presence of stagnant water. The side slope was kept as 1:1 because the texture of the soil was clay to heavy clay. Minimum bottom and top width, and height of the bund were kept as 8.0, 3.5 and 3.0 m, respectively. The height of the pond dyke was

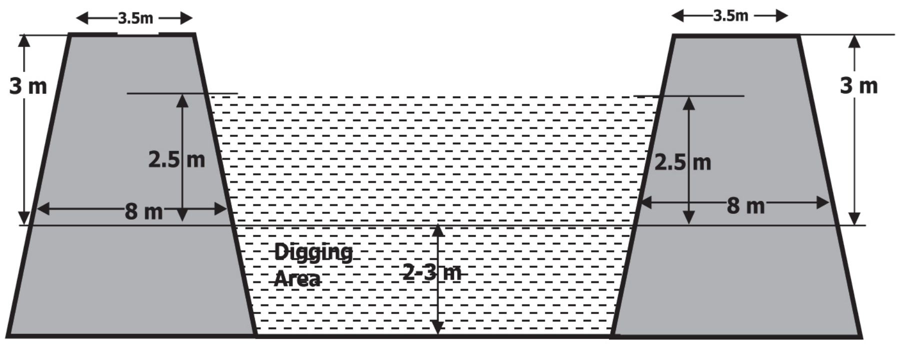

Fig. 2. Design of pond for water harvesting in waterlogged areas

determined by the flooding depth. It was found that a maximum waterlogging depth of 2.5 m appeared in saucer-shaped coastal plain. Therefore, keeping a free board of 0.5 m, maximum bund height of 3.0 m was constructed for creating water harvesting pond in seasonal waterlogged areas. To avoid soil erosion, pond bund was strengthened by planting dub grass (*Cynodon dactylon*). The depth of digging of pond ranged between 2.1-2.3 m depending upon the water requirement. However, too much shallow depth was avoided as it favoured high evaporation losses. The inlet and outlet systems were designed for controlling the water depth of the pond.

Development of pond based farming system to enhance water productivity

To transform unproductive waterlogged coastal areas into a productive and profitable one, pond based farming system was developed. Harvested water of pond was utilized in multiple ways (fisheries+on-dyke horticulture+growing of crops during dry season). Fresh water Indian major carps (*Catla, Rohi, Mrigal* in the ratio of 30:30:40) of 3 to 4 unit size @10, 000 ha^{-1} were released into the pond during August to utilize water in non-consumptive way. The harvested water of the pond was also utilized for providing supplemental irrigations (consumptive use) to grow vegetables crops (cucumber, watermelon, okra and ridge gourd), winter rice and medicinal plants (*Acorus calamas*) during winter and summer season (December to May). The winter rice provides food security to farmers of the region because the rice productivity during rainy season is low and unstable due to unpredictable seasonal flood. To utilize the pond dyke, creeper vegetables like bottle gourd, pumpkin and cowpea were grown on it with the help of harvested water. In this way, a pond based farming system was developed to enhance land and water productivity of seasonal waterlogged areas.

Results and Discussion

Seasonal distribution of rainfall in coastal districts

From the normal monthly rainfall, distribution during southwest monsoon (June-September), post-monsoon (October-November), winter (December-February) and pre-monsoon (March-May) were computed (Table 4). It was observed that 62-173 mm rainfall occurred during pre-monsoon period which would be useful for

Table 4. Season wise distribution of rainfall (mm) in coastal districts of Odisha

Districts	Monsoon		Post-monsoon		Winter		Pre-monsoon	
Puri	1062.8	(73.3)	224.9	(15.5)	47.7	(3.3)	113.7	(7.8)
Balasore	1107.7	(70.6)	213.3	(13.6)	54.9	(3.5)	192.5	(12.3)
Ganjam	862.8	(61.8)	248.4	(17.8)	44.0	(3.2)	140.4	(10.1)

Values in parenthesis indicate the percentage of total rainfall summer ploughing to make the land ready for final land preparation for deep rice crop during *kharif*.

Average rainfall during southwest monsoon months (June-September) were 863-1413 mm (62-88%) but major part of this is generally lost through runoff and creates waterlogging, which can be harvested and utilized for providing supplementary irrigation to crops during post-flood period. Among different months, rainfall was less variable in July and August. The summer and winter rainfall are meagre and highly variable. Growing of second crop during winter season after rice without supplementary irrigation would be risky. Crops like pulses (greengram, blackgram, peas) and oilseeds (linseed, safflower, niger) can be grown utilizing carry over residual soil moisture during post-flood period.

