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WTCER

WATER TECHNOLOGY CENTRE FOR EASTERN REGION
(Indian Council of Agricultural Research)
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FOREWORD

Waterlogging or excess water in agricultural field is a major constraint in our country in increasing agricultural productivity. High rainfall in short period, inadequate drainage, seepage from canal and irrigation channels, rise of water table due to irrigation network, flat land, saucer shaped physiography of the land, ingression of sea water are few major causes for waterlogging in our country. Vulne*rabi*lity of agricultural land is felt every monsoon rendering sizable area of cultivable tract to flooded. Even though needed, systematic approach to face such excess water situation has been scanty. To cope up with this ecological challenge, WTCER, Bhubaneswar took initiative in this direction. As a first step extensive survey was undertaken by multidisciplinary team of scientists of this Institute mainly to assess the situation in major flooded and flood prone areas of eastern India, covering four states. The stock of the situation of waterlogged areas were taken with a special focus on prevailing cropping pattern and socio-economic status of people of this region affected by excess water situations. An attempt has been made to record the agricultural activities with minor crops grown and their associated economics. Efforts were made to catalogue the survey experience as a benchmark document to underpin the status of agricultural activities of waterlogged areas in general and eastern India in particular.

AUTHORS

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1.0 INTRODUCTION

The food grain production in India (210 million tonnes in 2004-2005) got quadrupled in the recent years from 51 million tonnes at the time of its independence. However, the rate of increment in food grain production for last 6-7 years has not been significant to meet the food requirements of the burgeoning population which has already crossed 1050 million, including under nourished population of 270 million. This is quite alarming as the recent reports indicate that approximately 243 million tonnes of food grain production is required to feed the population by 2007. This slow rate of increment in food grain production is mainly due to several constraints that affect crop productivity negatively over a large area. Waterlogging is one of the most important constraints, which limits the crop production to a narrow limit. In India, approximately 6 m ha is under waterlogging where the establishment of any crop for commercial cultivation is not possible.

Waterlogging is a term used to describe the conditions when the water table comes near the surface, submerging the roots, so that crop growth is affected. The rising water table restricts root development of the crop and brings harmful substances to the root zone. Soil becomes saturated as a result of excessive rainfall, over-watering, and slow drainage. Finally the crop dies due to excess of water causing lack of oxygen for root aeration and nitrogen deficiency.

1.1 Response of Plants under Waterlogging

Several morphological, anatomical and physiological changes take place in plants subjected to waterlogging. The important changes are: shoot elongation, senescence, abscission and production of adventitious roots. The proportion of aerenchyma tissue in the root system increases. Respiration in the roots changes from aerobic to anaerobic, form with the result that toxic substances accumulate in the roots and damage the root tissues. Ethanol production increases and activity of alcohol dehydrogenases increases in the roots of waterlogged plants. Ethanol, in large quantity, is harmful to plants. Permeability of roots decreases due to shortage of oxygen. It results in decreased water uptake and wilting symptoms appear even though soil contains excess water. Permeability for nutrients is also reduced due to waterlogging.

1.2 Extent and status of waterlogging

About 25,000 ha of irrigated land are lost each year due to waterlogging and salinization. Management of waterlogging and agricultural development require multi disciplinary approach that integrates analysis of spatial and non-spatial data productions so that decision makers can implement plans for water use in the problematic areas.

The Soil Resource Mapping Programme conducted by NBSS & LUP (National Bureau of Soil Survey and Land Use Planning), Nagpur estimated taking in to account the areas under aquepts, auents and other soils under aquic moisture regime to work out the extent of soils under waterlogging condition in India. The estimate shows that the area prone to waterlogging is 11.6 million ha (ICAR, 2000).

The water logging problem in eastern India is mainly confined to deltaic region with sub-humid to humid tropical climate. In general, in this region by and large three types of excess water situations are encountered viz, (i.) High rainfall associated within very short period with inadequate drainage resulting into flood that extends over large areas., (ii.) Accumulation of water over prolonged period or seasonal in sporadic localized topographical depressions and (iii.) Intrusion of brackish or sea water in deltaic areas. Taking in to account of high rainfall situation and the difficulty in evacuation of high volume of water under flooded condition, the rice based cropping system serves as a suitable storage ground, accommodating moderate to low flow volume over large areas extending over more than 40.1 million ha. Due to uncontrolled excess water situation even rice growing areas are often subjected to waterlogging and flash flood. In eastern India about 10 million ha of rice growing areas are affected by excess water situation (Photo 1) (Sharma and Reddy, 1992). The predominance of clay soil in deltaic eastern zone make drainage extremely difficult. Thus high rainfall with insufficient drainage make topographical depressions susceptible to stagnant water. In this type of situation even with a brief spell of rain, water surfaces above ground takes place due to very slow drainage or evaporation for removing the excess water. This results in waterlogging situation extending for longer period of the year. In Orissa itself such excess water situation extends over more than an area of 84,000 ha (ORSAC, 1993).


Photo 1 : Rice field affected by waterlogging

Keeping this in view an integrated effort has been made by WTCER (ICAR), Bhubaneswar to study and analyse the areas affected by waterlogging and their nature and crop performance in Eastern India. After surveying these areas, different measures for improving productivity of waterlogging crops has been formulated. In addition, suitable *rabi* crops in post flooded areas also have been identified.

2.0 THE SURVEY OF WATERLOGGED AREAS OF THE EASTERN REGION

The salient findings of the survey conducted (Photo 2a) in West Bengal, Bihar, Jharkhand, and Orissa are as follows:

- Water chestnut (Photo 2b) is a major crop in shallow to deep waterlogged areas mainly in Southern parts of West Bengal and Bihar.

Photo 2a : Survey team with farmers at Darbhanga district in Bihar

Photo 2b : Harvest of waterchestnut

- Integration of aquaculture is a common practice with water chestnut in shallow waterlogged condition around railway tracks, high way side depressions and localized topographical depressions.
- Apart from capture fisheries, in this system farmers usually get a yield of around 200-259 kg/ha per crop of air breathing fishes along with water chestnut yield of 8-10 t/ha.
- Apart from water chestnut, other vegetable crops like colocasia (Photo 3) and swamp taro (photo 4). Makhana and non-food

Photo 3 : Local waterlogging tolerant Colocasia (Saru) cultivar.

Photo 4 : Swamptaro under partial submergence

Photo 5 : Typha cultivation in West Midnapur district in West Bengal

commercial crops like Typha (as thatching material) (photo 5) is also raised in non accessible marshy areas as there is no scope and demand for other produces in this region.

- In Midnapur, South 24 Paraganas, Part of Burdwan, Hoogly, Nadia districts most of the farmers prefer rearing of Indian major crops like Catla, Rohu, Mrigal and Common carp fingerlings along with water chestnut by providing a small open space in this system. Usually farmers get 300-400 kg of fish from this system with in a period of 4-5 months.
- Swamp taro is a remunerative crop in Southern Bengal. A net profit of more thanRs.9000 /ha is obtained from this crop in marshy waterlogged areas.
- In Howrah and adjacent Midnapur district large scale cultivation of cat tails ***"Typha sp"***, (locally known as hogla pata,) was observed on the marshy land. After harvest, mature leaves were used as thatching material. Traditionally known as hogla-pati (*Typha elephantina* and *Typha domingensis*), it is more commonly found in the wetlands of lower Bengal. Hogla plants normally grow in waterlogged wastelands with moderate salinity (0.5 - 1.0 ppm).The cultivation of hogla plant costs approximately Rs 3000 /ha/year. Approximately one bundle of 15kg leaves costs Rs.50/- in the local market. Net profit earned from selling of hogla products is about Rs 5000/- ha/yr, from the sale of mat and Rs 9000/- from the sale of rain-sheds.
- In Darbhanga sadar, Madhubani, Dalsinghsarai, Begusarai, Purnea and Jaynagar districts makhana is a unique and potential crop. The farmers are basically fishermen but they take up makhana crop on leased areas as family business. An area is usually kept free from makhana crop for pisciculture with

the help of net. After decomposition of makhana crop the net is lifted to allow the fishes to move in the entire area. Release of fish in standing crop of makhana is not favored due to thorny nature of the crop inflicting damage to fish. Makhana yield usually range between 0.7-1.0 t/ha.

