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Raised and Sunken Bed Technique for Improving Water Productivity in Lowlands

Ravender Singh, D.K. Kundu, Rajeeb K. Mohanty
Souvik Ghosh, Ashwani Kumar and K. Kannan

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(Indian Council of Agricultural Research)
Bhubaneswar 751023, India

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D.K. KUNDU
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SOUVIK GHOSH
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Preface

The challenging task ahead before the Indian agriculture is to produce more food to feed the burgeoning population from shrinking land and less water without eroding the ecological foundation. The surest mean to tide over this challenge is efficient management of natural resources for sustainable agricultural growth and development. Agricultural growth and development should not only provide more quantity of food, fodder and firewood but also provide better quality food, more income and jobs for rural population without harming the environment. Small and marginal farmers and farmers with tiny holdings must be contributing to the growth and benefited from this growth. Due to high rainfall in monsoon and delivery of excess water through canal irrigation systems, many low lying agricultural farms in eastern region of India remain saturated to over saturated through wet as well as dry season, and farmers can hrdly grow any other crop than rice. The productivity of water in this region is very low. Since rice farming is not remunerative, many farmers in this region do not like to grow two rice crops. Instead, they prefer to keep their land fallow during dry season. Modification in field topography through construction of alternate raised and sunken beds improves the physical environment, particularly aeration status of the soil and creates proper condition for growth of crops other than rice. It also provides an opportunity to partially diversify cropping under such situation. Rice being the staple food, it is very difficult to make complete substitution of rice crop. However, the "rice plus" cropping system in raised and sunken bed through land modification can be a potential option for growth and development of farming system and livelihood of small and marginal farmers. Results of land modification through raised and sunken bed system for improving water productivity are discussed in this bulletin. We hope information presented in this bulletin will be useful to the policy makers, scientists, scholars, developmental officials, farmers and others who are interested in crop diversification, enhancing crop production, use efficiency and productivity of available water in low land situations.

The authors are grateful to the Director General, Deputy Director General (NRM) and Assistant Director General (IWM), ICAR for their encouragement, suggestion and support in carrying out this research work. Assistance rendered by Sh. Ramesh Chandra Jena and Sh. V. K. Tripathi, Technical staff, WTCER is greatfully acknowledged. Our sincere thanks are also due to all the colleagues and staff members of WTCER, Bhubaneswar for their help and cooperation in conducting this study.

AUTHORS

1. INTRODUCTION

Agriculture in India is now facing a great challenge of declined water availability. Also inter-sectoral competition for fresh water is pressing agricultural researchers hard to eveolve water-use efficient technologies suiting to small and marginal farmers. Water management research is now experiencing a gradual shift from water-use efficiency to water productivity in different agro-ecological regions of India. Our country has to surmount pressure of increasing population, which is estimated to touch 1,225 million human and 600 million livestock by 2015 A.D, requiring 275 million tonnes of food grains, 1,083 million tonnes of green fodder and 235 million m^3 of fire wood against our current supplying capacity of 210 million tonnes of food grains, 513 million tonnes of green fodder and 40 million m^3 of firewood. The surest mean to tide over this challenge is efficient management of natural resources, for sustainable agricultural growth and development. Agricultural growth and development should not only provide more quantity of food, fodder and firewood but also provide better quality food, more income and jobs for rural population without harming the environment. Small and marginal farmers and farmers with tiny holdings must be contributing to the growth and benefited from this growth.

Out of total land area of the eastern region, about 48 per cent (12.9 mha) is under rainfed lowland and only 21.3 per cent (5.7 mha) is irrigated. For food and livelihood, farmers of this region heavily depend on the rainfed and irrigated medium and lowland ecosystem, which constitute more than 50 per cent of the total area of eastern India. Water productivity in the lowlands of eastern states is quite low than its potential. The region receives high rainfall during *kharif* (wet) season and sizeable area of this region comes under canal irrigation command. Root zone soils of most agricultural farms in this region remain saturated or over-saturated through *kharif* as well as *rabi* (dry) season, and farmers can hardly grow any other crop than rice there. The productivity of rice in this region is very low (average 2 t ha^{-1}). Since rice farming is not remunerative, many farmers in this region do not like to grow two rice crops. Instead, they prefer to keep their land fallow during *rabi* season. Fallow after rice is common in about 12 –16 million hectares of eastern India due to high rainfall, low lands, high water table condition and low alleviation.

Use efficiency of applied irrigation water, in canal command areas is very low often 30 per cent or less (Pande and Reddy, 1988). For achieving the stability in agricultural production under canal command area, more attention to the on-farm management is required (Ghosh *et al.* 2005). For which a package of economically viable technology will have to be developed by research institutions and demonstrated in farmers field. In this context, the Water Technology Centre for Eastern Region has developed raised and sunken bed technology for crop diversification in medium and low lands of eastern region and demonstrated on farmers fields since 2002.

Modification in field topography through construction of alternate raised and sunken beds improves the physical environment, particularly aeration status of the soil and creates proper condition for growth of crops other than rice (Siddiq and Kundu 1993; Tomar *et al*. 1996; Singh *et al*. 2003a; Singh *et al*. 2003b; Kannan *et al* 2003a; Kannan *et al*. 2003b and Singh *et al*. 2004a). It also provides an opportunity to partially diversify cropping under such situation.

2. RAISED AND SUNKEN BED SYSTEM

Fields may be modified into alternate raised and sunken beds by digging soil of one strip (4-5m wide) to a depth of 20 to 30 cm and putting the dugout soil over the adjacent strip (4-5m wide). The width of beds may be fixed as per convenience up to 5m and length may be fixed as per availability of land. Elevation of the raised beds thus may be 40 to 60-cm higher than that the adjacent sunken beds as shown in Figure 1. Top 20 to 30 cm soil of the raised beds remains in unsaturated condition. Arable status of such soils allows growing of several vegetable crops, and rice may be grown simultaneously in adjacent sunken beds where soils remain submerged.

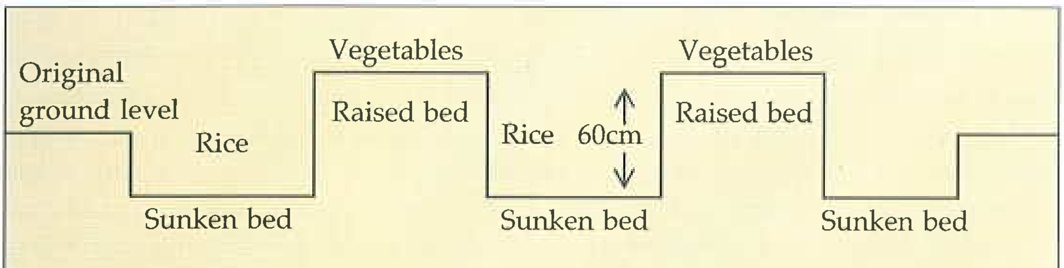

Fig 1. Schematic diagram of alternate raised and sunken bed system

Removal of topsoil may reduce fertility level and create poor physical conditions in sunken beds. To minimise this adverse impact, application of FYM or compost @ 10 t/ha and/ or growing of *sesbania* in sunken beds during dry season and mixing the same before rice planting is recommended for the initial 1-2 years. For checking soil erosion from the raised

Construction of alternate raised and sunken beds

beds, dwarf varieties of papaya plants may be grown along the borders at 1.5 m interval. Farmers thus get additional yield and income from the system. Nevertheless some soil may be eroded from raised beds and deposited in sunken beds during rainy season due to high intensity of rainfall, which may be recovered and fixed again on raised beds during dry season every year. Different vegetable crops may be grown on the raised beds. Recommended fertilizers, pesticides and weed control measures for the vegetable crops are required to be used in raised beds. Soil moisture conditions in raised beds at the time of establishing vegetable crops should be optimum. For this, a pre-sowing irrigation may be required in raised beds. No irrigation may be required after the establishment of the crops since a lot of moisture is available in 20 to 30 cm below the surface layer of these beds and in the adjacent sunken beds, which move both in lateral and upward direction to meet crop water requirements. Height and width of the raised beds may be fixed according to physical properties of the soils (soil texture) and type of vegetable crops (rooting depth) so that they do not require irrigation. Vegetable crops may be selected, according to the market demand, type of soil, root zone moisture availability and climatic conditions of the area. Under this system, farmers can put their lands under crops for a longer period than under conventional system and can get regular income. Dry season is the best time for preparation of raised and sunken beds. These beds may be prepared manually by the farmers themselves or by hired labourers. Preparation of beds by hired labourers costs about Rs 34,000 to 36,000 per hectare depending on soil type. The cost will be less for light soils than for heavy soils. Most of the farms in eastern region of the country are small in size and farmers themselves can prepare alternate raised and sunken beds in their farms during dry season when they do not have much work at hand. Labour and / or money spent for preparation of beds is one-time investment which is generally realized from the one or two years profit itself.

3. LOCATION OF THE STUDY AREA

The study was carried out in the farmers' fields during 2002 to 2004 in three different villages, viz. Biswanathpur, Khamang and Barillo of Balipatna block in Khurda district, Orissa. The experimental sites are located in the command area of Nimapara Branch Canal under Puri Main Canal Irrigation System of Mahanadi Delta Irrigation Project. The area lies at 20^{o} 21′ to N latitude and $85^{o}54'$to E longitude. The latitude and longitude of the area covered under this irrigation command are 19.7^{0}-20.4^{0} N and 85.8^{0}-86.2^{0} E, respectively with an altitude of 50 m above MSL (Figure 2). The study area largely consists of small farmers with average holding size of 1 ha or less. Rice- fallow is the predominant cropping system in this region. Rice-rice is most commonly followed cropping system in the event of water availability during dry season. Topography of the command area is relatively flat with general slope varying from 0.03 to 0.25 per cent. Average annual rainfall in this area is 1480 mm with nearly

80 per cent of it being received during monsoon period spreading over 100 rainy days. Maximum and minimum daily temperature ranges from 35^0 to 39^0 C and from 13.5^0 to18.6^0 C, respectively. Low input use, absence of field channel, uncontrolled irrigation and late transplanting of rice in wet season contributed to the low average yield (Singh *et al.* 2004b). Monthly income of the farmers was found to be very low with most of them earning not more than Rs 2000 per month (Ghosh *et al.* 2002).