Flooding-rainfall relationship in seasonal waterlogged areas of coastal Odisha

Study revealed that the first rise of accumulated depth of water levels in the region depended entirely on rainfall in the catchment areas. The onset of flooding can vary greatly between years depending upon the rainfall. The flood water depth in relation to rainfall during monsoon (June-October) at 3 experimental land ecologies (D_1, D_2 and D_3) are given in Fig. 3 a, b and c for the year 2005, 2006 and 2007, respectively.

In the year 2005, flood water depth at D_3 ranged between 0.41 to 1.89 m. The highest flood water exceeded 1 m depth on August 16 when the crop height was 1.1 m. From 17th to 22nd August, water depth varied from 1.70 to 1.76 m and crop was submerged for 9 days. The crop was at active tillering stage (75 DAS) and the height of the crop reached up to 1.25-1.4 m. After 30th August, the crop was visible when water level declined to 1.38 m. In D_2 location, the highest flood level (1.25 m) was found on 21st August. In D_1, it was 0.97m on 12th September.

In 2006, heavy rainfall occurred in first week of July and surface water accumulation started early. At that time, the crop was at early vegetative stage and the crop height was only 0.10-0.20 m. In this year, the highest flood water depths were 1.32, 1.48 and 2.49 m at D_1, D_2, D_3 locations, respectively. Early heavy rainfall and flood caused extensive damage of rice crop in the year 2006 in all the three locations because the crop height was very less during that time.

In 2007, flood water depth was 1.37 m on 19th August when the crop height was 1.4-1.5 m. With further increase of water, the crop was submerged for 5-7 days in D_3 but when the flood receded, the crop survived. The crop condition was nearly similar in 2005 and 2007 because heavy rainfall occurred and flood occurred when crop attained its height sufficient to overcome the excess water situations. But due to occurrence of early flood, the crop was damaged completely and no yield was obtained in 2006. Therefore, the dominant factors for determining the success or failure of rice in deep water ecology are the time of flooding, rate of rise and maximum depth of floodwater. A consistent record of water level is necessary to properly interpret the performance of DWR varieties and the reasons for the success, or lack of success for crop production.

Since, the success or failure of rice in deep water ecology depends upon onset of southwest monsoon, rainfall distribution and depth of flood water, the rainfall patterns in different years based on last 34 years' flood and rainfall data were also investigated. Based on the rainfall occurrence and distribution, different situations occurred in different years like (i) dry summer followed by early monsoon, (ii) good summer rains followed by early monsoon, (iii) good summer rains followed by a weak monsoon, (iv) heavy rainfall in July-August or later, and (v) well distributed rains until August or September followed by torrential October rains. The date of beginning of the waterlogging was also found to vary. Based on the study, it can be said that the best condition for obtaining successful rice crop in deep water ecology was summer rain, well distributed monsoons and the crop height should be more than 1 m before flooding sets in. The flooding could be as early as 10th June *i.e.*, just after the onset of southwest monsoon in the region but in