2.1 Study of floods and hydrology

Floods/submergence

In low land and deep-water ecosystems, submergence is a critical constraint to rice production. In deep-water areas, rice plants are subjected to submergence for most part of the growing season. Traditional varieties adapted to this situation are generally low yielder. In lowlands, most rice varieties can neither elongate fast nor survive inundation. The varieties that can survive often, suffer from lodging when water recedes. Sometimes flash flood submergence affect rice crop temporarily (for 10 days or less) before receding and most varieties are not adapted to such situations. Almost all lowland and deep-water areas of the region are prone to temporary inundation and hence suffer yield losses. Floods may occur any time between June and August. In Assam on an average 2,50,000 ha of rice area are affected by floods every year. Lakhimpur district is the worst flood affected area where about 60% of the rice lands are damaged annually. Sibsagar, Dibrugarh, Darang and Nowgong are the other districts, where considerable areas are vulnerable to floods. Chronically flood affected areas are situated in the districts of Kamrup and Goalpara. In flood prone areas around Tejpur, planting of rice is often carried out by the end of September and early October which is a common practice. There is no known means of achieving high yields from such late planted crop.

About 3,80,000 ha are flood prone out of the total 4 million ha under rice in Orissa. In West Bengal, sizeable rice area situated in Midnapore, Howrah, Hoogly, 24-Parganas, Nadia, Murshidabad and Malda districts are recurrently affected by floods. The flood affected and deep water rice areas in West Bengal are estimated as more than 0.4 million ha. Patna, Bhojpur, and Rohtas districts of Bihar are prone to flash floods. Flooding and waterlogging problems are also serious in parts of Nalanda, Samastipur, Darbhanga, East and West Champaran, Saran, Siwan, Gopalganj, Saharsa, Madhepura, Purnea, Katihar and Khagaria. Rice yields in the areas prone to flooding and waterlogging are in the range of 0.5 – 1.0 / ha.

Analysis of draught and flooding pattern, in the shallow rainfed lowland ecosystem reveals that 54.6% of the area (5.7 m ha) under this ecosystem is drought prone, 25.5% (2.7 m ha) are drought and submergence prone, 10.3% (1.1 m ha) submergence prone, and only 9.6% (1.0 m ha) are favorable for crop production. The entire area in the medium-deep rainfed lowlands is submergence prone.

Hydrology of Eastern India

The average annual rainfall of the region is approximately 1482 mm and the monsoon (June to October) rainfall is 1249 mm, which accounts for 84% of annual rainfall. On an average the water level appears above the ground surface from 3rd week of June, reaches maximum during first week of August and starts receding after that and remains above ground for nearly six months in a year. Water table depth below ground level varies from 5 cm to 167 cm during post monsoon period (December to June). The weekly rainfall, surface ponding and water table depth is presented in Figure 1. The steep rise and fall in water table may be due to its drainage into river system during low flow period and quick recharge of ground water during high flow period. In a surface drainage experiment in waterlogged area of Puri district it was observed that surface water ponding starts from 3rd week of June and increases to maximum up to 162 cm in last week of August and then reduces to surface level in December. Water table observation in that area has also given similar trend. So this type of hydrology is prevalent in 67% of the waterlogged area (84,800 ha) of Orissa state and 38% (3.28 m ha) of total waterlogged area (8.52 m ha) of the country. The technology feasible in this particular situation can be applied to 3.28 m ha (38%) waterlogged area of the country.

2.2 Average crop yield

The average yield of rice in eastern India is less than 1 t/ha, in spite of good amount of rainfall. This poor productivity is mainly due to waterlogging problem. Majority of the farmers have been unaware of the suitable alternate crops which perform better than rice under the waterlogged condition.

Eastern India comes under a zone of good potential to improve crop productivity. Management of waterlogged areas in this zone will certainly enhance the productivity of some crops like rice and also

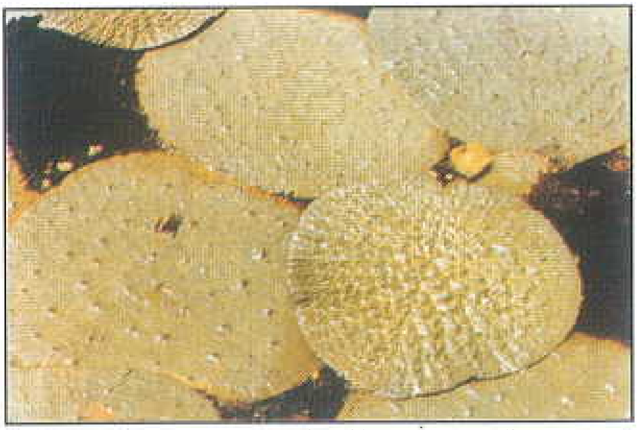

Photo 6 : A view of Makhana crop in Bihar help in establishing alternate crops like Water Chestnut, Makhana and Swamp Taro (photo 6). By integrating fish into this eco-system, the overall productivity of the zone could be increased tremendously which would meet the food grain requirement of growing population of our country. Approximately 6% of rice cultivated area (42 m ha) in India is under deep water rice which provides scope for rice-fish integration (Brahmanand and Mohanty, 1999).

3.0 REMEDIAL MEASURES

3.1 Engineering Options

Engineering options like surface drainage, land modification technology and recycling of drainage water seem to be feasible in these areas.

3.1.1 Surface Drainage:

In coastal waterlogged areas, different rivers and its triburoties were running across themselves in zigzag manner. The land is almost flat and sometimes saucer shaped. Monsoon rainfall is almost 80% of the annual rainfall. Under this condition there is little chance of surface drainage. But there are some areas where outfall is available and slope exists. In these cases surface drainage is a feasible solution. One such study is undertaken in Biswanathpur area of Puri district. The watershed area is 396.95 ha and waterlogged area in the watershed is 134.16 ha. Out of this 134.16 ha, severe waterlogging exists in 62 ha. In this 62 ha , nothing grows throughout the year. It is infested with ipomea cornea and aquatic weeds. According to severity the waterlogging area is divided into 4 categories.

