Managing soil and water for enhanced agricultural productivity

Conference Paper · January 2009

Bulletin of the Indian Society of Soil Science, No. 27. pp 0-0 (2009)

Managing Soil and Water for Enhanced Agricultural Productivity

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India is blessed with rich natural resources (soil, water, climate and agro biodiversity) with a geographical area of 329 Mha. Presently it supports 17% of global human population with the share of 2.5% area and 4% water in the world. The one billion population (2001) expected to reach 1.4 billion in 2025 will need 315 million tonnes of food grain with a projected decrease in per capita land availability to 0.08 ha against 0.15 ha in 2000. Soil resource base is also shrinking at 0.25 Mha yr^{-1} due to industrialization and urbanization. Decrease in organic matter, deficiency and toxicity of nutrients, and declining biological activity are other problems. Per capita availability of water projected to be less than 1500 m^3 by 2025 is considered as a big constraint for environment and human population. Out of 400 Mha-m rainfall in this country, 115 Mha-m is lost by run-off, causing moisture stress to crop in uplands and waterlogging in the lowlands. Harvesting of 25% of run-off water in farm ponds, creeks etc, can provide life-saving irrigation to the whole rainfed area of the country. With the availability of diversified natural resources, the farmers of different regions and states have traditionally kept on practicing multiple farming systems as per family needs, land holdings, availability of irrigation water and market demand. This paper deals with soil and water resources; constraints, issues and farming systems in the eastern states of India (Assam, Bihar, Chhattisgarh, Jharkhand, Madhya Pradesh (eastern part), Orissa, Uttar Pradesh (eastern part) and West Bengal of eastern India to attain the high agricultural productivity.

Soil Resources in Eastern India

The state-wise soil resource is described as under:

[1]Central Rainfed Upland Rice Research Station, Hazaribagh, Jharkhand
[2]Regional Rainfed Lowland Rice Research Station, Gerua, Kamrup, Assam
[3]Central Rice Research Institute, Cuttack, Orissa
[4]Indira Gandhi Agricultural University, Raipur, Chhattisgarh
[5]Orissa University of Agriculture and Technology, Bhubaneshwar, Orissa
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Assam

Wide range of climatic conditions, topographic variations and geological conditions and their interaction along with different vegetations have given rise to the formation of soils belonging to 4 orders, 9 suborders, 15 great groups, 26 subgroups and 83 family associations (Sen *et al.* 1997). Inceptisols occupy 41.4% of the area followed by Entisols (33.6%), Alfisols (11.3%) and Ultisols (5.6%). The remaining area is occupied by river bed (6.8%) and marshy lands (1.2%). Sen *et al.* (1999) further described Assam soils under 8 agro-ecological sub-regions.

Constraints

Soil acidity; low inherent fertility; runoff and soil erosion; stoniness; shallow soil depth; low base saturation; Al toxicity and toxicity of some micronutrients; flooding and waterlogging; high P fixation; low water holding capacity; seasonal water deficit; and landslides are major constraints.

Issues

Organic-matter-rich acid soils with low base status are suitable for plantation and horticultural crops. The potential lies in tea and mulberry plantations and raising horticultural crops (pineapple, pears, plum, orange, lemon and banana) with appropriate soil and water conservation practices. In low-lying areas soils are rich in nutrient reserves and paddy, sugarcane, banana, oilseeds, wheat, maize, beans and soybeans can be grown with improved soil, water and crop management practices using proper irrigation and soil amendments. Cultivation of coffee, tea, pineapple, rubber and other crops have scope in uplands because upland soils are rich in humus and are acidic in nature with favourable climate. These crops also tolerate high Al saturation. Upland soils can also be used for the cultivation of sesame, potato, maize, ginger, tapioca and vegetables. On contours, agro-forestry with bamboo, cane, and tall grasses can protect soil and improve available soil nutrient content, pre-requisite for high crop yields.

Bihar

Bihar state is divided into two physiographic regions namely, North Bihar and South Bihar. These regions are endowed with rich alluvial soils, enough ground and surface water (rivers), and favourable climate. South Bihar is better in respect to flooding and water-logging problems. The land distribution, crop sown area, cropping intensity are given in table 1.