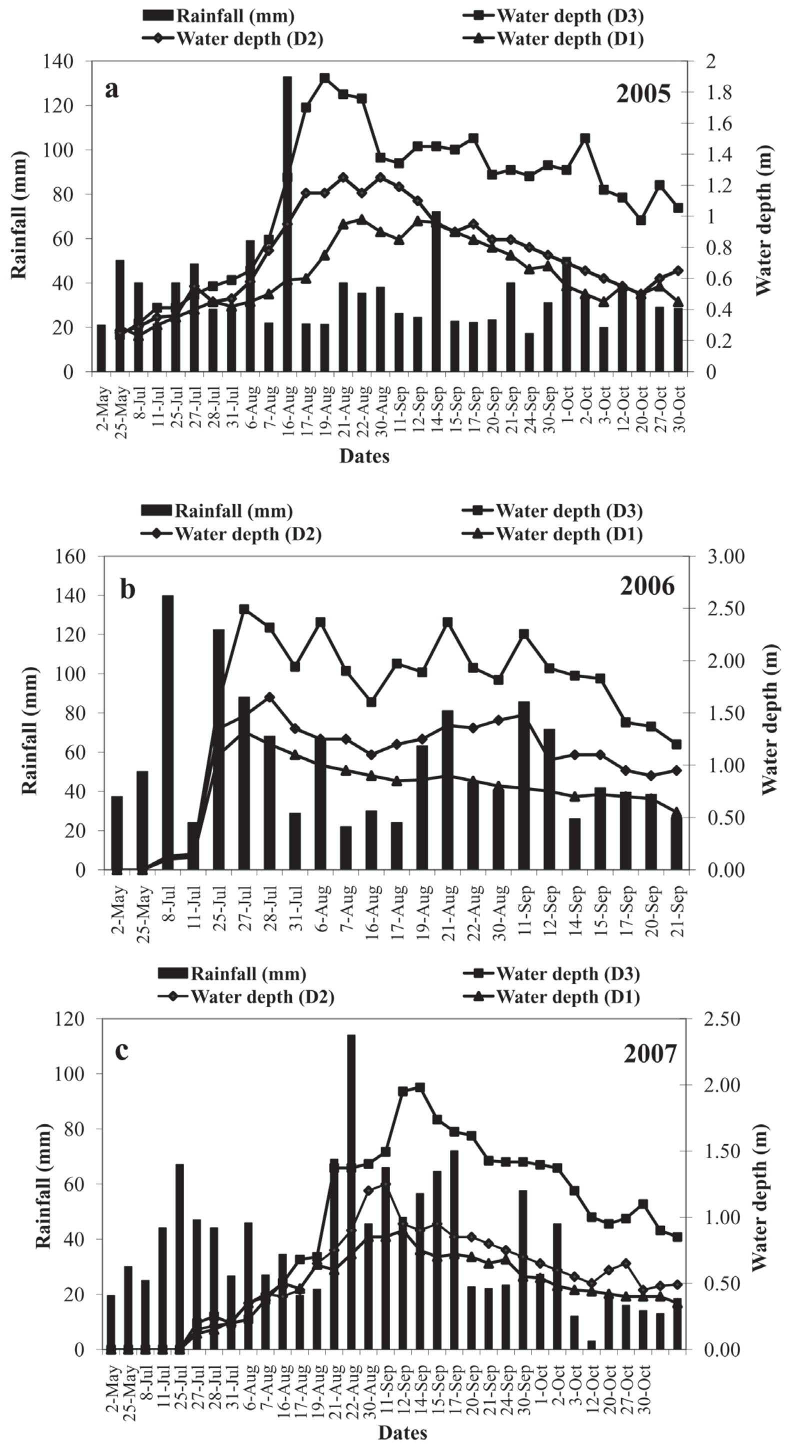

Fig. 3. Rainfall and accumulated water depth during *kharif* season of 2005 (a), 2006 (b) and 2007 (c)

exceptional years, it could be delayed until August-September. The probability of receiving floods after 15th August was 52% (crop height > 1 m) (Fig. 4). Thus, probability of receiving successful crop in deep water ecology was 52%. Therefore, farmers had to depend on other options like integrated pond based farming for their food and livelihood security.

Performance of DWR in wetlands

Based on rainfall-flood relationship, it was found that flooding pattern is completely

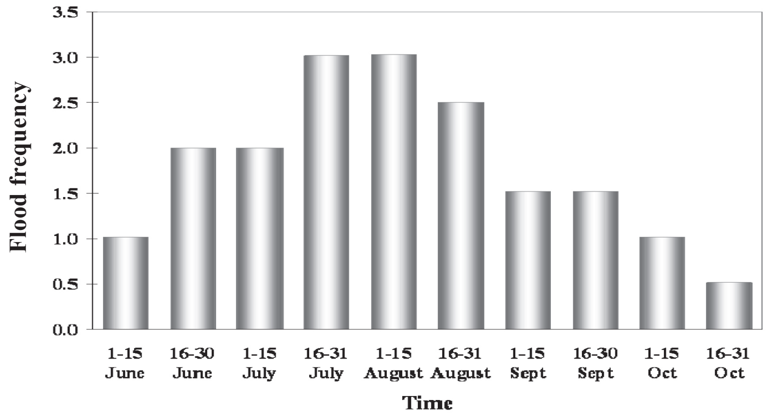

Fig. 4. Frequency analysis of timing of heavy rainfall and flood (>1m water depth)