Table 1. Waterlogging type in study watershed

Sl. No.	Type of waterlogging	Water level above ground	Area (ha)
1	Extremely severe	> 65 cm	62.00
2	Severe	40-65 cm	34.40
3	Moderately severe	30-40 cm	22.76
4	Slightly severe	< 30 cm	15.00
	Total		**134.16**

Gumble's extreme value distribution was used to compute drain discharge at 15,20 and 30 years recurrence interval for designing link drain, main drain and drainage outfall structures which are 0.70, 0.74 and 0.80 cumec/sq.km respectively. The design is based on CWC assumption. The design includes one main drain of 1.785 km, 4 nos of link drains, 3 nos of tanks and 6 nos of shallow tube wells. Impact of surface drainage is reflected in the crop yield of different crops in post drainage period. The water level in the field has been reduced by 20% to 33% in post drainage situation depending on topography of land. The drainage flow in the main drain increased by 6.1 to 73.1% in different months. Rice productivity and area under rice has been increased from 31% to 50% and from 25% to 75% respectively. Cropping intensity has been increased from 103.2 to 160.7%. Water table has also been decreased upto 16 to 20% depending on distance from the drain.

3.1.2 Land Modification Technology

In some cases in waterlogged area in spite of surface drainage, excess water cannot be drained out due to land topography. The ground level of those lands are so low that water cannot be drained out to main drains. In those cases land has been modified for (i) pond cum raised bed system (photo 7 & photo 8) and (ii) only pond system. The ratio of pond cum raised bed system depends on location. A study at CSSRI, Canning shows the ratio to be 10%. At CRRI Rice-fish land modification system ratio varies from 10 to 15%. Water Technology Centre for Eastern Region, has taken the land modification technology in Satakabat village of Biswanathpur in Khurda district. The total waterlogged area is 2212m^2. Two ponds of size 600m^2 and 1022m^2 were constructed and the excavated soil was spread around in an area of 590m^2. The height of the raised bed was 1 m above the surrounding field level. The idea of constructing two ponds was to rear fry in small ponds for about two months and then release fish in big pond at fingerling stage. A space of 553 m^2 was provided for cultivation of vegetable crop

Photo 7 : Pond-cum-raised bed system

Photo 8 : Periodic sampling of fish

both in *kharif* and *Rabi*. During *Rabi* season, the performance of different vegetable crops such as ladies finger and tomato was good in low lying areas. The increase in yields in the raised bed cultivation system was 20 to 40 percent more than that in the prevailing low land cultivation system for different crops. This was due to timely plantation of the crops in the raised bed and protective irrigation using pond water which was maintained by pumping from bore well during *Rabi* and summer season. In the low lying land *rabi* crop production has a set back due to delayed planting caused by excessive soil wetness for a significant part of post monsoon season and scarcity of irrigation water.

Table 2. Yield and Economics of pond and raised bed system

Season	Crop	Crop yield (q/ha)	Gross return (Rs)	Cost of cultivation (Rs/ha)	Net return (Rs/ha)
Kharif	Ladies finger	2.08	2496.00	543.00	1953.00
	Brinjal	3.00	3000.00	271.00	2729.00
Rabi	Tomato	1.20	1200	302.00	898.00
	Ladies finger	2.08	2496	543.00	1953.00
Summer	Chilli	2.00	1800	1357.00	443.00
Bund plantation	Pumpkin	0.50	200	50.00	150.00
	Papaya	3.00	900	150	750.00
	Banana	9 bunch	1350	81	1269.00
	Cowpea	0.5	250	15	235.00
	Green leaf	0.05	50	10	40.00
Pond	Bitter gourd	0.62	620	35.00	585.00
	Fingerling	1200 nos.	1200.00	450.00	750.00
	Big fish	0.75	3150.00	950.00	2200.00

**A space of 183 m^2 for vegetable and 224 m^2 for bund vegetables and 90 m^2 for scaffold is earmarked.*

The study of comparative economics between pond cum raised bed system and low-lying adjoining land reveals that benefit cost ratio (B: C) in the improved system is 2.45 where as in the low lying system (original condition) it is only 0.7.

The other land modification technology is complete conversion of the low land into pond on dyke system. It was developed in Khentalo village of Nischintakoili block in the district of Cuttack. The total area of the system (2.47 ha) consisted of 1.5 ha swampy 'Kia' forest and rest 0.97 ha waterlogged area which was being cultivated with long duration variety of local paddy (yield 1.1 t/ha). Out of 2.47ha of low productive swampy waterlogged low land, a pond was constructed in 1.64 ha and the dug out earth was put in the bund to raise it for horticultural crops (photo 9, 10 & 11). The bund area was 0.83 ha. The width of bund in north side was 21 meter and 10 meter each in east, south and west side. The pond dimension was 195m x 84 m. The depth of pond was 2 m. The weekly rainfall, surface ponding and water table depth is presented in fig 1. The details of year-wise input and returns from the pond as well as bund system (integrated farming system) is given in Table 3.

Photo 9 : Newly constructed monolateral type deepwater rice-fish culture unit

Photo 10 : Fully developed pond with plantation on dikes in an ideal integrated farming system

Photo 11 : On-dyke horticulture on rice-fish culture unit

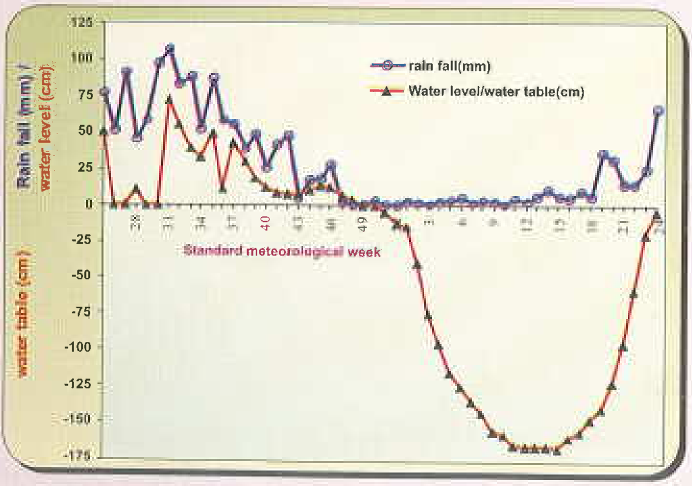

Fig. 1. Weekly rainfall, surface ponding and water table depth of the project site

Source: Samra et al. 2003.

Table 3. Economics of Rice-fish system

Year	A: Input cost (Rs)							B: Gross return (Rs)					Net return in Rs/ha	Net return in rupees (B-A)
	Pond construction & infrastructure	Horticulture / vegetable seed, fertilizer etc. ***	Fish and prawn seed	Fish feed	Labour	Misce llaneous. *	Total in rupees	Fruits & Vegetable	Fish & prawn	Coconut	Poultry **	Total in rupees		
1988	1,23,910 (excavation)	-	-	-	-	20,000	143910	-	-	-	-	-	-	
1989	-	12600	12000	28730	14000	13000	80330	110400	70100	-	-	180500	100170	40,554
1990	-	12000	14700	29750	14000	13500	83950	114000	88000	-	-	202000	118050	47,793
1991	-	12000	16400	31200	14000	14800	88400	98600	96750	-	-	195350	106050	42,935
1992	-	10400	18000	36900	17500	14500	97300	44000	172800	30000	-	246800	149500	60,526
1993	-	8700	23000	42850	17500	16000	108050	42800	199000	45000	-	286800	178750	72,368
1994	-	8900	28300	48700	17500	19000	122400	46000	269200	48500	-	363700	241300	97,692
1995	-	7500	30100	54225	21000	30500	143325	52100	329700	59000	-	440800	297475	1,20435
1996	-	3200	33200	64650	21000	28600	150650	47200	345000	76900	-	469100	318450	1,28,927
1997	-	2850	35500	81000	24500	29000	172850	35450	372400	93250	-	501100	328250	1,32,894
1998	130000 (stone lining)	2900	48900	86800	28000	23000	319600	48300	383900	105000	-	537200	217600	88,097
1999	320000 (poultryshed)	3000	53100	69500	28000	380000	753600	14000	218200	80500	324000	636700	(-) 116900	(-) 47,327
2000	-	2660	42200	92000	17500	31000	185360	1300	249500	2400	-	253200	67840	27,465
2001	-	2550	58700	106000	17500	34550	219300	12900	541000	6000	-	559900	340600	1,37,894
2002	-	2500	69615	156400	17500	42580	288595	23000	617160	10950	-	651110	362515	1,46,767
2003	-	2600	70060	161300	18400	44160	296520	25500	672280	11700	-	709480	412960	1,67,190
2004	-	2650	71120	164100	19200	46070	303140	27100	686150	11400	-	724650	421510	1,70,651
Grand Total on 17 year basis							35,57,280					69,58,390	34,01,110	13,76,967