With the flow of several rivers (Ganga, Ghaghara, Gandak, Burhi Gandak, Kamala, Balan, Adhawara, Kosi, Mahananda, Sone, Punpun, Paimar, Chandan etc.) across the state, good rainfall and vegetation, the soils of Bihar are divided into

(i) North-west alluvial plain is spreads over 3.26 Mha area. The net sown area in the zone is 2.15 Mha and only 0.86 Mha is under irrigation. The farmers practice sustenance farming. High P fixation in upland soils (0.32 Mha), low nutrient use efficiency due to increasing salinity, zinc and boron deficiency, flooding and water-logging are the major soil-related constraints.

(ii) North-east alluvial plain occupies 2.08 Mha. This zone has 1.21 Mha net sown area and 0.24 Mha is under irrigation. Soils are very poor in N; low to medium in P and K; deficient in Zn and B; and toxic in manganese. Heavy-leaching-created soil acidity and nutritional disorder are responsible for poor seed setting in cereals and pulses.

Table 1. Land distribution in Bihar

S. No.	Land distribution	Area (Mha)
1	Forest land	0.616
2	Barren and uncultivable land	0.437
3	Land under non-agricultural use	1.638
4	Cultivable wastelands	0.046
5	Pasture and grazing lands	0.018
6	Miscellaneous trees and grooves	0.213
7	Other fallow	0.138
8	Current fallow	0.567
9	Net area sown	5.668
10	Total cropped area	7.995
11	Area sown more than once	2.327
12	Cropping intensity	141%

(iii) South Bihar alluvial plain is spread in 4.03 Mha in the south of river Ganga and is further sub-classified into (a) South Bihar alluvial plain- east zone, and (b) South Bihar alluvial plain-west zone. The net sown area is 2.17 Mha, out of which 1.58 Mha (72.7%) is under irrigation. This zone is called the rice bowl of Bihar. Inspite of major area under irrigation, a vast stretch of back water (0.1Mha) known as *Tal* area in Patna, Nalanda, Munger and Bhagalpur districts and 0.18 Mha *Diara* area need special care.

In broad sense, the soils are upland (soils situated at top of the topo-sequence, are light in texture, have poor water holding capacity, and are drought-prone due to surface run-off), medium land (soils where water stagnates up to 25 cm with drainage facilities and good fertility), lowland (most predominant ecology: 40-45% of total rice acreage, where water stagnates up to 50 cm without proper drainage facilities), and deepwater (it constitutes 8-10% of total rice acreage in the state without proper drainage system and is classified (i) shallow deepwater (water depth up to 1 m), (ii) deep water (water depth up to 2 m) and (iii) floating area (water depth goes up to 3 m). The soil of state is very fertile as it is developed by the deposits of river Ganga and its tributaries. Through scientific management of crops, animals, and agro-forestry by timely supply of quality inputs, it can feed half of the country's population. In spite of suitable area available for multiple cropping, a vast area of problem soils (2.074 Mha) in the state needs special care (Table 2).

Table 2. Extent of problem soils in Bihar state

S. No.	Soils	Area (lakh ha)
1	Acid soils	0.02
2	Salt affected soils	3.20
3	*Tal* land soils	1.00
4	*Diara* land soils	9.30
5	Waterlogged soils	4.00
6	*Chaur* soils	1.00
7	Calcareous soils	1.00
8	Eroded soils	0.20
9	High bulk density soils	1.00
	Total	20.74

Issues

After flooding in *kharif* season, bumper crop can be harvested in *rabi* season with timely supply of quality inputs (seeds, fertilizers, insecticides) in north Bihar. Introduction of crop diversification (pulses and vegetables) and soil reclamation; rice-wheat productivity; and soil fertility as well as farm productivity of south Bihar can be improved considerably.

Chhattisgarh

'Land distribution and availability of irrigation are the important determinants of household food security in Chhattisgarh. Agriculture is dominated by rice and accounts for 75% of the annual cropping (3.50 out of 4.8 Mha of the net sown area). Presently, 29% cultivable area is irrigated and rest of the 75% can be irrigated by using ultimate irrigation potential of the state. Based on land features, Chhattisgarh is classified into three agro-climatic regions namely: (i) Chhattisgarh plains, (ii) Bastar plateau, and (iii) Northern hills. The soils of state are broadly classified as Entisols (*Bhata*), Inceptisols (*Matasi*), Alfisols (*Dorsa*) and Vertisols (*Kanhar*). In Bastar plateau, Mollisols are also found. Soils of northern hills are classified as eroded hilly soils, named as *Goda/Tikra* soils, *Goda-chawar* soils, *Chawar* soils and *Bahra* soils. The important characters of major soils are presented in table 3.