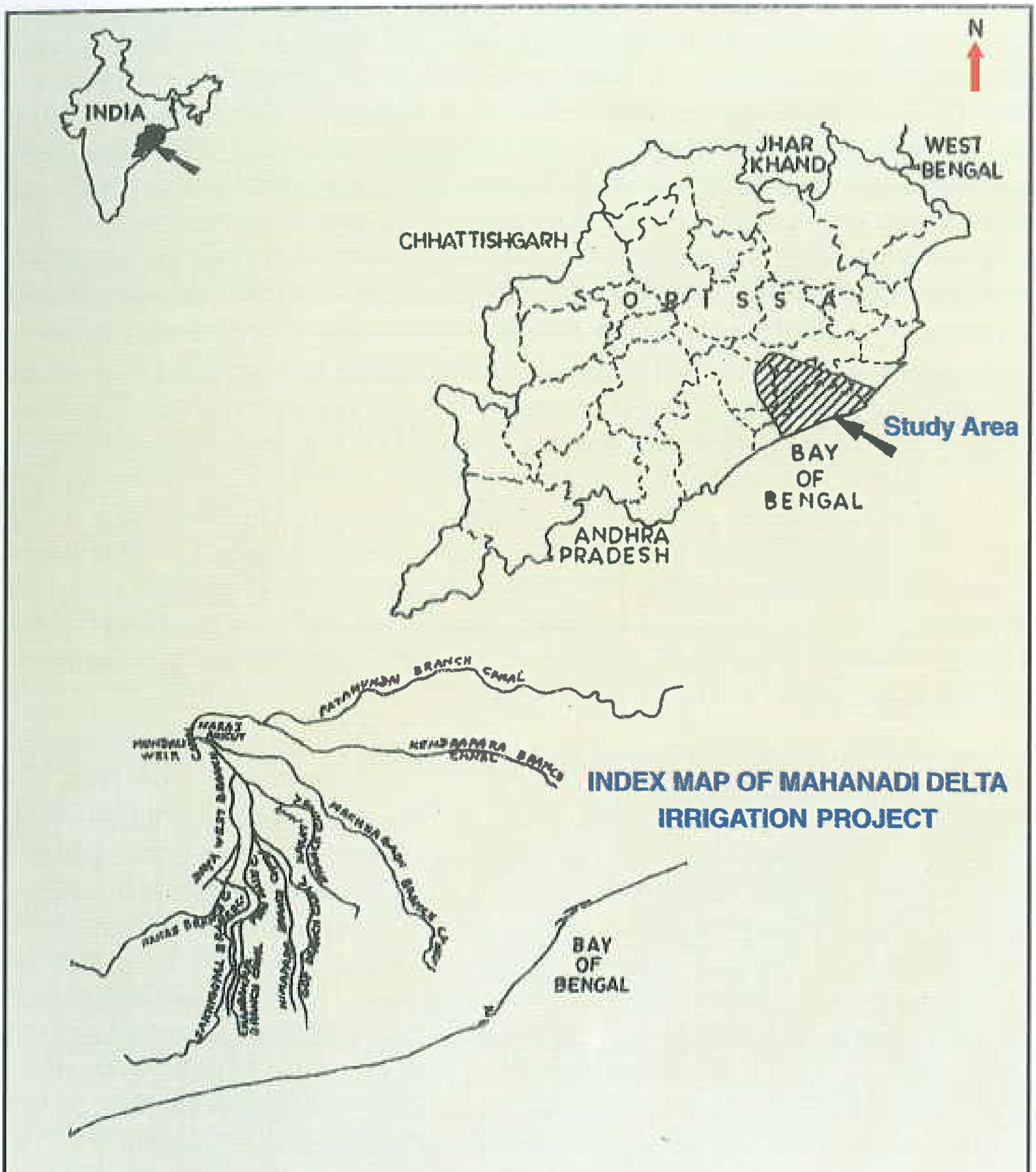

Fig 2 : Location Map of Study Area

4. MATERIALS AND METHODS

4.1. Biswanathpur experimental site

4.1.1. Physico-chemical and hydrological properties of soil

Soils of the experimental plots were deep, poorly drained, fine, mixed loamy, hyperthermic, Aeric Tropaquepts of alluvial origin. Important physico-chemical properties of the soils at Biswanathpur site are presented in Table 1a and 1b. The physicochemical and hydrological characteristics of the soils were determined using standard procedures (Black 1965; Jackson 1973).

Table 1a. Physico-chemical characteristics of the soil at Biswanathpur

Soil depth (m)	Particle size distribution (%)				Tex. class	EC_2 (dS/m)	pH_2	OC (%)	CEC (c mol kg^{-1})	Bulk density (Mgm^{-3})
	Fine sand	Coarse sand	Silt	Clay						
0 –15	24.0	20.7	24.8	30.5	cl	0.16	6.4	0.35	10.09	1.40
15 –30	24.7	17.3	26.6	31.4	cl	0.32	6.5	0.20	11.13	1.44
30 –45	17.8	15.8	29.8	36.6	cl	0.31	6.4	0.38	10.09	1.49
45 –60	18.8	8.1	31.2	41.9	c	0.37	6.7	0.14	12.17	1.54
60 –90	12.2	5.7	35.4	46.7	c	0.29	7.3	0.30	12.17	1.58
90 –120	7.6	5.1	40.4	46.9	c	0.24	7.4	0.26	14.17	1.60

Table 1b. Hydraulic characteristics of the soil at Biswanathpur

Soil depth (cm)	Saturated hydraulic conductivity, air entry suction and soil parameter				Soil moisture retention (m^{3}m^{-3}), suction kPa		Available water capacity (m^{3}m^{-3})
	Ks(cm/d)	ψ_e	b	n	33	1500	
0 – 15	1.54	54.7	3.430	2.875	0.312	0.096	0.216
15 - 30	1.18	92.7	3.738	2.803	0.408	0.103	0.305
30 -45	0.91	102.3	3.869	2.775	0.455	0.141	0.314
45 -60	0.79	128.9	4.212	2.712	0.494	0.165	0.329
60 - 90	0.77	125.4	4.551	2.659	0.503	0.193	0.310
90 -120	0.74	131.3	4.553	2.659	0.528	0.208	0.320

Surface soil of Biswanathpur experimental site was clay loam in texture (30.5% clay, 24.8% silt, 24.0% fine sand and 20.7% coarse sand) and had pH_2 6.4, EC_2 0.16, CEC 10.09 me/100g, and organic carbon 0.35 % (Table 1a). The moisture content at 33 and 1500 kPa suction of undisturbed soil samples of top 0 – 15 cm was 0.312 and 0.216 m^3m^{-3}, respectively (Table 1b). Clay content and bulk density increased with soil depth and ranged from 41.9 to 46.9 % and 1.54 to 1.60 Mgm^{-3}, respectively. Saturated hydraulic conductivity decreased with soil depth and ranged from 1.54 to 0.74 cmd^{-1}. Air entry suction and soil parameter 'b' increased with soil depth and ranged from 54.7 to 131.3 and 3.430 to 4.553, while value of 'n' another soil parameter decreased with soil depth and ranged from 2.875 to 2.659. The texture of the sub soil was clay.

4.1.2. Selected cropping systems

At Biswanathpur, six cropping systems were tested, viz. C1- conventional system (*rabi* rice followed by *kharif* rice with no land modification); C 2- alternate raised and sunken bed system (rice grown in sunken bed and tomato – cowpea grown in raised bed); C 3- alternate raised and sunken bed system (rice grown in sunken bed and brinjal – okra in raised bed); C 4- alternate raised and sunken bed system (rice grown in sunken bed and pointed gourd grown in raised bed); C 5- alternate raised and sunken bed system (rice grown in sunken bed and pointed gourd + papaya grown in raised bed); C 6- alternate raised and sunken bed system (rice grown in sunken bed and cucumber – leafy vegetable – brinjal grown in raised bed). *Rabi* rice (*Oryza sativa* L.) variety "Lalat" was transplanted in the 2nd week of January and harvested in the last week of April. During *kharif* season rice variety "Durga" was transplanted in the 3rd week of July and harvested in last week of November. Tomato (*Lycopersicon esculentum*) variety "BT-10" was transplanted in last week of January every year and harvested upto 2nd week of April. Pointed gourd (*Trichosanthes dioica*) variety "Swarn Rekha" and papaya (*Carica papaya*) variety "Honey Dew" were transplanted in 1st week of January and harvested upto last week of December. Brinjal (*Solanum melongena*) variety "Long Green" was transplanted in the 1st week of June and harvesting was completed in the last week of December. Cucuber (*Cucumis sativus*) variety "Local"; leafy vegetable (Saga) variety "Local"; vegetable cowpea (*Vigna unguiculata*) variety "Yard long Beans" and okra (*Abelmoschus esculentus*) variety "Parbhani Kranti" were sown in the 1st week of January, 3rd week of March, last week of May and 2nd week of September, respectively. Their harvesting was completed by 2nd week of March, 1st week of May 2nd week of September and 3rd week of November, respectively. Size of each of the raised and sunken beds was 5 m x 25 m, respectively.

4.2 Khamang experimental site

4.2.1. Physico-chemical and hydrological properties of soil

Important physico-chemical properties of the Khamang experimental site are presented in Table 2a and 2b.

Table 2a. Physico-chemical characteristics of the soil at Khamang

Soil depth (m)	Particle size distribution (%)				Tex. class	EC_2 (dS/m)	pH_2	OC (%)	CEC (c mol kg^{-1})	Bulk density (Mgm^{-3})
	Fine sand	Coarse sand	Silt	Clay						
0 – 15	34.1	23.2	21.9	20.8	scl	0.11	6.0	0.39	10.43	1.46
15 – 30	28.9	24.6	23.8	22.7	scl	0.13	6.4	0.17	10.26	1.48
30 –45	29.5	18.4	24.5	27.6	scl	0.16	6.5	0.14	10.78	1.50
45 -60	43.1	18.8	16.2	21.9	scl	0.14	6.7	0.10	11.48	1.54
60 - 90	39.8	20.9	16.7	22.6	scl	0.10	6.8	0.11	10.43	1.56
90 -120	36.3	17.6	22.3	23.8	sl	0.13	6.7	0.20	13.74	1.58

Table 2b. Hydraulic characteristics of the soil at Khamang

Soil depth (cm)	Saturated hydraulic conductivity, air entry suction and soil parameter				Soil moisture retention (m^3m^{-3}), suction kPa		Available water capacity (m^3m^{-3})
	Ks(cm/d)	ψ_e	b	n	33	1500	
0 – 15	6.43	17.9	3.706	2.809	0.262	0.077	0.185
15 - 30	5.01	40.0	3.533	2.849	0.311	.088	0.223
30 -45	3.96	55.3	3.581	2.838	0.385	0.109	0.276
45 -60	2.03	36.0	4.032	2.744	0.381	0.123	0.258
60 - 90	1.96	42.5	4.266	2.703	0.386	0.128	0.258
90 -120	1.41	77.7	3.931	2.763	0.397	0.126	0.271

Texture of the soil at Khamang was sandy clay loam upto 90 cm depth, below which it was sandy loam (20.8% clay, 21.9% silt, 34.1.0% fine sand and 23.2% coarse sand in 0-15 cm soil depth and 23.8% clay, 22.3% silt, 36.3.0% fine sand and 17.6% coarse sand in 90-120cm soil depth). Surface soil had pH_2 6.0, EC_2 0.11, CEC 10.43 me/100g, and organic carbon 0.39 % (Table 2a). The moisture content at 33 and 1500 kPa suction of undisturbed soil samples of surface 0 – 15cm was 0.262 and 0.077 m^3m^{-3}, respectively (Table 2b). Bulk density increased with soil depth and ranged from 1.46 to 1.58 Mgm^{-3}. Saturated hydraulic conductivity decreased with soil depth and ranged from 6.43 to 1.41 cmd^{-1}. Air entry suction increased with soil depth and ranged from 17.9 to 77.7.

4.2.2. Selected cropping systems

Altogether five cropping systems were tested at Khamang site: C1- conventional system (*Rabi* rice followed by *kharif* rice with no land modification); C 2- alternate raised and sunken bed system (rice grown in sunken bed and tomato – cowpea grown in raised bed); C 3- alternate raised and sunken bed system (rice grown in sunken bed and okra-brinjal grown in raised bed); C 4- alternate raised and sunken bed system (rice grown in sunken bed and pointed gourd grown in raised bed); C 5- alternate raised and sunken bed system (rice grown in sunken bed and pointed gourd + papaya grown in raised bed). *Rabi* rice (*Oryza sativa* L.) variety "Lalat" was transplanted in the 2nd week of January and harvested in the last week of April. During *kharif* season rice variety "Durga" was transplanted in the 3rd week of July and harvested in the 1st week of December. Tomato (*Lycopersicon esculentum*) variety "BT-10" was transplanted in the 1st week of January and harvesting completed by 1st week of April. Pointed gourd (*Trichosanthes dioica*) variety "Swarn Rekha" and papaya (*Carica papaya*) variety "Pusa Nanha" were transplanted in the 2nd week of January and harvested by the 3rd week of November. Brinjal (*Solanum melongena*) variety "Long Green" was transplanted in 1st week of May and harvesting completed by last week of December. Okra (*Abelmoschus esculentus*) variety "Parbhani Kranti"; and cowpea (*Vigna unguiculata*) variety "Yard long Beans" were sown in the 2nd week of January and 3rd week of May, respectively, and harvesting completed by 3rd week of April and October, respectively. The size of each of the raised and sunken beds was 5m x 25m, respectively.

4.3. Barillo experimental site

4.3.1. Physico-chemical and hydrological properties of soil

At village Barillo, experiments were conducted at two sites. Important physico-chemical properties of the soil at Barillo are presented in Table 3a and 3b.