* Miscellaneous includes lime, cow dung, pumping, irrigation system, masonry work etc. ** Poultry was added in the year 1999

*** Horticulture including banana, papaya, pineapple, mango, areca nut etc. Average net return per ha per year on 17 year basis from IFS = Rs. 80,998

Photo 12 : Visit of Dr. J.S. Samra, DDG (NRM), ICAR to the project site

The system suffered loss only in the year 1999 to the tune of Rs 1,16,900 due to devastation caused by super cyclone. Further the impact of cyclone affected the net return\ in the subsequent year 2000 in which the net return was only Rs. 67.840. The net return was Rs, 1,00,170 in the first year of operation of the system, which has enhanced to the maximum of Rs. 4,21,510 in the year 2004. The comparative net return from the IFS (photo 12 & 13) and rice cultivation in rupees per hectare per the year is presented in the figure 2.

Photo 13 : Director, WTCER, Dr.Ashwani Kumar vists experimental site with farmer

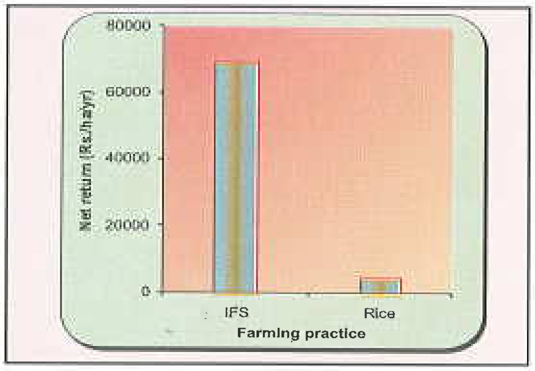

Fig. 2. Comparative net return from IFS and rice cultivation   Source : Samra etal., 2003

3.1.3 Improvement of Capacity of Natural storage of drains:

In lowland, there are many localized pockets which are completely unfit and unsuitable for growing rice. Sometimes the water depth reaches upto 4 m. In those cases, the storage space should be reconstructed and made further deep during summer season, to receive more water. This will help adjoining lands to moderately suffer from drainage congestion. Such pockets are there in Gobari Doab in Kendrapara and Rajnagar area. Even in the Chilika lake, the coastal sides are silted up, due to which lowland drainage waters could not be discharged. Tanks in the lowland area should be deepened to store more water as in case of Puri and Ganjam districts of Orissa.

3.1.4 Construction of High tidal dykes:

High tidal dykes are meant for not allowing water from the sea to enter into the land area. Instead, at low tide period it will drain out the water to the sea. High tidal dykes with shutter system are constructed in the coastal belts of Balasore, Bhadrak and Puri districts.

3.1.5 Leeve Management:

Lowland rice, at times, also suffers from severe drought. Rainfall usually ceases during 2nd week of September. For long duration varieties, attimes during flowering period severe drought occurs. To overcome this difficulty leeve management is essential. The lowland area should be bunded and the leeve height should remain at least 15 cms high, so that it can improve water storage and sustain the crop for a period of 10 to 15 days, during flowering to grain formation stage.

3.1.6 Recycling of drainage water:

Long-term engineering measures are associated with some novel short term measures. These are recycling structures to reuse the drainage water from command areas. Recycling of the unutilized drainage water can be made at the plot level, lateral drain level or at the drain level. After meeting irrigation requirement of an outlet command, the excess water flows to the disposal drain which can be called lateral drains. Here suitable recycling structures can be constructed to reuse the drainage water. Table 4 shows the structures built in the lateral drain level in Hirakud project. Total area benefited was 71.27 ha and total cost of recycling structures was Rs. 30,000/-.

Many recycling structures have come up along main drain level in the Mahandi delta command area. Table 5 shows different recycling structures with their utility and benefit cost ratio (Patra et al, 1984).

Table 4. Reuse of Waste water in Kabrapalli minor

Village	**Recycling project (Nos)**	**Area Benefitted (ha)**
Sanatan Palli	5	8.653
Poda Pada	1	2.372
Kabarapalli	10	60.245

Source: Patra et al (1984)

Table 5. Recycling structures in Mahanadi Delta Command area (rain drain level)

Name of the project	Cost of the project (in lakh)	Crest length (m)	Area commanded (ha)		B.C.R. (Rs.)	Cost ha^{-1}
			Kharif	*Rabi*		
Sirilo	0.23	4	52	-	-	-
Nabanga	1.26	9.304	500	355	1.71	354.42
Nagpur	2.15	17.400	800	597	1.55	359.00
Badgaon	1.76	7.94	600	492	1.60	358.93

Source: Patra et al (1984)

In addition to these hardware options, some software options may also have to be integrated in management of waterlogged areas. These include 1. Growing of waterlogging resistant paddy varieties 2. Floating rice 3. Growing aquatic crops like water chestnut, swamp taro and makhana.

3.2 Agronomical Options

3.2.1 Suitable rabi crops in waterlogged eco-system:

In several areas of eastern Indias the waterlogging is quite seasonal. It is mainly rainfed depending on the frequency and extent of annual rainfall. Hence the crop can be grown when the water level reduces periodically in *rabi* season under post flooded situation. However, suitable crops are to be selected which perform favourabely under *rabi* season (Photo 14).

Photo 14 : Scaffold for utilisation of pond space

The crops like pulses and oil seeds fit well in this cropping system as they can resist drought which may result in post flooded situation. Pulses like black gram, (urd) green gram (mung) cowpea and horse gram can result in reasonably better yield with supply of one or two irrigations at their critical growth stages. For example, if water can be supplied at flowering and pod formation stages, black gram results in favourable pod yield. Similarly oil seed crops like groundnut and sesamum can be successfully cultivated in *rabi* season with irrigation at critical stages irrigation during post waterlogging situation.

Shallow tube well can be dug in post flooded season which can supply water at critical stages. A case study has been made by the scientists of WTCER (ICAR), Bhubaneswar at Barang, 8 km away from Bhubaneswar. It represents a rainfed waterlogged conditions where the waterlogging resistant rice varieties like Durga, Panidhan, Sarala and Tulasi were tested in *kharif* season (Brahmanand *et al.*, 2001). After the harvest of these paddy varieties, three *rabi* crops i.e. groundnut, green gram and cowpea were grown with critical stage irrigations. The water was supplied from shallow dug well made in the farmers field. The rice groundnut cropping system performed superior in terms of crop yield and economics in waterlogged eco-system. If waterlogging occurs in a loamy soil, some medicinal plants like Coleus may be grown in *rabi* season which requires less irrigation frequency. The successful management of waterlogged areas has to finally result in emergence of an integrated farming system which would certainly enhance the over all productivity and economics of farmers.