Table 3. Important characteristics of the Chhattisgarh soils

S. No.	Characters	Entisols (*Bhata*)	Inceptisols (*Matasi*)	Alfisols (*Dorsa*)	Vertisols (*Kanhar*)
1	Slope	Undulating	Level	Level	Level
2	Colour	Redish-dark to redish brown	Yellow	Brownish grey	Dark grey-brown to black
3	Texture	Gravely coarse loamy to sandy loam	Sandy loam	Silty clay	Clayey
4	Structure	Massive blocky	Angular	Sub-angular to angular blocky	Angular blocky
5	Depth	Very shallow	Moderate	Medium to deep	Deep
6	Internal	Rapid	Moderate	Medium to slow	Slow

Chhattisgarh Plains Zone

It contributes major food grain production of the state and soils of the zone are (i) *Bhata* soils; red in colour, gravely with low water holding capacity and acidic in nature, (ii) unbunded black soils having poor internal drainage and low fertility status, (iii) bunded rice fields (rainfed) situated on little lower terraces and have waterlogged condition, and (iv) rice bunds around the plots are huge for rainwater and soil conservation and these bunds occupy about 8-10% of the rice cultivated area.

Constraints

Bhata soils are prone to high infiltration rate and are acidic in nature; low in organic C, N and P; and are mono-cropped with sesame or kept fallow. Unbunded black soils have poor drainage and are planted in *kharif* with traditional varieties of minor millets (*Kodo-Kutki*) as sole and as an intercrop with pigeonpea and in *rabi* with chickpea, linseed and coriander. Bunded rice fields are poor in soil organic C, water-logged and drought-prone. Traditional rice varieties are grown with *Biasi* operation and the rice field bunds are used for a year or two for growing various upland crops specially pulses and thereafter bunds are left fallow/unused.

Issues

In *Bhata* soils with field bunding for water harvesting, agro-forestry and fruit trees in upper reaches, fodder in middle and arable crops like black gram in the lower parts can be grown. With improved drainage, unbunded black soils can be used for cultivation of soybean, chickpea, pigeonpea, and linseed crops which can improve the soil quality and productivity. Bunded rice fields need green/organic manuring, and recycling of weeds in the soil. The improvement in *Biasi* operation with seedling distribution after *Biasi* may improve the rice productivity. Pigeonpea, fodder crops, Sudan grass and hybrid sorghum are good options for cultivation for animal feed production and better income.

Bastar Plateau

This region has a variety of soils as per landscape. The soils are grouped as (i) *Marhan* soils: poor soil physical conditions, coarse sandy texture, low soil fertility, drought-prone, and mono-cropping are main feature of these soils. (ii) *Tikra* soils: sandy soils are low in fertility, acidic in nature, low water holding capacity, and (iii) *Gabhar* soils; these soils are situated in lower terraces with good soil fertility and water availability.

Constraints

In *Marhan* soils the yields of upland rice, lathyrus and minor millets are very low due to traditional farming with minimum inputs. *Tikra* soils are acidic, low in organic C, N, P and K; and have poor water holding capacity. Waterlogging is major constraint in *Gabhar*.

Issues

For the Bastar plateau agro-forestry, agri-horticulture and silvi-pasture are recommended by Indira Gandhi Krishi Vishwavidyalaya, Raipur. Intercropping, agro-forestry, acidity- loving fruit crops are other options. Growing rice varieties (Mahamaya and Mahsuri), demonstrating paddy-cum-fish culture and vegetable cultivation in summer with water harvested in deep ditches made in the corner of plot may improve the cropping intensity, livelihood of farm families and job opportunities to rural youth.

Northern Hills Zone

This zone has two broad groups of soils namely upland and lowland soils. Inspite of good rainfall main concerns are drought and waterlogging. The soils are classified into

(i) Unbunded uplands (*Goda/Tikra/Dand* lands): These soils are less fertile, red coloured, low in organic C, highly soil erosion-prone, well drained, and shallow.

(ii) Bunded uplands (*Goda/ Chawar* lands): These are sandy loam in texture, poor in fertility; low in water holding capacity and CEC; and are highly P fixing.

(iii) Bunded lowlands: Heavy textured with good water holding capacity and acidic in nature.