Table 3a. Physico-chemical characteristics of the soil at Barillo

Soil depth (m)	Particle size distribution (%)				Tex. class	EC_2 (dS/m)	pH_2	OC (%)	CEC (c mol kg^{-1})	Bulk density (Mgm^{-3})
	Fine sand	Coarse sand	Silt	Clay						
0 – 15	35.6	36.7	14.1	13.6	sl	0.13	5.8	0.40	5.30	1.47
15 – 30	29.9	35.8	15.6	18.7	sl	0.09	6.1	0.28	6.61	1.49
30 –45	29.3	33.8	17.4	19.5	sl	0.06	6.3	0.17	9.45	1.50
45 -60	26.8	37.8	16.0	19.4	sl	0.09	6.4	0.17	9.40	1.52
60 - 90	20.6	50.3	11.9	17.2	sl	0.09	6.6	0.10	6.84	1.54
90 -120	19.3	63.4	6.8	10.5	ls	0.07	6.6	0.06	3.30	1.56

Table 3b. Hydraulic characteristics of the soil at Brillo

Soil depth (cm)	Saturated hydraulic conductivity, air entry suction and soil parameter				Soil moisture retention (m^3m^{-3}), suction kPa		Available water capacity (m^3m^{-3})
	Ks(cm/d)	ψ_e	b	n	33	1500	
0 – 15	16.03	32.0	3.812	2.787	0.216	0.071	0.145
15 – 30	15.38	33.4	3.555	2.844	0.281	0.097	0.184
30 –45	14.32	37.2	3.943	2.761	0.317	0.109	0.208
45 -60	13.16	47.8	3.725	2.805	0.320	0.109	0.211
60 - 90	11.36	101.2	3.709	2.809	0.254	0.084	0.170
90 -120	17.81	13.42	3.671	2.817	0.183	0.055	0.128

Soil at Barillo experimental site was sandy loam in texture with 13.6% clay, 14.1% silt, 35.6% fine sand and 36.7% coarse sand in 0-15 cm soil depth, and with 10.5% clay, 6.8% silt, 19.3% fine sand and 63.4% coarse sand in 90-120 cm soil depth. The surface soil had pH_2 5.8, EC_2 0.13, CEC 5.30 me/100g, and organic carbon 0.40 % (Table 3a). Organic carbon deceased with depth and ranged from 0.40 to 0.06%. Moisture content at 33 and 1500 kPa suction of undisturbed soil samples of surface 0 – 15cm was 0.216 and 0.071 m^3m^{-3} and subsurface 90-120 cm was 0.183 and 0.055 m^3m^{-3}, respectively (Table 3b). Bulk density increased with soil depth and ranged from 1.47 to 1.56 Mgm^{-3}. Saturated hydraulic conductivity of the soil was very high; it was 16.03 and 17.81 cmd^{-1} in 0-15 and 90-120 cm depth, respectively. Available water capacity was 0.145 m^3m^{-3} for 0-15 cm depth and 0.128 m^3m^{-3} for 90-120 cm depth.

4.3.2. Selected cropping systems for experimental site-1

At Barillo site-1, seven cropping systems studied were: C1- conventional system (*rabi* rice followed by *kharif* rice with no land modification); C 2- alternate raised and sunken bed system (rice grown in sunken bed and cabbage – brinjal grown in raised bed); C 3- alternate raised and sunken bed system (rice grown in sunken bed and pointed gourd grown in raised bed); C 4- alternate raised and sunken bed system (rice grown in sunken bed and pointed gourd + bitter gourd grown in raised bed); C 5- alternate raised and sunken bed system (rice grown in sunken bed and pointed gourd + papaya grown in raised bed); C 6- alternate raised and sunken bed system (rice – rice+ fish grown in sunken bed and pointed gourd grown in raised bed); C7- alternate raised and sunken bed system (rice – fish grown in sunken bed and snake gourd + pointed gourd grown in raised bed, though snake gourd grown in sides of raised bed but they spread over open space of sunken bed). *Rabi* rice (*Oryza sativa* L.) variety "Lalat" was transplanted in the 2nd week of January and harvested in the last week of April. During *kharif* season, rice variety "Durga" was transplanted in the 3rd week of July and harvested in the 3rd week of November. Cabbage (*Brassica oleracea*) variety "Capitata" was transplanted in the 1st week of January and harvested in the 2nd week of April. Pointed gourd (*Trichosanthes dioica*) variety "Swarn Rekha" and papaya (*Carica papaya*) variety "Pusa Nanha" were transplanted in the 1st week of February and harvested upto 2nd week of November. Brinjal (*Solanum melongena*) variety "Long green" was transplanted in the 2nd week of April and harvesting was completed in the 2nd week of October. Bitter gourd (*Momordica charantia*) variety "Co 1" was sown in the 3rd week of April and harvesting was completed by 1st week of October. Snake gourd (*Trichosanthes cucumerina*) variety "APAU Swetha" was sown in the 3rd week of April and harvesting was completed by 1st week of October. In two sunken beds, one with rice and another without rice crop, fish fry (< 1.2g) of IMCs were stocked during last week of July and harvested during 3rd week of November. Size of each of the raised and sunken beds were 5m x 50m. For growing fish, $20m^2$ area of sunken bed at one side was deepened further to 2 m depth to enable total 40 m^3 for fish. Fish had open access to move all-round the field of 250 m^2 and finally come to the deeper portion ($40m^3$).

4.3.3. Selected cropping systems for experimental site-2

At Barillo site-2, four cropping systems were tested: C1- conventional system (*rabi* rice followed by *kharif* rice with no land modification); C 2- alternate raised and sunken bed system (rice grown in sunken bed and pointed gourd + papaya grown in raised bed); C 3- alternate raised and sunken bed system (colocasia grown in sunken bed and pointed gourd + papaya grown in raised bed); C 4- alternate raised and sunken bed system (rice grown in sunken bed and cabbage + snake gourd grown in raised bed). *Rabi* rice (*Oryza sativa* L.) variety "Lalat" was transplanted in the 2nd week of January and harvested in the last week. During *kharif* season, rice variety "Durga" was transplanted in the 3rd week of July and harvested in the 2nd week of November. Cabbage (*Brassica oleracea*) variety "Capitata" was transplanted in the 1st week of January and harvesting was completed by 2nd week of April. Pointed gourd (*Trichosanthes dioica*) variety " Swarn Rekha" and papaya (*Carica papaya*) variety "Pusa Nanha" were transplanted in the 1st week of February and harvested upto last week of November. Colocasia (*Colocasia esculenta*) variety "Panchamukhi" was transplanted in the last week of February and harvesting was completed by 2nd week of November. Snake gourd (*Trichosanthes cucumerina*) variety "Co 1" was sown in the 3rd week of April and harvested upto 2nd week of October. Size of each of the raised and sunken beds was, 5m x 35m, respectively.

Cultural practices, fertilizers management, insect and pest control practices were followed as per recommended packages for cultivation of these crops. All the vegetable crops were irrigated at the time of transplanting or sowing.

4.4. Rainfall and evaporation

Average rainfall and pan evaporation of the study area are shown in Figure 3. Data revealed that from 26th to 44th meteorological week rainfall was much higher than pan evaporation.

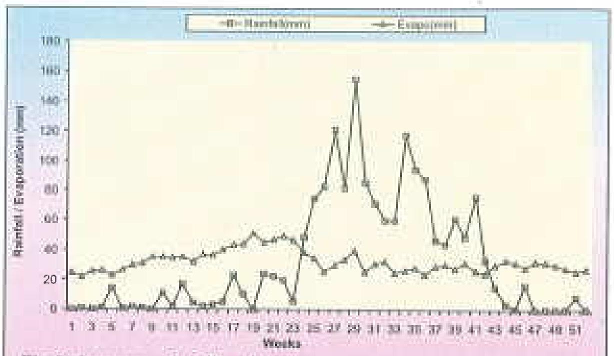

Fig 3. Average rainfall and pan evaporation at experimental site

4.5. Water-table depth

Water-table depth was measured weekly at all the three experimental sites and depicted in Figure 4. Data presented in figure 4 revealed that the water table fluctuated between surface to 1 m depth and during *kharif* season it was all the time near to surface.

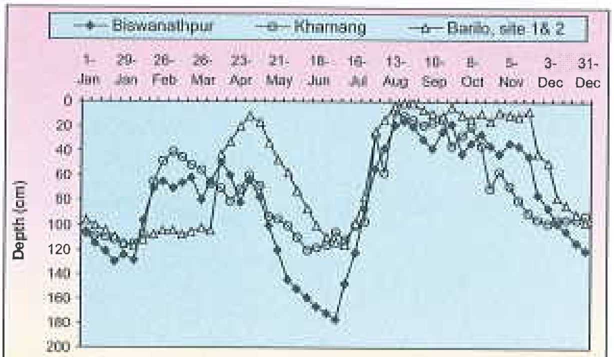

Fig 4. Water-table fluctuation in experimental sites

4.6. Variables and their measurements

4.6.1. Rice equivalent Yield

Production potential in terms of rice-equivalent yield (REY) of different crops in the cropping system was calculated as:

$$REY = \frac{\text{Economic yield of a crop (kg) x price per kg of same crop}}{\text{Price per kg of rice}}$$

4.6.2. Effective rainfall

Water expense (mm/ha) was calculated by adding amount of water used for irrigation and effective rainfall during the crop-growing period. Effective rainfall (ER) is that portion of rainfall, which contributed to the water requirement of growing crop in the field. The rainfall is only effective when it is stored and used by the growing crops. For raised and sunken bed system, where most of the rainwater is stored in sunken beds for growing rice crop, the effective rainfall was determined by the drainage model of International Rice Research Institute (IRRI, 1997) as follows:

$$ER_i = \left[\frac{1 - DR_i}{RF_i + IR_i}\right] \times RF_i$$

Where RF_j is the rainfall during the period, cm; IR_j the irrigation applied during the period, cm; DR_j the drainage from the sunken bed, cm; ER_j the effective rainfall during the period, cm. Drainage has to be considered when standing water depth exceeds the maximum allowable water depth in the sunken bed.

4.6.3. Water expense efficiency

The water expense efficiency (WEE) was calculated as follows:

$$\text{WEE} = \frac{\text{Total rice-equivalent yield of a cropping system (kg/ha)}}{\text{Total water expenses for that cropping system (cm)}}$$

4.6.4. Water productivity

Gross water productivity (GWP) and net water productivity (NWP) were calculated as follows:

$$\text{GWP} = \frac{\text{Gross return from a cropping system (Rs)}}{\text{Total water expenses for that cropping system (m}^3\text{)}}$$

$$\text{NWP} = \frac{\text{Net return from a cropping system (Rs)}}{\text{Total water expenses for that cropping system (m}^3\text{)}}$$

4.6.5. Land use efficiency and benefit cost ratio

Land use efficiency was calculated from total duration of crops (in individual cropping system) divided by 365, and production efficiency from total economic yield (total rice-equivalent yield, kg/ha/year and net return, Rs/ha/year) in a cropping system divided by total of crops in a system. Economic and byproduct yields, cost of cultivation and net returns were recorded separately for the component crops. Net returns (Rs/ha/year) were calculated for each cropping system every year. Benefit cost ratio was calculated from gross return in a cropping system (Rs/ha/year) divided by total cost of cultivation of that cropping system (Rs/ha/year).

4.6.6. Net present value and internal rate of return

For economic evaluation of the system, two dynamic economic indices, net present value (NPV) and internal rate of return (IRR) were used to compare the cropping systems in raised and sunken beds for 3 year period, 2002, 2003 and 2004. A discount rate of 10% is used for NPV calculation. The selling price of rice was Rs 4/kg, the selling price of vegetable crops varied several time during sale of vegetable, we took the average price of a season for calculation purpose. Selling price of tomato, veg. cowpea, brinjal, okra, pointed gourd, papaya, cucumber, leafy vegetable, cabbage, bitter gourd, snake gourd and colocasia was rupees 3.00, 10.00, 10.00, 10.00, 10.00, 4.00, 6.00, 6.00, 4.00, 12.00, 7.00 and 6.00, respectively. The selling price of fish seed was rupees 40 per kg. Labour cost was calculated separately by for each season. During transplanting season, the labour rate was Rs 50/day and during lean period it was Rs. 40/day (for 6 working hours). The present value of gross profit (GB) and total cost (TC) are calculated as follows:

$$GB = \sum_{t=1}^{n} \frac{B_t}{(1+i)^t}$$

$$TC = K_1 + K_2 + \sum_{t=1}^{n} \frac{C_t}{(1+i)^t}$$

Where B_t is the gross profit at the t^{th} year, C_t the cost of the t^{th} year, i is the discount rate, K_1 the investment on construction of raised and sunken bed system (Rs 36000/ha required for construction), K_2 the investment on maintenance of the system in proper form (Rs 4000/ ha/ year required for maintenance from the second year onward) from the next year of construction and n is the calculation period. Therefore, the net present value of profit is

NPV = GB -TC

If NPV > 0, the system is accepted, if not the system is not feasible. The time period when the net revenue compensates for the total investment is the capital recovery period.