3.2.2 Cultivation of bio-drainage species:

Several engineering approaches like installation of tube well, surface, sub-surface drainage has been adopted to deal with the problem of waterlogging as physical drainage measures since long even though with several limitations In this context use of vegetation to influence water table (mostly for drainage) appears promising. It is reported that trees could be used to manage shallow water table and salinity problem. The clear impact of lowering of water table is evident even within 10 years of establishment of vegetation. The approach is relatively cheaper, sustainable and ecologically compatible depending on natural capability of vegetation to transpire water. Few important profusely transpiring trees as promising bio-drainage candidate are detailed below.

Eucalyptus

For raising seedling seeds are sown in March on raised beds in lines at a spacing of 10 cmx30 cm. The broadcasted seeds are sown at the rate of 20g/m². The seed beds are covered with straw mulch with frequent spray of water to keep the bed moist. The seedlings are transplanted in pits of size 30cmx30cmx30cm. The filling material for the pit is soil, FYM mixed with 10-15g Lindane 20 EC powder (photo 15).

Photo 15 : Eucalyptus as bio drainage species being grown in waterlogged area

Casuarina

Casuarina glauca grows in difficult saline sites, which are unsuitable to many other trees and can grow at a rainfall range between 500-4000 mm. It is mainly used as a wind break or fire- or fuel wood or as fodder. The leaf contains about 9% crude protein, 37% crude fibre and 37% digestable nutrients. It is a dioecious tree and with male and female trees exist in 1:1 proportion in natural stand . The plants are generated from seeds. Seeds germinates well in temperature range of 25-30°C and do not require any pre treatment. The species include C. *cunninghamia* and *C equisetilolia*. In symbiotic association with actinomycetes *Frankia* it produces root nodules and fixes nitrogen even in saline or water logged soil . The inoculation of nursery seedlings is done with crushed nodules or soil beneath mature trees (photo 16).

Photo 16 : A view of Casuarina as bio drainage species vegetation being grown in waterlogged area

Lucerne (Medicage sativa)

It is a perennial forage tree typical for climate with cold winter and semiarid hot summer. It responds to rainfall and survive dry summers in dormant state. The deep root systems intercept water even well below 2-3 meters. This makes the species suitable for recharge areas to reduce waterlogging.

3.2.3 Other crops suitable for water logged areas:

Kalmi Sag (*Ipomoea aquatica;* family Convolvulaceae): This semiaquatic plant grows on the banks of water logged areas and grows as leafy vine on the surface of water. The vines are used as leafy vegetable.

Thankuni sag (*Hydrocotyl asiatica* ; family Umbelliferae): This herb also grows naturally on swampy area. The creeping plant usually propagates by means of runners. The leaves are generally consumed either as raw paste with rice. It is consumed for its medicinal value for curing dysentry. Sometimes pastes are dried into tablets for medicinal use.

Shola (hatplant) cultivation :The soft stem pith of *Aeschynomene aspera* produces shola and its cultivation for commercial purposes is restricted to mostly in mid- to southern part of West Bengal.. Nearly 800 ha area of wetlands of North 24 Parganas is now used for shola cultivation. During colonial regime shola was used for making hats. After wards it found its place in making various ritual items for puja and other social customs. The net profit of as high as Rs 40,000 /ha can be earned from shola cultivation by selling of its ornamental products. The export value of particularly idols made at Shola could earn many folds.

Mat cultivation :Mat known as "sopo" in Oriya or madur in Bengalee is obtained from two species of sedges, viz., *Cyperus pangorei* and *Cyperus corymbosus*. Inferior quality of mat is also prepared from several members of this family Cyperaceae like *Cyperus malaccensis, Cyperus iria, Cyperus exaltatus* etc.

Good quality mat plant is cultivated in wet soil but waterlogging for a substantial period hinders the growth. The plant grows well in potash rich soil. Potash rich tank silt is ideal bed for mat plant cultivation while phosphate and nitrogen rich soil promote blight. The plant is tolerant of subsoil salinity. It can also grow well in domestic wastewater saturated soil but cannot tolerate very high Biological Oxygen Demand (BOD) and Chemical Oxygen Demand (COD) (Ghosh and Santra, 1996). Major wetlands used for mat cultivation lie in the districts of Medinipur and North 24 Parganas and partly in Haora. Net profit earned from cultivation of mat plants is about Rs 1,00,000 /ha/yr. It has been estimated that a 5-member rural family managing wetland area of 2000 sq.ft. can expect a return of about Rs 1250/- to

Rs 1500/- per growing season. Presently beautiful paintings and silk-screen printing are done on fine mats (madar mats or mataranji) which have become very popular in the fancy markets (Ghosh, 1998).

3.2.4 *Aquatic Medicinal Plants*

Some aquatic medicinal plants like Brahmi, Keshori, Impomea and Kulekhara can also be fitted in to this waterlogged ecosystem.

Brahmi: It is a small perennial aquatic creeping herb, commonly growing in moist, wet, marshy places through out the plains of India, extending to an altitude of 1320 m (Puste,2004). The herb is more habituated with wet places such as on transitional shallow water depths of channels, streams, wells, irrigated fields, tanks etc. It is suitable mostly in north-eastern parts and peninsular India. It is valued in medicine as a tonic for nerves and is prescribed in nervous disorders, mental diseases and constipation. The plant is also considered as a blood purifier (Jain, 1996).

Keshori or The Kesuti : It grows commonly in moist , marshy, wet places as a weed over the plains of India, ascending up to 2,000 m on the hills. The juice of the leaves is used as atonic and deobstruent in hepatic and spleenic enlargements and in skin diseases. The plant juice also helps in curing catarrhal jaundice. The role of Keshori in curing viral hepatitis has been reported by Bose et al., 2001. The crop is raised as rainfed during wet months while extra irrigation should be provided during dry months of the year in absence of proper rain. A shallow water depth of 5-7cm should be maintained round the year for it.

Ipomea or Swamp Cabbage: An aquatic, trailing or floating, herbaceous perennial, sometimes annual species common through out India, and especially abundant on the surface of tanks in West Bengal, Bihar, Orissa, Assam and some other states in India. In addition to its usage as vegetable and fodder, it is also used as an emetic in cases of Opium and arsenic poisoning.

Kulekhara or Talmakhana : It is a marshy , small spiny bush, hispid, tall herb. It occurs commonly through out India along the banks of fresh or stagnant water ditches, low-lying areas and swampy moist grounds mixed with marshy grasses and sedges. It has medicinal properties in all its parts in curing hepatic obstruction, dropsy, rheumatism, jaundice and the diseases of genito-urinary tracts.

3.3 Integrated Aquaculture Options and Bio Management of Waterlogged Ecosystem

In waterlogged ecosystems, integrated aquaculture, even in small scale and low yielding in terms of aquatic produce, has an integral and sometimes pivotal role in integrated resources management (IRM). The IRM approach integrates the management of new enterprises, particularly aquaculture, with those of the existing farming system and with their respective natural resource systems so that opportunities for rehabilitation and synergism can be exploited. Further, integrated aquaculture-based farming systems, are less risky because of their efficiency derived from synergism among other components, their diversity of produce and their environmental soundness. In waterlogged ecosystem, stand fish farming alone can be risky venture for resource-poor farmers because of their environmental effects, economic factors such as price volatility etc. Therefore, keeping in view the efficiency, environmental factors and diversity of produce, integrated farming systems are widely hailed as a panacea for aquaculture development to benefit small-scale farmers especially of waterlogged areas.