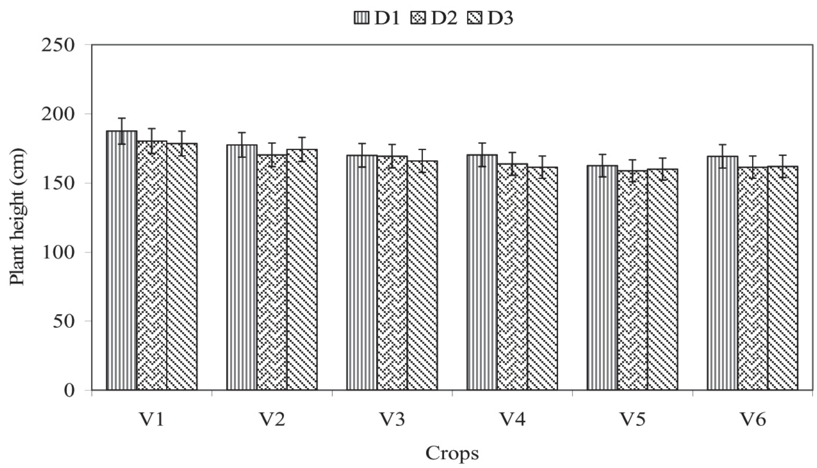

Fig. 5. Maximum plant height of different deep water rice varieties at three depths

dependent on rainfall in the catchment area and performance of rice crop is highly influenced by flooding time and depth. Among the study years (2005, 2006, 2007), crop growth and yield attributes were recorded for two successful years (2005 and 2007) at three water depths. Mean values are presented in Figs. 5-10.

In three ecologies (D_1, D_2 and D_3), maximum crop height of 6 rice varieties was measured. Analysis of pooled data of 2005 and 2007 revealed that the maximum crop height of 1.78-1.87 m was achieved by Hangseswari (V_1) in 3 waterlogging depths. Maximum crop heights of 158.8-169.2 m were recorded for 2 local DWR cultivars [Bankui (V_5) and Dhalakartik (V_6)]. However, the differences were not significant in different land ecologies. (Fig. 5). Average productive tillers m^{-2} were 179-198 in 4 improved DWR varieties in D_1 land ecology. With increasing water depth, the number of productive tillers decreased (Fig. 6). In D_2, the reduction was not significant but at D_3, productive tillers reduced by 19.2-25.7%. In all the land ecologies, introduced varieties like Hangseswari (V_1), Saraswati (V_2), Sabita (V_3) and Ambika (V_4) performed better than that of local varieties (V_5 and V_6). Prolonged waterlogging of 0.5-2.5 m caused reduction in productive tillers by 37.8-48%, but DWR varieties were less damaged. Similar trend was also observed for effective panicles m^{-2}. Highest number of panicles m^{-2} of 186, 180 and 151 were observed by Hangseswari variety in D_1, D_2 and D_3 locations, respectively. Panicle length varied from 18.3–24.8 cm in different rice varieties in D_1 ecologies. Among the varieties, highest panicle weight, filled-grain

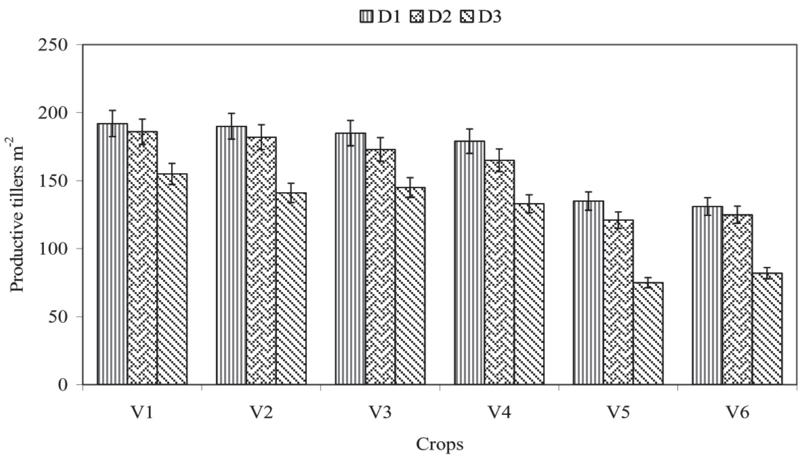

Fig. 6. Productive tillers of different deepwater rice varieties at three water depths