We fixed three years.

The internal rate of return was calculated as follows:

$$\sum_{t=1}^{n} \frac{B_t}{(1+IRR)^t} - \left[K_1 + K_2 + \sum_{t=1}^{n} \frac{C_t}{(1+IRR)^t}\right] = 0$$

Where IRR is the internal rate of return. The IRR is acceptable if it is greater than minimum expected interest rate (if it is more than 10%).

5. RESULTS AND DISCUSSION

5.1. Biswanathpur experimental site

5.1.1. Yield of different cropping systems

During both the seasons (*rabi* and *kharif*), higher rice yield was obtained from sunken bed than unmodified field (conventional system). It was 13.6% higher during *rabi* and 15.7% higher during *Kharif* season. Rice yield in *rabi* season was always higher than that in *kharif* season. It may be due to longer sunshine hours during *rabi* season. Among different vegetable crops, tomato gave the highest yield (24.66 t/ha) followed by brinjal (15.23 t/ha), and the lowest yield (3.33 t/ha) was obtained for leafy vegetable (Table 4).

Farmer standing on raised bed with brinjal crop grown

5.1.2. Rice equivalent yield

Rice equivalent yield (REY) of all the cropping systems was significantly higher in raised and sunken bed system than in non-modified fields. It was due to high yield obtained from different vegetable crops grown in the raised beds. Among different cropping system in modified land, C3 (rice-rice grown in the sunken bed and brinjal-okra grown in the raised bed) produced the highest (32.42 t/ha) rice equivalent yield. Higher production of brinjal and okra and higher prices of these crops were responsible for higher rice-equivalent yield under this cropping system. This was followed by C6 (rice-rice grown in the sunken bed and cucumber-leafy vegetable-brinjal grown in raised bed) cropping system. On modified land, lowest rice equivalent yield (13.89 t/ha) was recorded in C4 (rice-rice grown in sunken bed and pointed gourd grown in raised bed) due to growing of only one vegetable crop under this cropping system (Table 5).

Vegetable cowpea on raised bed and rice crop in sunken bed

Land utilization efficiency of all the cropping systems was significantly higher in modified than in original low land. In modified land, highest land utilization efficiency was recorded in C5 (rice-rice grown in sunken bed and pointed gourd+ papaya grown in raised bed) as this cropping system occupied the field for longest period (285 days).

Table 4. Duration of the cropping systems and crop productivity in original and modified lowland at Biswanathpur (pooled data of 3 years)

Treatments	Duration (days)	Yield (t/ha)	Production in cultivated area (t)	Rice equivalent production in the cultivated area (t)
Original land				
C1-Rice alone(Ra)	226	4.20	4.20	4.20
Rice alone (Kh)		3.57	3.57	3.57
Modified land				
C2- Rice (Ra)	240	4.77	2.39	2.39
Rice (Kh)		4.13	2.07	2.07
Tomato		24.66	12.33	9.25
Veg. cowpea		4.47	2.23	5.58
C3- Rice (Ra)	262	4.77	2.39	2.39
Rice (Kh)		4.13	2.07	2.07
Brinjal		15.23	7.62	19.04
Okra		7.13	3.57	8.92
C4- Rice (Ra)	280	4.77	2.39	2.39
Rice (Kh)		4.13	2.07	2.07
Pointed gourd		7.55	3.77	9.43
C5- Rice (Ra)	285	4.77	2.39	2.39
Rice (Kh)		4.13	2.07	2.07
Pointed gourd		7.01	3.51	8.77
+ Papaya		4.07	4.07	4.07
C6- Rice (Ra)	269	4.77	2.39	2.39
Rice (Kh)		4.93	2.07	2.07
Cucumber		5.40	2.70	4.05
Leafy vegetable		3.33	1067	2.50
Brinjal		8.40	4.20	10.50

Rb-*rabi* crop, Kh- *kharif* crop

The lowest land use efficiency was recorded under C2 (rice-rice grown in sunken bed and tomato-cowpea grown in raised bed) cropping system (Table 5).

Land utilization efficiency under C3 and C6 cropping systems were comparable. Rice equivalent production efficiency was significantly higher in all the cropping systems under modified than under original land condition. Highest rice equivalent production efficiency (123.74 kg/ha/day) and monetary return efficiency (Rs 300.21 /ha/day) was also recorded in C3 (rice-rice grown in sunken bed and brinjal-okra grown in raised bed) cropping system (Table 5).

Table 5. Rice equivalent yield and other efficiency parameters of different cropping systems in original and modified lowland at Biswanathpur (pooled data of 3 years)

Treatments	Efficiency parameters			
	Rice equivalent yield (t/ha)	Rice equivalent production efficiency (kg/ha/day)	Monetary return efficiency (Rs/ha/day)	Land utilization efficiency (%/annum)
Original land				
C1	7.77	34.38	55.03	61.92
Modified land				
C2	19.29	80.38	229.01	65.75
C3	32.42	123.74	300.21	71.78
C4	13.89	49.61	112.20	76.71
C5	17.30	60.70	134.01	78.08
C6	21.51	79.96	193.91	73.70
LSD (P=0.05)	1.41	6.60	22.62	2.50

5.1.3. Water expense, water expense efficiency and water productivity

Different cropping systems used varied quantities of water (effective rainfall+ irrigation). Total water use by rice-rice (C1) cropping system was maximum in conventional land use system than cropping system tested in raised and sunken bed system. In modified land use system, significantly higher water was used by C6 (rice-rice grown in sunken bed and cucumber-leafy vegetable-brinjal grown in raised bed) cropping system followed by C5 (rice-rice grown sunken bed and pointed gourd+ vegetable papaya grown in raised bed). The lowest water was used in C2 (rice-rice grown in sunken bed and tomato- vegetable cowpea grown in raised bed) cropping system. Water used by C6 and C5 cropping systems were statistically comparable. Similarly water used by C6 and C1 cropping systems were statistically at par.

Water expense efficiency of all the cropping systems were significantly higher in raised and sunken bed system than in unmodified field. In modified land, significantly higher water use efficiency was observed in C3 (rice-rice grown in sunken bed and brinjal- okra grown in raised bed) cropping system followed by C2 (rice-rice grown in sunken bed and tomato-vegetable cowpea grown in raised bed) cropping system. Lowest water use efficiency (69.00 kg /ha-cm) was observed in C4 (rice grown in sunken bed and pointed gourd grown in raised bed) cropping system. This was because pointed gourd was a long-duration and high water-requiring crop (Table 6).

Table 6. Water productivity parameters of different cropping systems in original and modified lowland at Biswanathpur (pooled data of 3 years)

Treatments	Water productivity parameter			
	Water expense (mm /ha)	Water expense efficiency (kg/ha-cm)	Gross water productivity (Rs/m^3)	Net water productivity (Rs/m^3)
Original land				
C1	2260	34.38	1.38	0.55
Modified land				
C2	1732	111.37	4.46	3.17
C3	1963	165.16	6.60	4.01
C4	2013	69.00	2.76	1.56
C5	2113	81.87	3.28	1.81
C6	2207	97.46	3.90	2.36
LSD (P=0.05)	126	8.14	0.33	0.26

The gross and net water productivity was significantly higher for all the cropping systems tested in raised & sunken bed system than in unmodified low land situation. Among different cropping systems in modified land, highest gross and net water productivity was recorded in C3 (rice-rice grown in sunken bed and brinjal -okra grown in raised bed) followed by C2 cropping system (rice-rice grown in sunken bed and tomato-vegetable cowpea grow in raised bed) (Table 6). The lowest gross and net water productivity was computed in C4 (rice-rice grown in sunken bed and pointed gourd grown in raised bed) cropping system. The net water productivity for cropping system C4 (rice-rice grown in sunken bed and pointed gourd grown in raised bed) and C5 (rice-rice grown in sunken bed and pointed gourd + papaya grown in raised bed) were comparable.

5.1.4. Net return and benefit cost ratio

Significantly higher net return was recorded in C3 (rice-rice grown in sunken bed and brinjal-okra grown in raised bed) followed by C2 cropping system (rice-rice grown in sunken bed and tomato-vegetable cowpea grown in raised bed). But the highest B: C ratio (3.48) was observed in C2 cropping system followed by C3 and C6 cropping system. The B: C ratio of C3, C4 and C6 cropping system were at par. The lowest B: C ratio and net return were recorded with the C1 (rice-rice grown in un modified field) cropping system (Table 7).

Table 7. Benefit cost ratio of different cropping systems in original and modified lowland at Biswanathpur (pooled data of 3 years)

Treatments	Economic parameters			
	Gross returns (Rs/ha/year)	Cost of cultivation (Rs/ha/year)	Net returns (Rs/ha/year)	B: C ratio
Original land				
C1	31080	18644	12436	1.67
Modified land				
C2	77160	22198	54962	3.48
C3	129680	51024	78656	2.54
C4	55560	24143	31417	2.30
C5	69200	31006	38194	2.23
C6	86040	33878	52162	2.54
LSD (P=0.05)	5635	2256	4946	0.14

5.1.5. Economic evaluation of the raised and sunken bed system

The net present values (NPV) for C2, C3, C4, C5 and C6 cropping systems were calculated and presented in Fig 5. The NPV of C4 and C5 cropping systems were lesser than those of the C2, C3 and C6 cropping systems. It is also evident that among these 5 cropping systems, NPV was the highest for C3 and the lowest for C4 cropping system. The capital recovery period of C2, C3 and C6 was 1 year, while capital recovery period of C4 and C5 was < 2 years. The two indices, NPV and capital recovery period, show that in order to increase farm income and economic return on invested capital, it is important to select proper cropping system. NPV of C3 (rice-rice grown in sunken bed and brinjal and okra grown in raised bed) cropping system was the highest followed by C2 (rice-rice grown in sunken bed and tomato vegetable cowpea grown in raised bed). Comparison of internal rate of return (IRR) for all the cropping systems in raised and sunken beds was made. Results are presented in Fig 6. IRR of all the cropping systems in modified land were much higher than the prevailing interest rates of banks. The IRR of C3 cropping system was higher than IRR of other cropping systems.

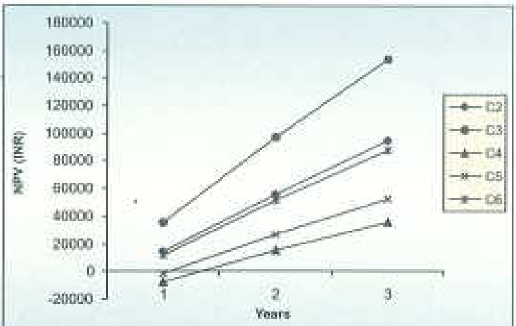

Fig 5. comparison of NPV for five cropping systemsin raised and sunken beds at Bishwanathpur (interest rate 10%)

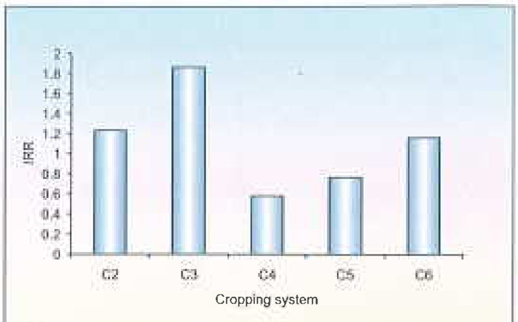

Fig 6. Comparison of internal rate of return at Biswanathpur under different cropping systems of raised and sunken beds

5.2. Khamang experimental site

5.2.1. Yield of different cropping systems

Yields of both *rabi* and *Kharif* rice were higher in sunken beds than in the unmodified field. Among different vegetable crops grown in the raised beds, tomato gave the highest yield (17.12 t/ha) followed by brinjal (8.67 t/ha). Pointed gourd produced 6.2 and 5.67 t/ha and the lowest yield was recorded for vegetable papaya crop (Table 8).