(iv) Waterlogged soils: Heavy textured clayey soils.

Constraints

Soils of hill region of Chattisgarh are acidic in nature; prone to leaching; erosion; and nematodes incidence; low in organic C, N, P and K; and highly P-fixing. In lowest part of terrain, waterlogging is extended to winter months and these soils are not suitable for *rabi* crops.

Issues

Crop diversification with supply of quality seeds of vegetables, pulses, rice in *kharif* followed by *toria* and linseed in *rabi*, popularization of agro-forestry, and fruit crops are the best options. Liming of soil is must for all the crops for good harvest. In lower terrace, with available residual moisture, cultivation of rainfed wheat and peas can be popularized. Paddy-cum-fish culture and *boro* rice cultivation are other options. Community involvement may use these lands for perennial ponds for multiple cropping.

Jharkhand

The soils of Jharkhand state are spread in 7.97 Mha area with 2.85 Mha being suitable for agriculture, 2.42 Mha gross cropped, 1.34 Mha under uplands and 1.07 Mha under lowlands. About 90% area is rainfed (2.29 Mha). Soils are predominantly classified under the Alfisols. The landscapes are divided into hilly terrains, undulating plains, plateau and valleys (Sarkar 2002). Hill terrains, which are under forest cover, are not used for agricultural activities. The other three landscapes are used for agricultural activities. Soils of state are sloppy and undulating, deep (100-150 cm), well drained, acidic, fine textured and medium in available water holding capacity in upper terraces; terraced bunded fields are very deep (>150 cm), drained to poorly drained, neutral to slightly acidic, fine loamy texture and have medium to high water holding capacity in lower terraces. The soils are low in organic C, N, and P. In broad sense, soils of Jharkhand state have been classified into two groups (Table 4) as per revenue class namely, *Tanr mitti* (Upland soils) and *Don mitti* (Lowland soils).

Constraints

Poor soil fertility, drought in upland and drought as well as waterlogging in lowlands are the major constraints. The undulating topography causes soil erosion and surface run off of water.

Issues

These lands are used by farming communities for growing paddy, minor millets, maize and pulses. Crop diversification has started in some parts with vegetable crops, especially rainy season tomato. Introduction of horticulture crops, fruit trees and tuber crops are best option in uplands and rice-wheat, rice-mustard, rice-summer vegetables in lowland if water harvesting structures are developed in the lowest part of the topo-sequence.

Table 4. Land classification by revenue class, local class and by hydrology in Jharkhand state

Revenue class (Group)	Sub-group	Local name	Category by Hydrology	Description
Tanr land	*Tanr* III	*Tanr*	Upland	Sloppy and gravelly lands, shallow in depth, low water holding capacity and poor soil fertility. The lands are generally on the upper most topo-sequence of the landscape.
	Tanr II	*Tanr/Gora* land	Upland	Gentle sloppy to sloppy land, adjacent to the vil lage with good soil depth, coarse textured, poor in organic matter, have low water holding capacity, are erosion-prone and acidic in nature.
	Tanr I	*Bari* land	Upland (Kitchen garden land)	Land immediately adjacent to the homestead used for vegetables, maize and growing rice seedlings.
Don land	*Don* III	*Chater/ Chaura/ Badi* (3 number)	Drought-prone shallow lowland	Transitional land between *tanr* and *don* categories moving from shallow to deep soils, have greater bund heights, flat surface, higher water holding capacity, and are suitable for short duration crops.
	Don II	*Tarkha* (2 number)	Favourable shallow lowland	These are the best lands for rice cultivation and follow-up crops. These lands rarely face drought. Major rice production in Jharkhand comes from these lands.
	Don I	*Garha/ Ghoghra* (1 number)	Favourable lowland to medium deep	Lowlands with water accumulation up to 40-50 cm; lowest in topo-sequence and are suitable for long duration rice crop.

Orissa

The soils of Orissa come under 4 orders, 10 sub-orders, 17 great groups and 41 sub-groups. The soils with area under each order are presented in table 5.

Table 5. Soil taxonomic orders and their extent

Orders	Area (Mha)	Per cent of the total geographical area of the state
Inceptisols	7.49	48
Alfisols	5.62	36
Entisols	1.53	10
Vertisols	0.93	6

The soils of Orissa have been broadly classified into 8 groups (Table 6). The characteristics of each group and their production constraints are discussed below.