Integrated aquaculture can be classified into three major systems with twelve major models. The most popular models preferred in India and suitable for waterlogged ecosystem are mainly pond-dyke integration, fish-rice-duck/poultry-vegetable, fish-water chestnut/makhana-vegetables and fish-cow/pig-duck/poultry-vegetable. In this system, marginal land/wet lands are brought into productive use and aquaculture units serve as a focal point for direct or indirect links between other natural resource. In addition to economic consideration, these systems are based on multiple recycling of carbon, energy and nutrients from biomass to livestock and minimize environmental loading with pollutants. The overall system is highly efficient in absorption of inputs and production of goods and services.

3.3.1 Fish - duck integration:

Three types of fish-duck integration are prevalent in India, i.e "ingrazing type" where ducks are grazed by one person in the pond/tank/reservoir during day time and kept in pens during night time; "enclosures based" where duck rearing is done in enclosures near the pond and "in pond raising" where enclosure is made by fencing a part of the pond where ducks are kept. In this systems a total of 200-300 ducks are sufficient to fertilize the pond and fish utilizes the nutritious duck droppings as food while the high manurial value of duck droppings helps in reducing the fertilizer input rate. Ducks also keep aquatic plants/weeds/insects in check and help in raking pond bottom and releasing of nutrients from soil which increase the pond productivity. Duck gets about 50-75% of their total feed requirement from pond/tank ecosystem in form of aquatic weeds, insects, molluscs etc. which do not form the food of fish and ultimately helps in high production of fish (3-4 t/ha/yr), duck eggs (4000-6000/yr) and duck meat (500-750 kg/yr) in an unit time and water area.

3.3.2 Fish - poultry integration:

In this system, the poultry birds are kept under intensive system (cage system/ deep litter system). The deep litter system is more preferred over cage system due to higher manure values of the litter. It is reported that, under this system, the fully built up poultry litter/fresh poultry droppings when recycled in the fish pond/ tank, results in production of 4500-5000 kg of fish, 7,000 eggs and about 1250 kg live chicken meet from one ha of pond area per annum . In this system 500 birds are adequate to fertilize 1ha pond and the dosage of application of poultry manure is about one-third of the rate of cow dung.

3.3.3 Fish - cattle/pig/sheep/goat integration:

Generally, an average sized cow/buffalo, pig and sheep/goat voids about 7.0 kg, 1.5 kg and 0.5 kg of manure per day respectively, which corresponds to 2500 kg, 550 kg and 180 kg of manure per year. These wastes/manure when applied to a fish pond are utilized in two ways. It acts as a fertilizer (Table 6) and is also consumed by fish directly. Bacteria use suspended organic matters while phytoplankton as well as aquatic plants, which enrich the aquatic food chain, take up soluble nutrients. It is reported that 2.5 –4.0 kg of organic manure can produce one kg of fish against 2.5 kg of pellets or 3-4 kg of grains. Cow dung alone, when applied @ 200-1000 kg/ha/day increased fish biomass @ 20-40 kg/ha/day without application of supplemental feed . It is estimated that 3-4 cattle, 30-40 pigs and 40-50 sheep/goat are sufficient to fertilize 1 ha pond.

Table 6. Average composition (%) of commonly used manure

Manure	N	P	K	C:N:P
Cow dung	0.5	0.1	0.5	17:1:0.2
Pig	0.6	0.2	0.4	13:1:0.3
Poultry	1.6	0.7	0.7	9:1:0.4

3.3.4 Fish - Water chestnut/Makhana – vegetable:

In this system, fish culture is carried out along with water chestnut or makhana in a pond. Usually, air-breathing fish such as catfish, murrels etc. are reared in presence of water chestnut or makhana at a very low stocking density without/with supplemental feed for a period of 5 to 6 months. The dykes are used for growing vegetables and other fruit trees like papaya and banana to make the system more economically viable. Vegetables such as gourd, raddish, brinjal, leafy vegetables during the pre and *kharif* season and vegetables such as tomato, french bean, raddish, bitter gourd, cucumber, cauliflower, cabbage, brinjal pumpkin and leafy vegetables such as coriander, amaranthus and Indian spinch are also grown during winter. Vegetables such as snake gourd, bitter gourd, ridge gourd, bottle gourd or ash gourd are also grown through out the year on raised platforms. Under this system, average productivity of water chestnut, makhana and fish range between 8.0-9.0 t ha^{-1}, 0.7-0.8 t $ha^{-1}$and 1.4 -1.8 t ha^{-1} respectively. WTCER, Bhubaneswar has standardized a production system of aquatic crop (Roy Chowdhury et al., 2004a, 2004b) along with aquaculture. An yield of up to 8 t/ha of water chestnut with a fish (air breathing fish) yield of 1.6 t/ha can be achieved from such integrated co-production system in shallow waterlogged

3.3.5 Eco-agriculture through deepwater rice-fish culture:

Eco-agriculture is ecologically balanced, highly efficient and rational agricultural system. It is assessed not only in terms of grain out put, but also in terms of total biological out put and profit. There is unity in economics and ecological objectives. Rice-fish integration is therefore a primary option when trying to develop ecological agriculture that exploit maximum benefit from the system, avoid harmful effects and strive for maximum out put using available energy and materials. Further, Adding fish to the rice field ecology helps increase production and achieves social, economic and ecological benefits.

Mutualism of Rice and Fish: Some of the ecological requirements of rice and fish are similar and this provides the basis for their synchronized growth under one ecosystem. Water is a prerequisite for raising fish and for growth and development of rice. Water, as a component of plant cytoplasm, is indispensable for the synthesis of organic matter in plants and for the absorption and transfer of nutrients. Further, when fish, especially herbivorous and omnivorous fish are introduced into the rice fields, they add a new link to the existing food chain. They feed on primary producers and therefore reduce energy losses, improve the use of photosynthetic products and promote transformations in the rice field ecosystem that increase the carrying capacity of the rice field (Brahmanand and Mohanty 1999). Rice plants provide protection to fish/ prawn from predation by birds and fish gets sufficient oxygen released by rice and phytoplankton for survival and growth. Fish diseases are rare in rice-fish culture, due to clear aquatic environment, high oxygen content and rich natural food that produce strong and disease resistant fish/prawn. After harvest of rice, the roots and remaining parts of straw (straw contain 9-13% cellulite, 1.5-3% potassium and 30-40% cellulose) provide organic matter and favours growth of microorganism, the ultimate natural food of fish/ prawn.

In rice-fish fields the rice stabilizes water temperature and quality, therefore, provides an environment that is conducive to the reproduction of natural fish food organisms. These primary producers convert solar energy into food energy that is required by fish for their survival. The sequential relationship in the distribution of rice and fish is apparent. Fish in rice field feed on available plankton (that compete with rice for fertilizer), weed (that compete with rice for nutrients), insect and bacteria (that harm rice plant) and mosquito larvae (harmful to humans). Fish assimilate only 3-4% of these feeds and discharge the rest in to rice field that acts as manure. Because the fish consume phytoplankton, zooplankton and weeds that compete with rice, they play an important role in recovering lost energy and adjusting energy flow. When they swim in water, release carbon dioxide and that increases the amount of carbon available to the plants. They also break the soil surface and oxidize layers of soil, which increases the supply of oxygen, promotes root growth and tillering capability of rice plant. It is reported that under this system, paddy yield has been increased as high as 47% (29% in India). The increase in the yield of paddy probably results due to better aeration of water and greater tillering effect caused by the presence of fish. The excreta of fish, left over supplemental feed and additional fertilizer used also help in increasing the soil fertility and productivity. Rice-fish mutualism is therefore, the best way to maximize the output of the ecological system, that turn material and energy into fish production, accelerate the growth of rice and increase the solar energy fixation, thus raising the productivity of paddy fields.