Brinjal crop on raised bed and rice crop grown in sunken bed

5.2.2. Rice equivalent yield

Significantly higher rice equivalent yield (22.05 t/ha) was observed in C3 (rice-rice grown in sunken bed and okra-brinjal grow in raised bed) cropping system followed by C2 (rice-rice grown in sunken bed and tomato-vegetable cowpea grown in sunken bed) and C5 (rice-rice grown in sunken bed and pointed gourd + papaya grown in raised bed). Lowest rice equivalent yield was observed in conventional C1 (rice-rice grown in unmodified field) cropping system. However rice equivalent yield of C1 cropping system was statistically comparable

Table 8. Duration of the cropping systems and crop productivity in original and modified lowland at Khamang (pooled data of 3 years)

Treatments	Duration (days)	Yield (t/ha)	Production in cultivated area (t)	Rice equivalent production in the cultivated area (t)
Original land				
C1-Rice alone (Ra)	223	4.37	4.37	4.37
Rice alone (Kh)		4.03	4.03	4.03
Modified land				
C2- Rice (Ra)	245	5.10	2.55	2.55
Rice (Kh)		4.70	2.35	2.35
Tomato		17.12	8.56	6.42
Veg.cowpea		4.47	2.23	5.58
C3- Rice (Ra)	263	5.10	2.55	2.55
Rice (Kh)		4.70	2.35	2.35
Okra		5.13	2.57	6.42
Brinjal		8.67	4.33	10.83
C4- Rice (Ra)	267	5.10	2.55	2.55
Rice (Kh)		4.70	2.35	2.35
Pointed gourd		6.20	3.10	7.75
C5- Rice (Ra)	290	5.10	2.55	2.55
Rice (Kh)		4.70	2.35	2.35
Pointed gourd		5.67	2.83	7.08
+ Papaya		4.00	4.00	4.00

Rb- *rabi* crop, Kh- *kharif* crop

with C4 (rice-rice grown in sunken bed and pointed gourd grown in raised bed) cropping system.

The highest land utilization efficiency was found in C5 (rice-rice grown in sunken bed and pointed gourd + papaya grown in raised bed) as this cropping system occupied the field for longest period (290 days). Land utilization efficiency in C3 (rice-rice grown in sunken bed and Okra-brinjal grown in raised bed) and C4 (rice-rice grown in sunken bed and pointed gourd grown in raised bed) cropping systems were statistically comparable. The lowest land utilization efficiency was observed in C1 (unmodified field) cropping system.

Rice equivalent production efficiency of C1 (unmodified field) and C4 (rice-rice grown in sunken bed and pointed gourd grown in raised bed) cropping systems were statistically at par. However, rice equivalent production efficiency of other cropping systems was higher than under conventional land use system. Among modified land use systems, highest rice equivalent production efficiency was observed (84.22 kg/ha/day) in C3 (rice-rice grown in sunken bed and okra-brinjal grown in raised bed) cropping system followed by C2 (rice-rice grown in sunken bed and tomato-vegetable cowpea in raised bed (Table 9). Similar trends of variation in cropping systems were also observed for monetary return efficiency. It is because selling price of brinjal was much higher than the price of tomato.

Table 9. Rice equivalent yield and other efficiency parameters of different cropping systems in original and modified lowland at Khamang (pooled data of 3 years)

Treatments	Efficiency parameters			
	Rice equivalent yield (t/ha)	Rice equivalent production efficiency (kg/ha/day)	Monetary return efficiency (Rs/ha/day)	Land utilization efficiency (%/annum)
Original land				
C1	8.04	37.67	60.00	61.10
Modified land				
C2	16.90	68.98	187.15	67.12
C3	22.15	84.22	180.00	72.05
C4	12.65	47.38	106.04	73.15
C5	15.98	55.10	123.15	79.45
LSD (P=0.05)	5.12	21.92	45.63	3.63

5.2.3. Water expense, water expense efficiency and water productivity

Different cropping systems used different quantity of water. Water used by C1 (unmodified field), C 4 (rice-rice grown in sunken bed and pointed gourd grown in raised bed) and C5 cropping systems (rice-rice grown in sunken bed and pointed gourd+ papaya grown in raised bed) were at par. Water used by C2 (rice-rice grown in sunken bed and tomato and vegetable cowpea grown in raised bed) and C3 (rice-rice grown in sunken bed and okra-brinjal grown in raised bed) cropping systems were also statistically comparable. The least quantity of water was used by C3 cropping system while the highest quantity of water was used by C1 cropping system. Among modified land use systems, the lowest water expense efficiency was observed for C4 cropping system. The economic index of gross water production was 1.47, 3.51, 4.71, 2.45 and 2.95 Rs/m^3 for C1, C2, C3, C4 and C5 cropping system, respectively. Gross water productivity of C1, C4 and C5 were at par. The net water productivity was significantly higher in modified than that in original low land. Among different cropping systems in modified land, C3 (rice-rice grown in sunken bed okra and brinjal grown in raised bed) gave the highest net water productivity. Net water productivity of C4 and C5 cropping system was at par. Water productivity for all the cropping systems tested in modified land were higher than that for rice cultivation in original low land. In modified land, rice-rice in sunken bed and okra and brinjal in raised bed proved the most water efficient cropping system (Table 10).

Table 10. Water productivity parameters of different cropping systems in original and modified lowland at Khamang (pooled data of 3 years)

Treatments	Water productivity parameter			
	Water expense (mm/ha)	Water expense efficiency (kg/ha-cm)	Gross water productivity (Rs/m^3)	Net water productivity (Rs/m^3)
Original land				
C1	2287	36.73	1.47	0.58
Modified land				
C2	1928	87.66	3.51	2.38
C3	1882	117.69	4.71	2.52
C4	2068	61.17	2.45	1.37
C5	2165	73.81	2.95	1.65
LSD (P=0.05)	233	36.75	1.52	0.76

5.2.4. Net return and benefit cost ratio

Highest net return of Rs 47311 was recorded in C3 (rice-rice grown in sunken bed and okra- brinjal grown in raised bed) cropping system followed by C2 (rice-rice grown in sunken bed and tomato and vegetable cowpea grown in raised bed) cropping system. Net returns recorded in C4 (rice-rice grown in sunken bed and pointed gourd grown in raised bed) and C5 (rice-rice grown in sunken bed and pointed gourd +papaya grown in raised bed) cropping systems were comparable. The lowest net return was recorded for conventional C1 (rice-rice grown in unmodified field) cropping system. Net return recorded for all the cropping systems in modified land were significantly higher than that recorded for un-modified fields. The highest benefit cost ratio was recorded for C3 cropping system and the lowest for C1 cropping system. B: C ratio for C3, C4 and C5 cropping system were statistically comparable (Table 11).

Table 11. Benefit-cost ratio of different cropping systems in original and modified lowland at Khamang (pooled data of 3 years)

Treatments	Economic parameters			
	Gross returns (Rs/ha/year)	Cost of cultivation (Rs/ha/year)	Net returns (Rs/ha/year)	B: C ratio
Original land				
C1	33600	20230	13370	1.66
Modified land				
C2	67600	21748	45852	3.11
C3	88600	41289	47311	2.15
C4	50600	22287	28313	2.27
C5	63920	28207	35713	2.27
LSD (P=0.05)	19217	11758	10375	0.39

5.2.5. Economic evaluation of the raised and sunken bed system

Net present values (NPV) of all the cropping systems in raised and sunken bed are presented in Fig 7. Among all the cropping systems, the net present values were higher in C3 (rice-rice grown in sunken bed and okra-brinjal grown in raised bed) followed by C2 cropping system (rice-rice grown in sunken bed and tomato-vegetable cowpea grown in raised bed). The lowest net present values (NPV) were recorded for C4 (rice-rice grown in sunken bed and pointed gourd grown in raised bed) cropping system. The capital recovery period for C2 and C3 cropping systems was 1 year, while capital recovery period for C4 and C5 was > 1 year but < 2 year. Both these two indices show that C3 cropping system had the best return on investment followed by C2 cropping system. Similarly internal rate of return (IRR) was the highest for C3 followed by C2 cropping system (Fig 8). The internal rate of return of all the cropping systems in raised and sunken bed system was much higher than the prevailing interest rates of the banks.

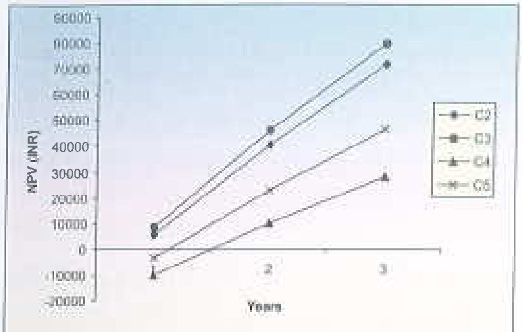

Fig 7. comparison of NPV for four cropping systems in raised and sunken beds at Khamang (interest rate 10%)

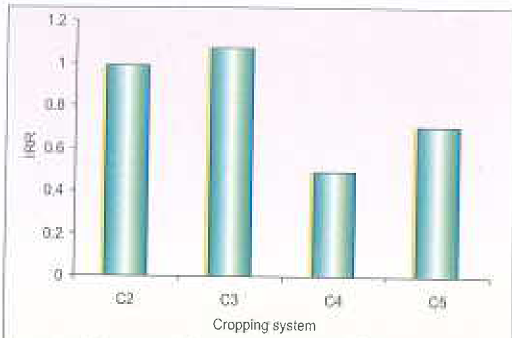

Fig 8. Comparison of internal rate of return for different cropping systems of raised and sunken beds at Khamang

5.3 Barillo experimental site- 1

5.3.1. Yield of different cropping systems

Yield of both *rabi* and *kharif* rice was higher in sunken bed than in un-modified field. Among different vegetable crops tested in raised bed, cabbage gave the highest yield (27.30 t/ha) followed by snake gourd (20.94 t/ha) and bitter gourd (7.13 t/ha). The lowest yield was recorded in pointed gourd crop (5.38 t/ha). Cabbage gave the highest yield but price of this crop was only Rs 4.00 per kg. Though bitter gourd gave the third highest yield but it fetched very good price Rs 12/kg. Fish grown with rice in sunken beds gave more yield than fish grown without rice crop (Table 12).


Cabbage on raised bed and rice crop in sunken bed

5.3.2. Rice equivalent yield

Rice equivalent yield of all the cropping systems in raised and sunken beds was higher than in original lowlands. The highest rice equivalent yield (38.80 t/ha) was recorded in C7 (rice- fish grown in sunken bed and snake gourd +pointed gourd grown in raised bed) cropping system followed by C2 (rice-rice grown in sunken bed and cabbage-brinjal grown in raised bed) and C6 (rice-rice + fish grown in sunken bed and pointed gourd grown in raised bed) cropping systems. Rice equivalent yields of C2 and C6 cropping systems were statistically comparable. There was no significant difference between rice equivalent yields of C1 (conventional field) and C3 (rice-rice

Table 12. Duration of the cropping systems and crop productivity in original and modified lowland at Barillo site-1 (pooled data of 3 years)

Treatments	Duration (days)	Yield (t/ha)	Production in cultivated area (t)	Rice equivalent production in the cultivated area (t)
Original land				
C1-Rice alone (Rb)	218	3.93	3.93	3.93
Rice alone (Kh)		3.75	3.75	3.75
Modified land				
C2-Rice (Rb)	254	4.38	2.19	2.19
Rice (Kh)		5.09	2.54	2.54
Cabbage		27.30	13.65	13.65
Brinjal		6.66	3.33	8.32
C3-Rice (Rb)	265	4.38	2.19	2.19
Rice (Kh)		5.09	2.54	2.54
Pointed gourd		5.38	2.69	6.73
C4-Rice (Rb)	265	4.38	2.19	2.19
Rice (Kh)		5.09	2.54	2.54
Pointed gourd		5.38	2.69	6.73
+Bitter gourd		7.13	3.57	10.70
C5-Rice (Rb)	282	4.38	2..19	2.19
Rice (Kh)		5.09	2.54	2.54
Pointed gourd		5.38	2.69	6.73
+ Papaya		4.00	4.00	4.00
C6-Rice (Rb)	265	4.38	2.19	2.19
Rice (Kh)		5.09	2.54	2.54
-Fish		3.05	1.53	15.25
Pointed gourd		4.85	2.42	6.06
C7-Rice (Rb)	265	4.38	2.19	2.19
Fish		2.44	1.22	12.22
+ Snake gourd		20.94	10.47	18.33
Pointed gourd		4.85	2.42	6.06

Rb- *rabi* crop, Kh- *kharif* crop

grown in sunken bed and pointed gourd grown in raised bed). This may be due to growing of only one crop of pointed gourd in raised bed.