In Orissa, the red soils occupy 7.14 Mha covering 10 western districts; mixed red and yellow soils occupy 5.5 Mha, being the second highest in area. Black soils are spread in patches covering 0.96 Mha. Lateritic soils occupy 0.70 Mha in the districts of Puri, Khurda, Nayagarh, Cuttack, Dhenkanal, Keonjhar, Mayurbhanja and Sambalpur. The deltaic alluvial soils cover about 0.67 Mha in Balasore, Bhadrak, Kendrapada, Jagatsinghpur, Cuttack, Puri, Ganjam and Gajapati districts. The coastal saline soils occupy an area of about 0.254 Mha in the coastal districts of Balasore, Bhadrak, Jagatsinghpur, Kendrapada, Jajpur, Puri, Khurda and Ganjam. The brown

Table 6. The soil groups in Orissa

S.No.	Nomenclature	Soil groups
1	Red soils	Haplustalfs, Rhodustalfs, Ustorthents
2	Mixed red and yellow soils	Haplustalfs, Paleustalfs
3	Black soil	Chromusterts, Ustorthents
4	Lateritic soils	Haplustalfs, Plinthustalfs, Ochraqualfs
5	Deltaic alluvial soils	Haplaquepts, Fluvaquents, Haplustalfs
6	Coastal saline and alluvial soils	Halaquepts
7	Brown forest soils	Haplustalfs, Rhodustalfs
8	Mixed red and black soils	Association of Alfisols, Vertisols and vertic intergrades

forest soils occupy about 0.17 Mha in the districts of Kalahandi, Nayagarh and Ganjam and the mixed red and black soils occur as intermix of both red and black soils and occupy about 0.16 Mha. Red soils are found in upper ridges whereas black soils exist in the lower topographic situations. These soils are distributed in the districts of Sambalpur, Bargarh, Sonepur and Bolangir.

Constraints

Red soils are lighter in texture; low in organic C, N, P, Ca, Mg, S and B; and are characterized by low CEC and high P-fixation capacity. Mixed red and yellow soils are moderately acidic and low in N and P; whereas lowland soils are slightly acidic and moderate in P and rich in K. Black soils of Orissa have high water holding capacity but low availability of water. The plant suffer from drought even at moderate soil moisture status. Soils are alkaline (pH 7.5–8.0), rich in Ca and K but crops suffer due to P and Zn deficiencies. In lateritic soils, surface crusting is a big constraint in the uplands. The soils are low in organic C, N, P, CEC and base saturation but medium in K. Higher amounts of exchangeable Al impart strong acidity to the soil. Phosphorus fixation is very high. Deltaic alluvial soils are coarse sand to clay in texture, poorly drained, poor to highly fertile, deficient in N and P but medium in K. Coastal saline soils are poor in N and P but rich in K. Boron toxicity is a problem in the saline soils. The soils are rich in Cl^- and $SO_4^{2-}$of sodium. Brown forest soils are rich in N and medium in available K and P. Shifting cultivation in these areas leads to land degradation. Mixed red and black soils are light to medium in texture and neutral in reaction. Black soils are rich in Ca whereas red soils are rich in Fe. Zinc deficiency occurs in rice on medium lands.

Issues

Application of lime @ 20% LR through paper mill sludge, mixture of rock phosphate and SSP (3:1), gypsum (30 kg ha^{-1}) in red soils increases the yields of pulses and oilseeds by 10–25%. In general, red soils respond to application of B and Mo. Winter vegetables, cole crops and groundnut need application of 1-2 kg B ha^{-1}. Crops like rice, finger millet, potato, egg plant, groundnut and fruit crops (mango, jack fruit, guava, and papaya) are successfully grown on mixed red and yellow soils. Upland soils are suitable for rice, millets and vegetables. Lowland soils are suitable for rice followed by pulses as *paira* crop. In black soils, application of organic manure, rice straw, saw dust, molasses, etc. improves the physical condition of soil. Chickpea, sunflower, mustard, cotton and sugarcane can profitably be grown on these soils. In lateritic soils, rice in lowlands suffers from iron toxicity. Liming is the recommended practice for *rabi* crops namely groundnut and pulses. Application of 1 kg B ha^{-1} to vegetables enhances the yield by 20–30%. In the deltaic alluvial soils, rice is the usual crop in *kharif* and groundnut, mustard, potato, pulses, vegetables are successfully grown in the winter season. Growing salt-tolerant rice varieties and chilies in summer are better option for the coastal saline soils. Ginger, turmeric, tapioca, maize, wheat, mustard, niger, minor millets, etc. can be grown well in the brown forest soils. To make the system profitable and sustainable, soils of the highest elevation should be put to forest plantation, medium elevation to horticulture crops and lower topo-sequence to agricultural crops. In the mixed red and black soils, maize, sugarcane, minor millets, groundnut and vegetables are grown successfully with adequate fertilization and proper management.