Production Intensification Approach: The strategy for rice cultivation under rice-fish system, is low planting density (20-30% lower than the density used in regular fields), a small population and less fertilizer application. This helps in better root zone development, increasing number of tillers and improving ecological conditions (ventilation and illumination) that prevent lodging and help produce heavier grains, high and stable yields. The criteria of selection of fish species for stocking into rice-fish farming system should be based on the ability of fish species to filter and feed on plankton (bacteria, phytoplankton, and zooplankton) and to tolerate low levels of dissolved oxygen. An optimal stocking density of fish/prawn species is critical in attaining high cumulative fish yields and in reaching the upper carrying capacity of the system (Mohanty *et al.*, 2004). Ways to intensify fish production from integrated rice-fish farming system involve management strategies like high-density rearing (stocking with a higher initial fish biomass) followed by phased/selective harvesting, when the growth curve of stocked fish/prawn starts to slow down. The productivity of the current practices of rice-fish farming has a great potential for improvement with further integration with duck/poultry and nitrogen-fixing aquatic fern *azolla*. Fish, azolla and ducks integrated with a rice farming system can result in nutrient enhancement, pest (weed, insect, golden apple snail) control, feed supplementation and biological control.

Rice-fish integration: For rice-fish integration in waterlogged ecosystem, rice fields with infield refuge (1.5 - 2.0m depths) of 30-40% area of rice field, peripheral trench of 0.5m depth and 2.0m width and moderate slope towards refuge is most preferred, for adoption of rice-fish farming system. Water and soil quality variables generally determine the production potentiality of this system, as several *biotic* and *abiotic* factors play a key role in enhancement of productivity (Mohanty etal., 2004). Therefore, intensive hydro-biological studies prior to site selection are essential. Generally soil with higher percentage of clay and pH ranging from 6.5 to 7.5 is considered suitable. The lands having higher water table and with suitable drainage system may be preferred.

Species suitability: Fish species should be compatible, resistant to environmental changes, high-yielding and be able to tolerate heavy doses of fertilizer. Since the water column in the refuge, perimeter canal and the paddy field in the system is suitable for rearing of Indian major carps, i.e., *Catla catla, Labeo rohita and Cirrhinus mrigala*, prawn (*Macrobrachium rosenbergii* and *M. malcolmsonii*) and exotic carps like silver carp and common carp may be stocked for culture in the integrated system. Improved high-yielding, tall, long-duration, submergence and pest resistance variety of rice with in-built characteristics of photoperiod-sensivity, strong seedling vigor can be tried.

Rice cultivation: Land preparation for rice crop is done at the beginning of the season with minimum tillage and leveling for uniform crop establishment. Sowing of rice is usually preferred over transplanting, as sowing helps in establishment of a good crop stand of rice by the time the field is waterlogged during monsoon. Normally line sowing and skip-row method of sowing are followed to provide fish passage and to encourage movement of fish inside the rice field when it is flooded with water. When sowing of rice is not feasible due to unprecedented rainfall or some other reason, transplanting is done with 25-30 days old rice seedling, after proper land preparation, preferably when the water level is around 5-10 cm in rice field. Fertilizer @ 40:20:20 kg NPK ha^{-1} at seeding should be applied (apply 50% N at seeding and rest 50% after weeding). FYM @ 5 t ha^{-1} at the time of land preparation is also essential. To ensure better productivity, higher planting density must be avoided to provide greater ventilation and illumination, that helps in enhancing both plant and plankton growth which ultimately helps fish growth and yield. In fact, the yield of rice for a specific variety correlates positively with planting density.

Application of fertilizer and chemicals: The growth and development of paddy and the fish is greatly influenced by the kind and quantity of fertilizers applied. The improved technique of fertilization is to use nutrient rich organic manures as much as possible and inorganic fertilizer as little as possible. Organic manure should be applied after fermentation. Seventy percent of the total manure should be applied as basal and rest as supplementary manure. Although fish in rice fields can eat some of the pests and play a role in the biological control, they cannot totally replace insecticides, so chemical control is needed. However, chemical plant protection should be avoided to prevent fish/prawn mortality. In fact, in waterlogged situation, insecticide hardly works as high standing water dilutes the concentration. But in emergency, chemicals that have low toxicity, low residue, high effectiveness and a broad spectrum can be applied. Chemicals in powder form should be applied in the early morning hours, while there is still dew around, and application of sprays should be delayed until after the due fades. Nowadays, the splashing method is adopted with good results especially when the rice grows tall.

Fish culture: After proper refuge preparation, liming @ 500-750 kg ha^{-1}, manuring with raw cattle dung @ 5000-7000 kg ha^{-1} as basal dose should be carried out at the onset of monsoon during June. Before fingerlings are released in the rice field refuge,

Photo 17 : Phased harvesting of advanced fish fingerling

it is essential to clear it from aquatic vegetation and predatory fishes, if any (photo 17). During the month of July-August, when the rainwater starts accumulating in the refuge and paddy field, early fingerlings of Catla, Rohu, Mrigal, Silver carp, Common carp and prawn juveniles may be stocked with a composition of 30:25:45 (surface feeder: column feeder: bottom feeder). *Labeo bata* can also form a stocking component in this system. As the culture duration is short, fingerlings (>15g size) should be stocked at a higher density of 15,000 – 20,000 per ha for continuous rearing for a duration of 4-5 months or advanced fry (<1.5g size) at a higher density of 75,000-1,00,000 per ha for advanced fingerling production, based on the principle of phased harvesting. An optional stocking density of fish/prawn species is critical in attaining high cumulative fish yields and in reaching the upper carrying capacity of the system. Ways to intensify fish production from integrated rice-fish farming system therefore, involve management strategies like high-density stocking (stocking with a higher initial fish biomass) followed by phased harvesting, when the growth curve of stocked fish/prawn starts to slow down. This will help in reducing the population pressure and enhance the growth of remaining stock. To augment growth, supplementary feed comprising mustard oil cake/ground nut oil cake and rice bran in 1:1 ratio may be given to fishes daily @ 3% in the initial two months and then 2.5% rate of mean body weight of stocked fish/prawn. In this culture system the fish/prawn will grow for a period of 3-4 months in the entire area and then 2-3 months in the confined area of infield refuge. Under this system, production range between 1400-1800 kg ha^{-1} (if stocking size <1.5g) or 2800-3200 kg ha^{-1} (if stocking size >15g) per crop with a survival rate of about 65-90 percent.

Water management in rice-fish culture: Water quality is a dynamic property of a system affected by chemical, biological and physical factors, which ultimately influences the aquatic environment and production of rice based integrated farming systems. Management of water quality includes the behavior of fish, nature of water and inputs of diligence from farmers. Since scientific water quality management and maintenance of tolerance limit of hydrological parameters cannot be expected at farmers end, the minimum adoptable techniques for water quality monitoring at farmers end should be encouraged. This includes periodic liming @ 100-150 kg/ha, phased manuring with raw cattle dung @ 1500-2000 kg/ha to maintain plankton bloom, which in turn regulates dissolved oxygen and pH of the eco-system. As these two parameters are too much critical for fish growth and survival, utmost care must be taken for bloom management. As the optimum ratio of phyto and zooplankton is 10:1, periodic estimation of plankton is essential. In case of plankton crash, re-inoculation should be carried out followed by fertilization with Urea + SSP (1:1) @ 2-3 ppm or systematic water replenishment in case of excessive bloom build up.