Highest land utilization efficiency (77.26%) was recorded in C5 (rice-rice grown in sunken bed and pointed gourd +papaya grown in raised bed) cropping system, as this cropping system occupied field for the longer period (282 days) and land utilization

Snake gourd trailing above the sunken beds

efficiency was the lowest under original land condition (Table 13). Land utilization efficiency under C3, C4, C6 and C7 cropping system were at par but significantly higher than that under C1 cropping system. Land utilization efficiency of all the cropping systems of modified land were significantly higher than that of original lowland.

Rice equivalent production efficiency of C1 and C3 cropping systems were statistically comparable. The highest rice equivalent production efficiency was observed in C7 followed by C2 and C6 cropping systems. Rice equivalent production efficiency of C2 and C7 cropping system were comparable. Similar trends were observed for monetary return efficiency (Table 13).

5.3.3. Water expense, water expense efficiency and water productivity

Quantity of water used by C1, C2, C4, C5, C6 and C7 cropping systems were comparable. C3 cropping system used significantly lower amount of water in comparison to all other cropping systems. Water expense efficiency of all the cropping systems in raised and sunken bed system was significantly higher than water expense efficiency of original land. Among different cropping systems of raised and sunken bed system, highest water expense efficiency was observed in C7 followed by C2 and C6 cropping systems. The lowest water use efficiency in modified land use system was observed for C3 cropping system. Water use efficiency of C2, C4 and C6 cropping systems were statistically comparable (Table 14).

Harvesting of fish from sunken bed

Table 13. Rice equivalent yield and other efficiency parameters of different cropping systems in original and modified lowland at Barillo site-1 (pooled data of 3 years)

Treatments	Efficiency parameters			
	Rice equivalent yield (t/ha)	Rice equivalent production efficiency (kg/ha/day)	Monetary return efficiency (Rs/ha/day)	Land utilization efficiency (%/annum)
Original land				
C1	7.68	35.23	53.38	59.73
Modified land				
C2	26.70	105.12	181.29	69.59
C3	11.46	43.25	72.24	72.60
C4	22.16	83.62	135.80	72.60
C5	15.46	54.82	97.39	77.26
C6	26.04	98.26	279.28	72.60
C7	38.80	146.42	442.08	72.60
LSD (P=0.05)	3.85	16.53	56.81	3.76

The gross water productivity of all the cropping systems tested in raised and sunken bed was significantly higher than the gross water productivity of rice-rice grown in original land. Among different cropping systems of raised and sunken bed, the highest gross water productivity (Rs 6.98/m^3) was observed in C7 followed by C2 and C6 cropping systems. Gross water productivity of C4 and C6 cropping systems were statistically at par. Similarly gross water productivity of C3 and C5 were statistically comparable. The highest net water productivity was computed for C7 followed by C6 and C2 cropping systems. The lowest net water productivity was computed for C1 followed by C3 cropping system. C1 and C3 cropping systems were statistically comparable as far as the net water productivity was concerned. Thus, growing of rice-fish in sunken bed and snake ground + pointed gourd in raised bed or growing of rice-rice+ fish in sunken bed and cabbage-brinjal in raised bed were the most productive way of using available water in lowlands.

5.3.4. Net return and benefit cost ratio

All the cropping systems except C3 in modified raised and sunken bed recorded significantly higher net return than net return recorded in original fields. Net return of C3 cropping system was statistically comparable with conventional system of rice

Table 14. Water productivity parameters of different cropping systems in original and modified lowland at Barillo site-1 (pooled data of 3 years)

Treatments	Water productivity parameters			
	Water expense (mm/ha)	Water expense efficiency (kg/ha-cm)	Gross water productivity (Rs/m^3)	Net water productivity (Rs/m^3)
Original land				
C1	2286	33.59	1.34	0.51
Modified land				
C2	2118	126.06	5.04	2.18
C3	2076	55.20	2.21	0.92
C4	2110	105.02	4.20	1.71
C5	2171	71.21	2.58	1.27
C6	2273	114.56	4.58	3.23
C7	2223	174.54	6.98	5.33
LSD (P=0.05)	200	21.20	0.83	0.71

growing. The highest net return (Rs 117152/ha/year) was recorded for C7 cropping system followed by C6 and C2 cropping systems. Similarly, highest benefit cost ratio was recorded in C7 followed by C6 cropping system. The benefit cost ratio for other cropping systems (C1, C2, C3, C4 and C5) were statistically comparable (Table 15).

Table 15. Benefit cost ratio of different cropping systems in original and modified lowland at Barillo site-1 (pooled data of 3 years)

Treatments	Economic parameters			
	Gross returns (Rs/ha/year)	Cost of cultivation (Rs/ha/year)	Net returns (Rs/ha/year)	B: C ratio
Original land				
C1	30720	19084	11636	1.61
Modified land				
C2	106800	60753	46047	1.76
C3	45840	26697	19143	1.72
C4	88640	52652	35988	1.68
C5	61840	34375	27465	1.80
C6	104160	30150	74010	3.45
C7	155200	38048	117152	4.08
LSD (P=0.05)	8189	3479	13426	0.36

5.3.5. Economic evaluation of the raised and sunken bed system

The net present values (NPV) of 6 cropping systems (C2, C3, C4, C5, C6, C7) tested in raised and sunken beds were computed, they are presented in Fig 9. The NPV was highest for C7 followed by C6 cropping system. The lowest NPV was computed for C3 cropping system. The capital recovery period for C2, C6 and C7 system was 1 year, for C4 and C5 was > 1 year, and for C3 was > 2 year. The internal rates of return (IRR) for all the cropping systems are presented in Fig 10. IRR of C6 and C7 cropping systems were higher than that of other cropping systems. The lowest IRR (21.73%) computed for C3 cropping system was also higher than the present interest rates of banks.

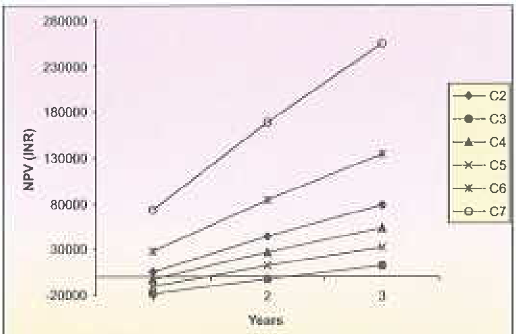

Fig 9. comparison of NPV for six cropping systems in raised and sunken beds at Barillo site 1 (interest rate 10%)

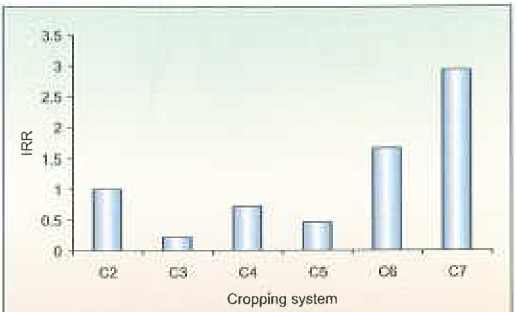

Fig 10. Comparison of internal rate of return at Barilo site 1 under different cropping systems of raised and sunken beds

5.4. Barillo experimental site- 2

5.4.1. Yield of different cropping systems

Rice and colocasia were grown in the sunken beds. Colocasia gave the highest yield of 42.27 t/ha, which was much higher than rice yield obtained from sunken beds and also from original fields. In raised beds, cabbage gave the highest yield of 26.87 t/ha followed by snake gourd (20.07 t/ha) and vegetable papaya gave the lowest yield (4 t/ha) (Table 16).


Colocasia in sunken bed and pointed gourd + papaya on raised bed

Table 16. Duration of the cropping systems and crop productivity in original and modified lowland at Barillo site-2 (pooled data of 3 years)

Treatments	Duration (days)	Yield (t/ha)	Production in cultivated area (t)	Rice equivalent production in the cultivated area (t)
Original land				
C1-Rice alone (Ra)	223	4.40	4.40	4.40
Rice alone (Kh)		3.78	3.78	3.78
Modified land				
C2-Rice (Ra)	286	5.40	2.70	2.70
Rice		4.85	2.43	2.43
Pointed gourd		12.37	6.18	15.46
+ Papaya		4.00	4.00	4.00
C3-Colocasia	307	42.27	21.13	31.70
Pointed gourd		12.37	6.18	15.46
+ Papaya		4.00	4.00	4.00
C4-Rice (Ra)	258	5.40	2.70	2.70
Rice		4.11	2.06	2.06
Cabbage		26.87	13.43	13.43
Snake gourd		20.07	10.03	17.56

Rb- *rabi* crop, Kh- *kharif* crop

5.4.2. Rice equivalent yield

Rice equivalent yields of all the cropping systems were significantly higher in raised and sunken bed system than rice yields in original field. Among different cropping systems tested in raised and sunken bed, C3 (colocasia grown in sunken bed and pointed gourd grown in raised bed) produced the highest (51.16 t/ha) rice-equivalent yield followed by C2 (rice-rice grown in sunken bed and cabbage-snake gourd grown in raised bed) cropping system. The lowest REY was observed in C2 (rice-rice grown in sunken bed and pointed gourd + papaya grown in raised bed) cropping system. Similar type of results was recorded for rice - equivalent production efficiency and monetary return efficiency.

Land utilization efficiency of all the cropping systems in modified land was significantly higher than that in original lowland. In modified land, highest land

Table 17. Rice equivalent yield and other efficiency parameters of different cropping systems in original and modified lowland at Barillo site-2 (pooled data of 3 years)

Treatments	Efficiency parameters			
	Rice equivalent yield (t/ha)	Rice equivalent production efficiency (kg/ha/day)	Monetary return efficiency (Rs/ha/day)	Land utilization efficiency (%/annum)
Original land				
C1	8.18	36.68	56.46	61.09
Modified land				
C2	24.59	85.98	198.60	78.36
C3	51.16	166.65	500.44	84.11
C4	35.75	138.57	328.91	70.69
LSD (P=0.05)	2.76	18.36	51.51	6.03

utilization efficiency of 84.11 %/year was recorded in C3 cropping system followed by C2 cropping system. The lowest land utilization efficiency was recorded in C4 (rice-rice grown in sunken bed and cabbage-snake gourd grown in raised bed) cropping system (Table 17).

5.4.3. Water expense, water expense efficiency and water productivity

Different cropping systems used different quantity of water. The highest amount was used by C4 cropping system. Water expense efficiency of all the cropping systems were significantly higher in raised and sunken bed system than in unmodified land. The highest water expense efficiency was recorded in C3 followed by C4 cropping system. Gross water productivity of all the cropping systems in raised and sunken bed were significantly higher than in unmodified land. Similarly net water productivity was significantly higher in C3 than in C4 cropping system. The highest water productivity was realized in C3 cropping system suggesting it the most effective way of using available water (Table 18).

5.4.4. Net return and benefit cost ratio

Significantly higher net return was recorded for all the cropping systems tested in raised and sunken bed than in original fields. The highest net return (Rs 153634/ha/year) and benefit-cost ratio (4.01) were recorded in C3 followed by C2 cropping system (Table 19).