Uttar Pradesh

The total geographical area of the state is 2,40,930 km^2 with a population of 7,86,32,552 as recorded in the Census of 2001. State is divided into 3 geographical regions: Himalayan region, Gangetic plain and Vindhyan region on the basis of natural resources, biodiversity and geographical diversity. The soils of the state are quite diverse ranging from heavy black clay to sandy loam with diverse fertility status. The information related to soil, water and farming system is exclusively related to eastern U.P, which is most populous, diverse in natural resources and social-cultural indicators. The soils of eastern UP are grouped into *tarai*, alluvial and Vindhyan soils.

Tarai ***Soils***

These soils falling in the north-eastern plain zone (NEPZ) and are spread over 33,174 km^2 in11 districts and occupy 11.3% of the total area of the entire state. The soils of the zone are called *tarai* soils extending from Baharaich to Deoria districts. The recognized soil associations are (1) Gandak recent alluviums-calcium soil with a large reserve of soft lime, (2) Gandak flat leached calcium soils with a layer of nodular $CaCO_3$ accumulation, and (3) Gandak upland-degraded calcium soils which are alluvial in nature. *Tarai* soils consist of sandy loam, clay loam, silty loam, clay, calcareous (*Bhat*) with a diverse fertility status.

Alluvial Soils

These soils falling in eastern plain zone (EPZ) occupy 33,848 km^2 in the Gangetic belt of the districts of Barabanki, Faizabad, Ambedkarnagar, Sultanpur, Pratapgarh, Jaunpur, Azamgarh, Mau, Ballia, Ghazipur, Chandauli, Varanasi and Bhadohi. The soils of this region are alluvial, fertile and similar to NEPZ but sizable area of land is saline and alkaline, which is highly degraded and therefore unfit for agriculture.

Vindhyan Soils

These soils falling under Vindhyan Zone (VZ) are spread in 12,270 km^2 in Mirzapur, Sonebhadra, and parts of Varanasi districts. Soils of this zone have developed on Vindhyan rocks comprising of Vindhyan and Kaimur sandstones, shales, mixed conglomerates, calcareous and haematitic slates, schists, gneiss, carboniferous rocks and to some extent the limestones. Five soil associates have been recognized in this zone and are termed as Vindhyan Types 1 to 5. Vindhyan Types 1 and 2 occupy the uplands, Vindhyan Type 3 lies on flat lands while Vindhyan Types 4 and 5 rest on the lowlands. The major area is hilly terrain (Vindhyan hills), inhabited by the tribal people. The soils are of very diverse nature and textural class of these soils varies from clay to sandy loam with variable fertility status. The area, production and productivity of north eastern plain zone, eastern plain zone and Vindhyan zone are given in table 7.

Constraints

The major constraints in *tarai* soils are flooding, water-logging and micronutrient deficiencies especially those of zinc and iron. In alluvial soils, alkalinity, salt injury and poor fertility are

Table 7. Zone-wise area, production and productivity of major crops in Uttar Pradesh