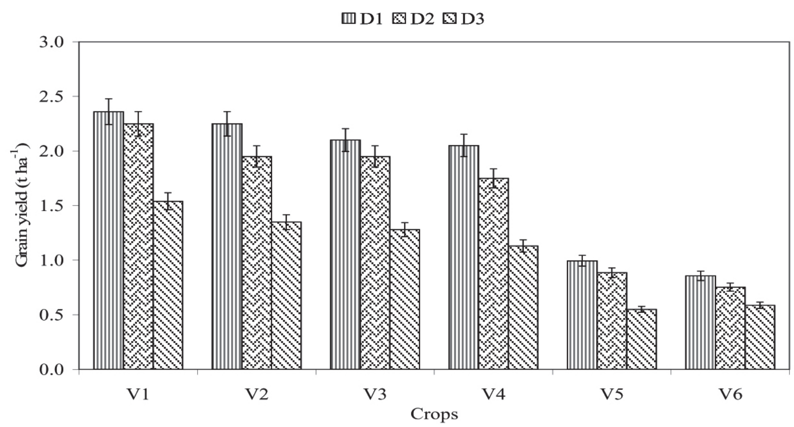

Fig. 7. Grain yield of different deepwater rice varieties as influenced by water depths

percentage and yield were obtained in Hangseswari. Low yield of rice in D_3 might be attributed to less number of ear-bearing tillers hill^{-1}. Hangseswari (V_1) exhibited higher yield under flooded condition which might be due to superior sink capacity in terms of higher panicle length and weight, spikelets panicle^{-1} and filled-grain percentage. Proper agro-technology needs to be developed for cultivation of this variety in the flood-prone areas. Poor grain yield of rice might be due to limited supply of assimilates to the developing grains (source limitation) or because of limited capacity of the reproductive organs to accept assimilates (sink capacity).

With the cultivation of improved DWR varieties, productivity of rainy season rice got enhanced and farmers received good yield (2.05-2.36 t ha^{-1}) and net return (Rs. 4000-5000 ha^{-1}) (Fig. 7). The productivity of all the varieties decreased with increasing water depth. In D_3 (>1.2 m depth), the yield reduced by 31.5 to 56.1% in different varieties. But in D_2, the reduction was not much significant in case of improved varieties. The yield was reduced by 21.2-25.1% in case of local cultivars Dhalakartik and Bankui, respectively.

In 2006, surface water accumulation occurred early and water depth of 1.5 m was recorded on 4th July, 2006 after early heavy rainfall on 2nd and 3rd July, 2007. The crop was at early vegetative stage and height of crop was only 0.25-0.35 m during 35 DAS. The water depth increased up to 2.0 m in 10 days and all varieties were damaged.

In 2007, waterlogging started on 5th August after heavy rainfall on 4th August. The crop was then at active tillering stage and attained a height of > 1.0 m. As a result, crop was successful.

Table 5. Net returns from pond based farming system (Mean of 2006-07 and 2007-08)

Pond	Pond based farming area (ha)	Income from Rainy season	Income from Dry season	Income from Fish	Income from On-dyke horticulture	Total income	Total exp. of cultivation	Net returns from the land	Net returns (Rs ha^{-1})
		Rs.							
P_1	0.63	-	16600	8572.5	2850	28022.5	14205	13817	21932
P_2	0.70	-	17995	11135	2500	31630	15310	16320	23314
P_3	0.70	-	17810	10020	2950	30780	15660	15120	21600
P4	0.82	-	20800	11330	3145	35275	16320	18955	23408

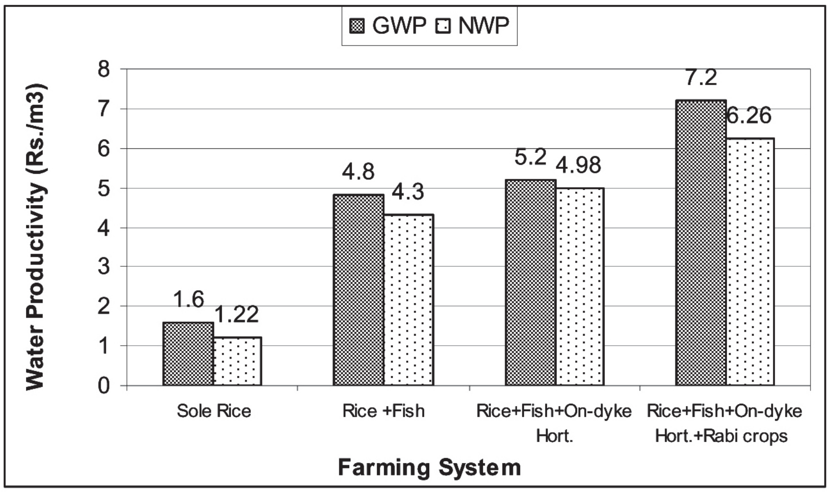

Fig. 8. Enhanced water productivity through multiple use of water in deep waterlogged areas