Table 18. Water productivity parameters of different cropping systems in original and modified lowland at Barillo site-2 (pooled data of 3 years)

Treatments	Water productivity parameter			
	Water expense (mm/ha)	Water expense efficiency (kg/ha-cm)	Gross water productivity (Rs/m³)	Net water productivity (Rs/m³)
Original land				
C1	2262	36.16	1.45	0.56
Modified land				
C2	2150	114.31	4.58	2.64
C3	1949	262.49	10.50	7.88
C4	2435	146.82	5.87	3.49
LSD (P=0.05)	125	19.85	0.80	0.55

Table 19. Benefit-cost ratio of different cropping systems in original and modified lowland at Barillo site-2 (pooled data of 3 years)

Treatments	Economic parameters			
	Gross returns (Rs/ha/year)	Cost of cultivation (Rs/ha/year)	Net returns (Rs/ha/year)	B: C ratio
Original land				
C1	30720	20129	12591	1.63
Modified land				
C2	98360	41561	56799	2.37
C3	204640	51006	153634	4.01
C4	143000	58141	84859	2.46
LSD (P=0.05)	11039	4394	6842	0.09

5.4.5. Economic evaluation of the raised and sunken bed system

Net present values (NPV) for all the cropping systems tested in raised and sunken beds were computed and presented in Fig 11. NPV of C3 (colocasia grown in sunken bed and pointed gourd + papaya grown in raised bed) was the highest followed by C4 (rice-rice grown in sunken bed and cabbage-snake gourd grown in raised bed). Among all the cropping systems, NPV computed was the lowest for C2 (rice-rice grown in sunken bed and pointed gourd + papaya grown in raised bed) cropping system. Capital recovery period was 1 year for all the cropping systems. These two indices (financial NPV and capital recovery period) showed that growing of colocasia in sunken bed in place of rice recovered the invested capital faster and gave higher farm income. Comparison of internal rate of return for all the cropping systems is shown in Fig 12. IRR of all the cropping systems tested in raised and sunken bed system were much higher than the present interest rate of banks. The highest IRR was computed for C3 cropping system.

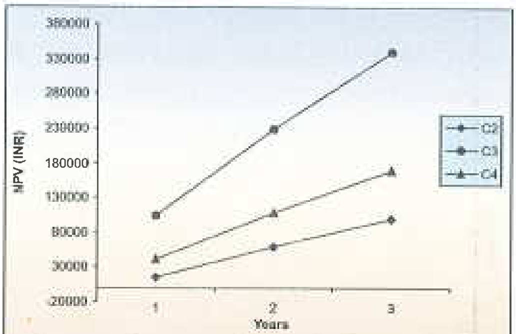

Fig 11. Comparison of NPV for three cropping systems in raised and sunken beds at Barilo site 2 (interest rate 10%)

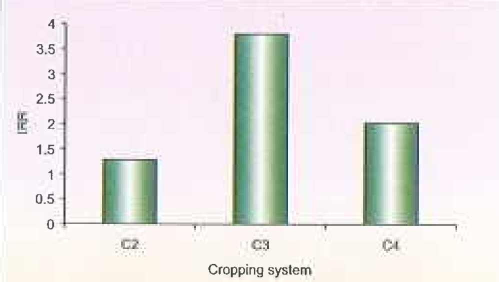

Fig 12. Comparison of internal rate of return at Barilo site 2 under different cropping systems of raised and sunken beds

6. RICE-FISH INTEGRATION IN RAISED AND SUNKEN BED SYSTEM

Stocking of healthy fingerlings of more than 100 mm length is essential to enhance fish production. However, inadequate land based nursery ponds available at present and financial constraints in developing new infrastructure facilities impede the desired stocking programme. With these constraints and available resources, rice field ecosystem provides a viable opportunity for mass scale fry to advanced fingerling rearing, as a part of stocking programme. Further, out of 44.5 million hectare of rice-cultivated land in India, 20 million ha is suitable for adoption of rice-fish integration system mainly in low and medium lands. However, only 0.23 million ha is presently under rice-fish culture. This low degree of adoption and yield is primarily due to introduction of high-yielding rice varieties involving the use of pesticides that has greatly impeded fish culture in paddy fields. Besides this, insufficient water availability, water level fluctuation and erratic monsoon have adversely affected fish rearing in rice fields. Achieving a higher productivity from these underutilized high-potential areas is thus an immediate need, particularly in the eastern region. If these lands were brought under integrated rice-fish system with suitable scientific intervention, it would help to compensate for the economic losses in rice production brought about by natural calamities. Integrated rice-fish farming not only accommodates crop diversification, enhance productivity, generate employment opportunity, increase income and provide nutritional security to resource-poor farming community but also distribute the risk (both biological and economic), since two or more subsystems are involved instead of a single-commodity farming system.

6.1. Species suitability

Fish species should be adaptable, compatible, resistant to environmental changes, high-yielding and be able to tolerate heavy doses of fertilizer. Since water column in the refuge and paddy field in the renovated system is suitable for rearing of carps, Indian major carps, viz. *Catla catla, Labeo rohita and Cirrhinus mrigala,* 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-resistant variety of rice with in-built characteristics of photoperiod-sensitivity, and strong seedling vigor can be tried along with fish.

6.2. Application of fertilizer and chemicals

The growth and development of paddy and the fish are greatly influenced by the kind and quantity of fertilizers applied and the method of application. Nitrogen, phosphorous and potassium needed by the paddy are also nutrients required by the planktonic and benthic organisms, which are in turn, the natural food for fish. But too much of inorganic fertilizer is also toxic to fish. Improved technique of fertilization needs 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, which should be applied in small amounts frequently.

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 mortality. But in emergency, broad-spectrum chemicals that have low toxicity, low residue and high effectiveness 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, splashing method is adopted with good results especially when the rice grows tall. It is always economical and advisable to reduce the water level before application of fertilizer and chemicals.

6.3. Fish culture

After proper preparation of sunken bed, liming @ 500-750 kg ha^{-1}, manuring with raw cattle dung @ 5000 kg ha^{-1} as basal dose can be carried out at the onset of monsoon during June. Before fish-fry are released in the sunken beds, it is essential to clear it from aquatic vegetation and predatory fishes. The floating and emergent weeds may be removed manually instead of using chemical weedicide. It is better to use MOC (mahua oil cake) @ 250 ppm at the onset of monsoon during June when rainwater starts accumulating. MOC not only helps in eradicating predatory / unwanted species such as catfish, *Channa punctatus, C. Orientalis, Glossogobius giuris, Puntius ticto, Esomus danricus, Ambasis* spp. and *Barilius* spp., but also acts as a manuring substance.

During the months of July-August, when the rainwater starts accumulating in the sunken bed, early fingerlings of catla, rohu, mrigal, silver carp, and common carp along with prawn seed (2-3/ m^2) of *M. rosenbergii* may be stocked with a composition of 20:30:50 (surface feeder: column feeder: bottom feeder). *Labeo bata* can also form a stocking component in this system. As the culture duration is short, fry (@ 50000/ha) or fingerlings (10-15 g 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, based on the principle of phased harvesting. An optimal stocking density of fish 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 helps in reducing the population pressure and enhances the growth of remaining stock. To augment growth, supplementary feed comprising mustard oil cake/groundnut 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 / perimeter canal. Under this system, production will range between 2400-3000 kg ha^{-1} per crop with a survival rate of about 70-90 percent.

6.4. Performance of fish under raised and sunken bed system : A case study

After proper field preparation, fish fry (<1.2 g) of Indian major carps and exotic carp were stocked with a species composition of 20:30:30:20 (*Catla catla: Labeo rohita: Cirrhinus mrigala: Cyprinous carpio*) in sunken-bed rice plots of 250 m^2 each. Approximately 15% area (40 m^2) of the individual sunken bed plots were deepened further for stocking of fish seed @ 50,000/ha (200 fry/plot). Fish seed had open access to move all-round the field of 250 m^2 and finally come to the deeper portion (40 m^2) when water recedes. In *kharif*, fish seed was incorporated in C6 (rice+ fish in sunken bed and pointed gourd grown in raised bed) and C7 (fish alone in sunken bed and snake gourd +pointed gourd grown in raised bed) cropping systems. 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. Various hydro-biological parameters except total suspended solid and dissolved oxygen, prevailing in different treatments were within optimum ranges and did not show any distinct trend between the treatments (Table 20). This was probably due to similar levels of input in all the treatments in the form of organic manure, inorganic fertilizer and periodic liming. Gradual increase in nitrite, nitrate, ammonia in all the treatment were attributed by intermittent fertilization, increased level of metabolites and decomposition of unutilized feed in absence of water replenishment. Plankton had a profound effect on water quality and is the major source of productivity in aquatic ecosystem, having a direct relationship with fish production. However, no perceptible trend in the total plankton density (4.4 x 10^2 – 13.6 x 10^3 nos l^{-1}) was observed between treatments attributable to the regular manuring /fertilization schedule at fortnightly intervals. Low primary production (84.9 – 121 mg C m^{-3} h^{-1}) in the initial phase of rearing was probably due to fixation of nutrient ions by suspended soil/clay particles as well as rich organic matter. In general, water reaction process is low during monsoon

Table 20. Water and sediment quality in sunken beds under two different cropping systems

Quality Parameters	Cropping system C6	Cropping system C7
Water pH	7.19-7.49 (7.21)	7.02-8.25 (7.45)
D O (ppm)	3.6-7.3 (5.3)	3.3-8.8 (6.1)
Temperature (^{0}C)	25.8-31.2 (28.4)	25.7-31.3 (28.3)
Total alkalinity (ppm)	69-111 (88)	68-101 (81)
D O M (ppm)	0.3-4.5 (3.2)	0.55-4.8 (3.6)
TSS (ppm)	81-282 (213)	72-277 (225)
Nitrite – N (ppm)	0.014-0.066 (0.031)	0.011-0.072 (0.037)
Nitrate – N(ppm)	0.26-0.51 (0.37)	0.29-0.42 (0.36)
Phosphate – P (ppm)	0.07-0.64 (0.33)	0.16-0.73 (0.39)
Total plankton (units/l)	1.03x10^3-4.3x10^3 (3.04x10^3)	2.4x10^3-1.3x10^4 (5.3x10^3)
Available-N (mg 100 g soil^{-1})	8.1-10.8 (9.3)	7.9-11.6 (9.8)
Available-P (mg P_2O_5-P 100 g soil^{-1})	1.83-3.29 (3.04)	1.78-3.56 (3.21)
O C in soil (%)	1.16-1.5 (1.31)	1.36-1.61 (1.49)
Soil pH	6.84-7.06 (7.02)	6.98-7.13 (7.05)

Figures in parentheses indicate average values. DO-dissolved oxygen, DOM-dissolved organic matter, TSS-total suspended solid, OC-organic carbon.

(July – August) due to dilution of alkaline substances or dissolution of atmospheric CO_2. Irrespective of treatment, average growth rate of *C. carpio* was maximum (195.5 g) followed by *C. catla* (128 g), *C. mrigala* (103 g) and *L. rohita* (79.2 g). Bottom feeder (*C.carpio* and *C. mrigala*) registered better growth rate than that of *L. rohita* (column feeder) probably due to its superior feed utilizing capability and to the fact that being a surface and column dweller, *L. rohita* is more sensitive to oxygen depletion, while being bottom dweller *C.carpio* and *C. mrigala* were more tolerant to fluctuation of oxygen concentration and suspended solids. After 120 days of rearing, fish @ 3050 and 2440 kg/ha/120 days was harvested from cropping systems C6 and C7, respectively (Table 12). Introduction of fish in sunken bed along with rice and gourd significantly enhanced the net water productivity to Rs 5.33/m^3 in C7 and Rs 3.23/m^3 in C6 respectively, while that of rice alone it was Rs 0.51/m^3 (Table 14). Similarly, highest rice equivalent yield and B: C ratio were also recorded in C7 and C6 (Table 13 and 15).

7. IMPACT ON LIVELIHOOD OF FARMERS

The selected canal command area largely consisted of small farmers with average holding size 1 ha or less and agriculture as main occupation. Water logging and shallow water table in the canal command forced farmers to grow rice in both wet and dry season. Therefore, modification of topography of land through construction of alternate raised and sunken beds provided the option of crop diversification by growing rice in the sunken bed and different vegetables in the raised bed. Further, converting part of land into pond at lower reach added the option of fish farming. To understand the impact of this intervention (diversified farming options through land modification) on livelihoods of selected farmers a study was carried out.

The potentiality of any intervention lies not only in efficient utilization of resources and enhanced production but also in improving the quality of life of the farmers on adoption of it. The increased farm production and income is expected to bring changes in livelihood of the farmers that includes physical, social, financial, human and natural assets of the farm households. To gather the data on these aspects, interview schedule survey method was followed covering 8 farmers who have adopted diversified farming through land modification.