S. No.	Crop	Area (Mha)	Production (Mt)	Productivity (t ha^{-1})
North eastern plain zone				
1.	Rice	1.32	2.84	6.38
2.	Wheat	1.34	3.53	7.94
3.	Barley	0.01	0.02	6.41
4.	Maize	0.31	0.24	3.51
5.	Sugarcane	0.21	10.99	160.57
6.	Potato	0.03	0.33	55.38
7.	Pea	0.04	0.05	3.76
8.	Chickpea	0.04	0.03	2.48
9.	Rapeseed and mustard	0.07	0.05	2.55
10.	Pigeonpea	0.08	0.06	2.31
Eastern plain zone				
1.	Rice	1.35	3.11	6.90
2.	Wheat	2.08	3.65	7.53
3.	Barley	0.03	0.05	5.66
4.	Maize	0.10	0.11	3.31
5.	Sugarcane	0.03	5.85	133.01
6.	Potato	0.07	1.41	54.91
7.	Pea	0.05	0.05	3.08
8.	Chickpea	0.06	0.06	3.00
9.	Rapeseed and mustard	0.03	0.02	2.21
10.	Pigeonpea	0.07	0.09	4.01
Vindhyan zone				
1.	Rice	0.02	0.51	2.29
2.	Wheat	0.22	0.44	2.02
3.	Chickpea	0.03	0.03	0.90
4.	Pigeonpea	0.03	0.03	3.00
5.	Barley	0.03	0.03	1.18
6.	*Bajra*	0.02	0.03	1.35
7.	Lentil	0.01	0.009	0.71
8.	*Jowar*	0.01	0.009	0.96
9.	Rapeseed and mustard	0.01	0.003	3.72
10.	Pea	0.01	0.009	1.04
11	Potato	0.005	0.10	20.92
12	Sugarcane	0.005	0.15	31.30
13	Groundnut	0.002	0.003	1.17

Source: Uttaranchal and Uttar Pradesh at a Glance, Districtwise Statistical Overview, 2005. Jagran Research Centre, Jagran Building, 2, Sarvodaya Nagar, Kanpur, U.P.

the major problems. The Vindhyan soils are undulating, acidic in nature, low in water retention, less fertile and are shallow in depth and erosion- prone.

Issues

The soils of *tarai* are fertile with high organic matter. Quality inputs (fertilizer, seeds, insecticides, electricity for irrigation) supply may increase production. Application of organic manure (Green manure and FYM) and crop diversification may help in sustaining the soil productivity. In alluvial soils, cereals, vegetables, oilseeds and pulses are grown. Development of salt-tolerant rice and wheat varieties with good management options are the central mandate of this region. Supply of gypsum, pyrites and pressmud for reclamation of sodic soils along with good drainage is needed. Vindhyan soils are undulating, acidic and erosion-prone. Terracing, soil and water conservation and liming are the best options for improving soil and crop productivity.

In broad sense, the soils in eastern UP includes irrigated lands, uplands, lowlands and deepwater lands. Irrigated lands are intensively cultivated and soil health and productivity can be maintained with application of green manure, FYM and animal wastes. The upland soils need liming, organic manuring, soil and water conservation devices for high productivity with crop diversification (vegetables, horticulture crops and agro-forestry). In lowlands, bunds and *levees* should be designed for water management. Developing water storage device (ponds) and demonstrating paddy-cum-fish culture, *boro* rice cultivation are profitable. Integrated farming system approach (livestock, fisheries, goatery, piggery and bee-keeping) may sustain the system. The zone-wise land utilization pattern in eastern UP is presented in table 8.

Table 8. Land use pattern in eastern UP

Land use	Area ('000 ha) in different zones		
	North eastern plain	Eastern plain	Vindhyan
Reported area	53.59	42.64	14.93
Cultural waste	3.16	0.92	0.66
Current fallow	0.09	2.84	0.67
Barren and uncultivable land	2.98	1.16	0.58
Non-agricultural use	1.36	4.96	1.16
Net sown area	6.65	29.02	5.58
Gross cropped area	10.89	44.98	7.98
Gross irrigated area	3.74	28.29	3.79
% gross irrigated area to gross cropped area	34.38	62.90	47.45

West Bengal

West Bengal located in strategic position in eastern India lies between 21°31′ and 27°14′ North latitude and 86°35′ and 89°53′ East longitude. It covers an area of 8.85 Mha. Two-third of total geographical area consists of a flat and gentle undulating alluvial plains, western part consists of upland; extreme north consists of steep hilly area and in extreme south, the tropical mangrove forest Sunder Bans exist. Based on rainfall, temperature, soil variations and topography of land, the state is divided into six agro-climatic zones.

(i) *Hill zone*: It is spread in 0.26 Mha area of Eastern Himalayas with rugged relief, very steep slope at 1000-2000 m altitude. The annual rainfall varies between 2500 and 3500 mm. The major soils of the zone are Entisols, Inceptisols and Mollisols. The soils are acidic, brown forest and gravely sandy loam. The major vegetation of the zone includes tea, pineapple, orange, peach, palm, large cardamum, forest, medicinal plants, maize and vegetables.