Multiple use of harvested water in pond based farming system

In order to obtain assured return form deep water ecology, pond-based farming system was developed and harvested water was utilized in multiple ways. The volume of excavated earth along with positive height of harvested area and water utilized for providing supplemental irrigations to crops in dry season (December to April) of 2006-07 and 2007-08 were recorded. Just after the wet season, the positive height of harvested water (1.8-2.4 m) and depth of digging (2.1 to 2.5 m) of the ponds were measured. In all the ponds, groundwater depth (1.6 m-1.9 m) was less than that of the digging depth and as a result, seepage loss from the pond was negligible. The only major loss of water was through evaporation, which was around 8-10% of total harvested water. About half of harvested water was utilized for providing supplemental irrigations to dry season crops.

After construction of ponds and utilization of harvested water in multiple ways (fisheries + on-dyke horticulture + growing of crops during dry season), the productivity of seasonal deep waterlogged areas was enhanced. Study revealed that with pond sizes of 1613 to 2012 m^3, net returns of Rs. 21600-23408 were obtained through multiple use of harvested water (average of 2006-07 and 2007-08) (Table 5). With pond based farming, net water productivity of the system was also enhanced up to Rs. 6.26 m^{-3} through multiple use of water from Rs. 1.22 m^{-3} through sole rice cultivation (Fig. 8).

Conclusions

With the introduction of improved deep water rice varieties, productivity of wetland during rainy season improved and farmers received better yields (2.5-2.8 t ha^{-1}) and returns (Rs. 4500 ha^{-1}). Success and failure of the rice crop in deep water areas depend on the time of onset of monsoon and its distribution, and time and depth of waterlogging. Knowledge of flood characteristics such as nature, duration and frequency of flooding, data on turbidity, water quality and water regimes in shallow, intermediate and deep water could be helpful for adopting deep water rice. Important crop traits like elongation capacity, tolerance for complete submergence for a minimum period of 7 days, photo period sensitivity, good tillering and kneeing ability, strong rooting system with non shattering grains are very much desirable for successful adoption of rice varieties in deep water ecology. Water harvesting was found to be the best options for enhancing productivity of seasonal waterlogged areas.

References

Ambumozhi, V., Yamaji, E. and Tabuchi, T. 1998. Rice crop growth and yield as influenced by changes in ponding water depth, water regime and fertigation level. *Agric. Water Manag.* **37**: 241-253.

Baruah, K.K., Rajkhowa, S.C. and Das, K. 2006. Physiological analysis of growth, yield development and quality of some deep water rice (*Oryza sativa* L.) cultivars. *J. Agron. Crop Sci.* **192**: 228-232.

Das, A. and Uchimiya, H. 2002. Oxygen stress and adaptation of a semi-aquatic plant rice (Oryza sativa L). *J. Plant. Res.* **115**: 315-320.

Kar, G., Sahoo, N., Ashwani Kumar, Das, M., Roychoudhury, S and Chandra, D. 2007. Integrated technologies to enhance productivity of seasonal deep waterlogged areas. Research Bulletin No. 40. Published by Director, Water Technology Centre for Eastern Region, (I.C.A.R.), Bhubaneswar, Orissa, India, pp 56.

Khakwani, A.A., Shiraishi, M., Zubair, M., Baloch, M.S., Naveed, K. and Awan, I. 2005. Effect of seedling age and water depth on morphological and physiological aspects of transplanted rice under high temperature. *J. Zhejiang Univ. Sci. B.* **6**: 389-95.

Kotera, A. and Nawata, E. 2007. Role of plant height in the submergence tolerance of rice: A simulation analysis using an empirical model. *Agric. Water Manag.* **89**: 49-58.

Rose-John S. and Kende, H. 1984. Short-term growth response of deep-water rice to submergence and ethylene. *Plant Sci.* **38**: 129-134.

Roy Chowdhury, S., Anand, P.S.B., Sahoo, N., James, B.K. and Ashwani Kumar. 2006. Comparative performance and physiological basis of yield variation in five rice varieties under waterlogged condition in farmers field. Int. J. Trop. Agric. **24**: 1-2.

Sahoo, N., Jena, S.K. and Srivastava, R. C. 2005. Sub surface water harvesting structure a new concept for water resource development in coastal area. *Agric. Eng. Today* **29**: 85-90.

Zeng, L., Lesch, S.M. and Grieve, C.M. 2003. Rice growth and yield respond to changes in water depth and salinity stress. *Agric. Water Manag.* **59**: 67-75.

Received: 31 December 2012; Accepted: 1 August 2013