Although there is no change in average land holding of the farmers as well as cultivated area during *kharif* season after adoption of intervention but it is interesting to note the increased area under cultivation during *rabi* season because of assured irrigation that attributed to farmers' investment to tap the ground water through bore

Table 21. Land utilization pattern and income of the selected 8 farmers before and after adoption of intervention

Particulars	Before intervention		After intervention	
	Kharif season	*Rabi* season	*Kharif* season	*Rabi* season
Average cultivated area (acre)	3.41	1.66	3.41	2.58
Average irrigated area (acre)	3.03	2.09	3.03	2.71
Average land holding (acre)	3.47		3.47	
Average area of modified land (acre)	-		1.01	
Average annual income (Rs)	46612		67875	
Average income from farming in modified land (Rs)	-		25175	

well and pump (Table 21). It is evident that about one acre of land (one-third of total land holding) is modified, farming in which has given an average annual income of Rs 25175 out of total average annual income of Rs 67875. The increased income because of diversified farming through land modification may have influenced the farmers to make further investment to utilize ground water for cultivation during dry season.

The farmers have largely followed rice-fallow, rice-black gram, rice-green gram, rice-horse gram sequences prior to land modification, which used to provide a meager income to the farmers as evident from data in Table 22. The lower return due to poor yield may be attributed to unassured irrigation supply, delayed planting and low input use. Land modification through raised and sunken bed has given the farmers opportunity to grow diversified crops that ensured year around income to the farmers. Cultivation of vegetable crops during both wet and dry season has created employment, reduced migration and met the household consumption from farm produce. Although average monthly household consumption expenditure has increased from Rs 3156 to Rs 4610 over a period of last 3 years, farmers have met the need of its major part from their own farm produce (Fig 13). Out of 8 farm-families, member of 3 families used to migrate to neighbouring villages during crop season (*kharif*) as agricultural labourers with a wage rate of Rs 40 per day for an average of 58 man-days that has reduced to 15 man-days after adoption of the intervention.

The measure of livelihoods gives an idea of the changes on standard of living of the farm families on adoption of diversified farming through land modification. Measure of livelihoods has considered the comparative position of physical, social, financial, human and natural assets of the farmers before and after adoption of the intervention. Physical assets include the type of housing condition, conveyance, electric

Table 22. Farming, average cost of cultivation and income of the selected 8 farmers from the area under land modification before and after adoption of the intervention

Particulars	Before land modification	After land modification
Farming pattern	4 farmers used to follow rice-fallow, 3 farmers used to follow rice-pulses (black gram, green gram, horse gram), 1 farmer used to grow also vegetables in small-scale and 1 farmer engaged in small-scale fish farming	All the 8 farmers grow rice in sunken bed and mostly vegetables in raised beds; 4 farmers engaged in fish farming by converting a portion of land in to pond
Average area (acre)	0.839	1.01 (inclusive of average area modified in to fish pond)
Average cost of cultivation (Rs)	2078	11131
Average income (Rs)	3412	25175

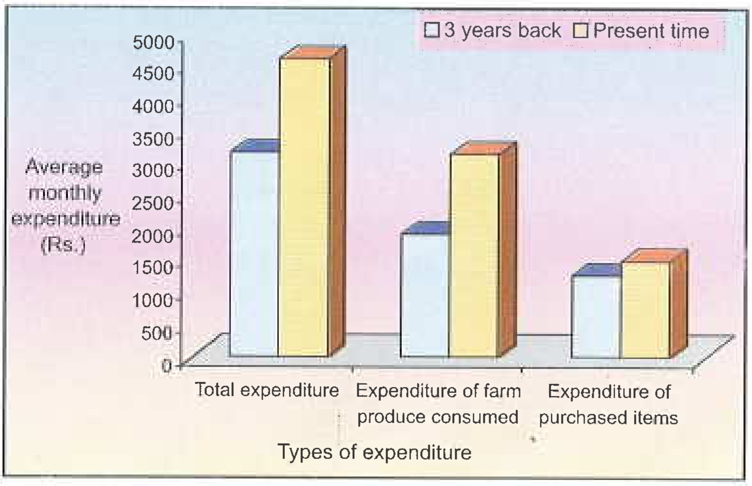

Fig 13. Average monthly household consumption expenditure pattern

and cooking facility. Social assets mainly refer to the recognition, social and political participation, active involvement in developmental works and common properties use pattern. Financial assets are measured on the basis of sources of income, kinds of savings and investments, lending and borrowing. Human assets involve communicational characteristics, education/literacy and mobility. Natural assets are the natural resources holdings of the farm family, *viz.* farm size, irrigated land, livestock holding, poultry and fishpond. All the above-mentioned variables under the 5 types of assets are measured on the basis of the responses of farmers on a 5-point continuum scale during interview schedule survey. Overall standard of living of 8 adopted farmers is assessed on the basis of their assets holding before and after adoption of diversified farming through land modification.

It is evident from the Fig 14 that there is an improvement in all the 5 types of assets of farm families during post-intervention period. Maximum improvement occurred in physical assets followed by human and natural assets that indicated the improvement in living condition, socio-personal profile and natural (farming) resource holding of farm families. The increased income through diversified farming has motivated the farmers to invest and intervene further leading to the growth in physical and natural assets. Improvement in socio-economic condition and social recognition are also reflected which will result in achievement motivation leading to inculcate entrepreneurial abilities of the farmers.

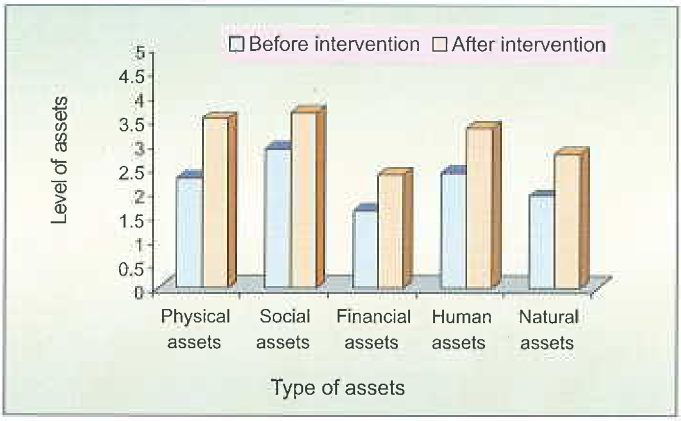

Fig14. Average level of different types of assets of farm families before and after diversified farming through land modification

The changes in overall standard of living of all the 8 farmers are presented in Fig 15. It can be noted that living standard of 6 out of 8 farmers was below average level prior to opting for diversified farming through land topography modification. However, diversified farming has helped in bringing the living standard of farm families above average level. As stated earlier, 4 farmers (farmer 4, 5, 6 and 7 as indicated in the figure) have also engaged in fish farming besides crop diversification through

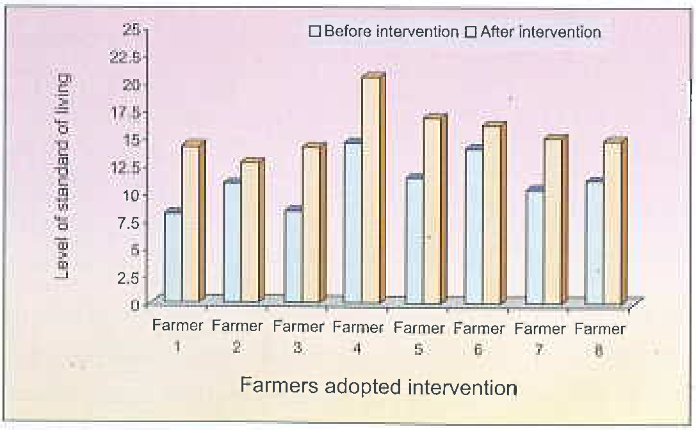

Fig 15. Overall standard of living of selected 8 farmers before and after intervention

raised-sunken bed technique and their standard of living has relatively highly improved.

The potentiality of diversified farming through land topography modification has been realized as it has facilitated the multifarious growth of overall farming system of the adopted farmers. It provides a better earning and living to the small and marginal farmers of the canal commands of high rainfall and shallow water table areas. Rice being the staple food, it is very difficult to bring complete substitution of rice crop. However, the "rice plus" cropping system in sunken and raised bed through land modification can be a potential option for growth and development of farming system and livelihood of small and marginal farmers.

8. CONCLUSION

Practice of raised and sunken bed technique for crop diversification improved productivity of water in lowlands over the conventional system of rice cultivation. For modification of land into alternate raised and sunken beds, Rs 36000/ ha was invested, which was recovered within a period of 1 to 2 years in most of the cases. Growing of rice + fish or colocasia instead of rice alone gave more return in sunken beds. Brinjal- okra, okra-brinjal or tomato-cowpea, pointed gourd+ snake gourd or pointed gourd +bitter gourd, cabbage + snake gourd or pointed gourd +papaya were observed to be remunerative cropping systems for the raised beds. Farmers could rotate different cropping systems to avoid insect and pest attacks or allelopathic effects of any crop. This on-farm research has been an eye-opener to the farmers of the project sites. Several small and marginal farmers in Balipatna block of Khurda district in Orissa have adopted this system and started realising benefits. This system not only increased farm production and income but also generated additional employment opportunity, livelihood options and provided food and nutritional security for poor rural masses. Large scale adoption of this technology could enhance productivity of fresh water resources used for farming on medium and lowlands of the eastern region.

9. REFERENCES

Black CA (Ed) (1965) *Methods of Soil Analysis, Part 1*, Monograph No **9**, Agronomy Series, Madison, Wisconsin, USA.

Ghosh S, Kannan K, Singh Ravender and Kundu D K (2002) Socio-economic profile and cropping pattern in canal command area in Khurda district of Orissa. Indian Journal of Extension Education 38 (1&2): 99-103.

Ghosh S, Singh Ravender and Kundu D K (2005) Evaluation of irrigation-service utility from the perspective of farmers. Water Resources Management 19: 467-482.

International Rice Research Institute, IRRI (1977) Annual Report for 1977. Los Banos, Philippines.

Jackson M L (1973) *Soil Chemical Analysis*, Prentice Hall of India Pvt. Ltd., New Delhi.

Kannan K, Singh Ravender and Kundu D K (2003a) Raised and sunken bed system for crop diversificationin high rain fall areas. Indian J Agric Sci. 73 (8): 453 –455.

Kannan K, Singh Ravender, Kundu D K and Reddy G P(2003b) Fitting Malabar Spinach in rice based cropping system by modifying microenvironment in canal command of eastern region. Environment & Ecology 21 (1): 1 – 3.

Pande H K and Reddy M D (1988) Improving efficiency of irrigation water-use in rice-based cropping system. In Proceeding of National Seminar on Water Management: The Key to Developing Agriculture. (ed. J. S. Kanwar). Agricole Publishing Academy, New Delhi, pp 652 – 82.

Siddiq E A and Kundu D K (1993) *Production strategies for Rice-based Cropping Systems in the Humid Tropics*, pp. 155-162. International Crop Science. Crop Science Society of America, WI 53711, USA

Singh Ravender, Kundu D K and Kannan K (2003a) Crop diversification through land modification in canal irrigation command of Eastern India. SAARC Journal of Agriculture 1(1): 99 – 104. .

Singh Ravender, Kundu D K, Kannan K and Verma H N (2003b) Modification of soil environment for crop diversification in high rainfall area. Paper presented during the National Symposium on Emerging Trends in Agricultural Physics, held at the division of Agricultural Physics, IARI, New Delhi from April 22-24, 2003.

Singh Ravender, Kundu D K, Mohanty R K and Ghosh S (2004a) Crop diversification in canal irrigation commands of high rainfall areas through land configuration. Page 105 *in* Abs. Proc. National Symposium on Recent Advances in Rice-based Farming Systems, held at CRRI, Cuttack on 17 – 19 Nov 2004. Central Rice Research Institute, Cuttack, Orissa 753006, India.

Singh Ravender, Souvik Ghosh, Kundu D K, Kannan K and Verma H N (2004b) Farm-level constrints to efficient use of canal water in coastal Orissa and some technological intervention to enhance crop production. Research Bulletin No. 18, Water Technology Centre for Eastern Region (ICAR), Chandrasekharpur, Bhubaneswar –751023, India.

Tomar S S, Terbe G P, Sharma S K and Tomar V S (1996) Studies on some land management practices for increasing agricultural production in vertisols of Central India. Agricultural Water Management, 30: 91-106.

Honourable DDG (NRM), ICAR visiting one project site and discussing with the farmers about benefits of the raised and sunken bed technology

Kisan Divas organized at one project site