On-dyke Horticulture: The peripheral dykes may be used for growing vegetables and other fruit trees like papaya and banana to make the system more economically viable. Vegetables such as gourd, radish, brinjal, leafy vegetables during pre and kharif season and vegetables such as tomato, french beans, radish, bitter gourd, cucumber, cauliflower, cabbage, brinjal, pumpkin and leafy vegetables (coriander, amaranthus and Indian spinach) can be grown during winter. Vegetables such as snakegourd, bittergourd, ridgegourd, bottlegourd or ashgourd can be grown throughout the year on raised platforms.

Water productivity of rice-fish farming system: The ultimate goal of any integrated farming system is to improve the overall water productivity (Rs/m^3) and maximize the net return. Consumptive water use index (water productivity) and economic indices of water productivity (EIWP) can be estimated keeping the total volume of water used (water contained in the harvested biomass + evaporation + deep percolation & seepage + average standing water volume + volume of water added from other source) in to account as follows.

Water productivity = Total production in Kg. / Total volume of water (m^3) used.

EIWP = Total value of produce (Rs.)– production cost (Rs.)/ Total volume of water (m^3) used. In this context several studies have been carried out in India and abroad (Table 7). The least return is always obtained from conventional rice farming, which go on increasing as more and more components are integrated. It is a fact that rice-fish-poultry/duckery-vegetable system in one-hectare area can generate employment for a person throughout the year. Addition of more profitable

Table 7. Recent trends in water productivity and net return of different rice-based integrated production system.

Production system	GWP (Rs/m^3)	NWP (Rs/m^3)	NR (Rs/ha)	Location and year
* *Kharif* rice (good management)	2.76	1.06	15,294	Orissa, WTCER, 2004
* Rice+fish (rainfed medium land)	2.94	2.7	17,460	Orissa, WTCER, 2004
* Rice + fish	—	—	17,847	Annamalai Univ., 2005
* Rice + fish + ODH+ *rabi* crop	5.87	3.76	29,617	Orissa, WTCER, 2004
* Rice + fish + rabbit	—	—	43,932	Annamalai Univ., 2005
* Rice + fish + Vegetable in raised-sunken bed system	4.58	3.23	74,010	Orissa, WTCER, 2005
* Deepwater rice+fish+prawn+ ODH followed by post-harvest 2nd crop (black gram) in waterlogged ecosystem	9.52	5.20	88,706	Orissa, WTCER, 2005
* Rice +fish + duck	—	—	98,936	Phillipines, 2000
* Rice + fish + prawn + Vegetable	14.02	7.52	1,46,767	Orissa, WTCER, 2003
* Rice +fish + poultry	—	—	2,28,090	Annamalai Univ., 2005

GWP: gross water productivity, NWP: net water productivity, NR: net return, ODH: on-dyke horticulture

enterprises such as apiary, mushroom, dairy, agro-forestry etc. can enhance the employment opportunities about three times.

Economic, Social and Ecological Efficiency: Rice fish culture makes multiple use of the rice field to maximize the utilization of land and water resources and can also increase the production value of rice fields. Profits can be even higher if fry are reared in the rice fields. The economic efficiency is increased because the fish have a high value. Fish as a bio-controller of insects and weed, reduces the input cost of insecticide and herbicide by 50-60% and toxicity accumulation is minimized. This is beneficial to human health and the ecological balance of the environment. When fish are introduced into rice field ecosystem, change in the population and composition of aquatic organisms, and relationships among them takes place. Rice-fish culture can change the direction of energy flow in the ecosystem. In the rice field the stocked fish transform stagnant energy (e.g., weeds) and possibly lost energy (e.g., phytoplankton, zooplankton, and aquatic insects) into useable products (fish and rice). In rice fields, mosquito larval, maggots, snails, and leeches, which are the intermediate host of malaria, encephalitis, dysentery, blood fluke and filaria, reproduce rapidly. Fish particularly common carp and other omnivorous fish, consume and eradicate these pathogenic parasites and minimize the infestation rate of human beings, thereby creating a better level of health for the farmers. In rice fields without fish, farmers must carry out regular and labour-intensive weeding. As a result, there is a heavy loss of soil fertility, solar energy and an increase of production cost. In some places, farmers do not plough the field when rice-fish culture is practiced. This further reduces the inputs needed for rice planting and therefore reduces production cost and increases the economic efficiency of rice cultivation. The voiding of poultry/duck/animals could be recycled as fish feed and this could also increase the biological productivity of water. Addition of animal/bird droppings in water reduce the fish feed cost by 40% and fertilizer cost by 60-65%.

3.3.6 Environmental Monitoring

Decades of neglect, apathy, ignorance and lack of technical know-how have resulted in improper development of waterlogged aquaculture resources in India. Development necessarily involves modification of the existing environment that invariably results in both beneficial and adverse impacts. Improper development without adequate knowledge of the environment could precipitate environmental catastrophes that would negate the very purpose of development. Therefore, environmentally sound and sustainable development (ESSD) of the resources is needed with a multi-sectoral structure as against the current narrow-compartmentalized structures and a holistic view of development is required as against the present day reductionist thinking. Horizontal or vertical development in future should be strictly guided by serious environmental issues on one hand and global competition on the other. But the guiding principle for optimizing aquaculture productivity should be through proper use of primary productivity, waste recycling, ensuring soil health and water quality by way of proper and timely monitoring.

The manure loaded fish ponds can be considered as a system to which mineral rich organic matter is added in the form of manure which results in the form of harvested fish biomass. Too much waste loading helps in reducing light penetration, photosynthetic rate, reactive distance of fish and prawn, frequently fluctuate water parameters, changes body colour, reduces ventilation and oxygen consumption rate of fish and prawn and finally helps in out break of disease. Therefore, maximum amount of organic waste loading in integrated aquaculture system should range within 100 - 200 kg/ha/day (dry weight) or 70 - 140 kg organic matter/ha/day. The estimation of waste loading rate squarely depends upon the rate kinetics of decomposition process and utilization of the degraded products in pond ecosystem, which is very much influenced by temperature, dissolved oxygen and intensity of solar radiation. Regular monitoring of water quality especially, dissolved oxygen and pH are very important from waste loading point of view.

4.0 CONCLUSION

Waterlogging problem has to be managed with an integrated approach as its nature and extent vary tremendously from one region to another. In the areas where surface drainage is possible, some engineering measures like land modification technology, recycling of drainage water and sub surface water harvesting structures can be employed. However, under uncontrolled drainage situations one has to prefer cultivating water loving crops like water chestnut, Makhana and some aquatic medicinal plants in addition to deep water rice varieties. Where ever the cultivation of water chestnut and makhana is found, the ideal package of practices would result in reasonably good jump in the crop productivity. The concept of bio-drainage has to be practically implemented for balancing the crop productivity in waterlogged ecosystem in long run. In addition, under severe waterlogged situations, Integrated aquaculture systems like Fish duck integration, fish-poultry integration and fish –water chestnut integration have to be fitted in the waterlogged ecosystem.

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