(ii) *Tarai zone*: At the foothills of Himalayas, along districts of Darjeeling, Jalpaiguri and Coochbehar, runs a belt of forests; the portion lying west of river Teesta is known as *tarai* zone. It occupies an area of 2.06 Mha and is situated at 130-150 m above mean sea level. The soil orders in this zone are Inceptisols and Entisols and type is sandy loam with low pH values.

(iii) *Old alluvial zone*: This region is centrally located in 1.23 Mha area with gentle slope, and spread around western parts of Murshidabad, eastern parts of Birbhum and Bankura, western parts of Hoogly, central parts of Burdwan and Midnapur and northern parts of Howrah. The soils are formed from the deposits of river Mayurakshi, Ajoy, Damodar, Kangsabati and other rivers originating from eastern part of the Vindhya ranges. The major soil orders are Inceptisols, Alfisols and Entisols with silty loam texture and are mostly neutral in reaction.

(iv) *New alluvial zone*: Non-saline recent alluvial soils are spread in 2.66 Mha in north and eastern parts of river Ganges comprising of Nadia, parts of Malda, West Dinajpur, Murshidabad, Burdwan, Hooghly and 24-Parganas district. This zone is also called Bengal basin. The soil orders are Inceptisols, Entisols, Alfisols and Vertisols with silty clay loam texture and neutral pH.

(v) *Red and laterite zone*: Chotanagpur plateau (granite, gneiss), with an area of 1.98 Mha is spread in parts of Birbhum, Burdwan, Bankura and Midnapur districts and entire Purulia district. The lands are undulating with ridges, low hills and valleys. The soils are acidic and grouped into Alfisols, Inceptisols, Ultisols and Entisols with sandy loam and sandy clay loam texture.

(vi) *Coastal saline zone*: Indo-Gangetic alluvial plain (Bengal basin) and upper and lower delta plain (marshes), are spread in area of 0.68 Mha in southern portions of 24-Parganas, Howrah and Midnapur districts. The soils are grouped into Entisols and Inceptisols with silty clay loam texture. The soil pH ranges from acidic to above neutral and changes with water regime.

Constraints

Hill zone soils are sloppy, prone to soil erosion, have shallow depth, and are acidic in nature; they suffer from Al toxicity, and deficiencies of N, P, K and some of the micronutrients. These soils have low fertilizer use efficiency and are characterized by slow release of N from organic matter. *Tarai* zone soils are highly acidic and suffer from more leaching due to light texture, low P availability, and deficiencies of boron and molybdenum. In old alluvial zone soils, annual flooding is caused by impeded drainage and the river-overflow during rainy season is a major problem. Inherently low in organic matter, these soils are deficient in N, P, K, S and Zn. New alluvial zone is full of basins and proper drainage is extremely difficult. Considerable area is subjected to inundation. Intensive cultivation without proper soil health care leads to soil health deterioration, deficiency of majority of nutrients, and poor soil physical condition with hard pan formation and is a home for the soil-borne pathogens. The new alluvial zone soils are acidic, highly eroded, causing loss in fertility and organic matter. High P fixation, deficiencies of Zn and B, leaching and run-off, shallow soil depth and coarse texture are the major soil-related problems. In the coastal saline soils, salinity/acidity, poor drainage, water-logging, heavy texture, low fertility, specially N, shallow brackish water table, poor irrigation water, and non-availability of quality seed of HYV are major constraints in the coastal saline zone.

Issues

Hill zone soils are rich in organic matter, and therefore these could be put under organic farming. Terrace and contour farming may be practiced with crop diversification for high production and erosion control. *Tarai* soils are suitable for tea, orange, pine apple, rice, jute, tobacco, vegetable cultivation and sal-tree plantation. Locally available lime can be used to correct acidity problems. In old alluvial zone, the introduction of high yielding varieties (HYVs) of rice, jute, wheat, mustard, pulses using balance fertilization, need- based (as per soil type) crop diversification with vegetable cultivation and growing horticulture crops are good options. In new alluvial zone, inclusion of horticultural crops in the cropping system and balanced fertilization with organic manure (green/compost/ FYM) are the best options. New alluvial zone can be better managed by crop diversification with plantation and horticulture crops, and vegetable cultivation. The residue management with proper water control is an other option. In coastal saline zone, conservation of rain-water for growing vegetables is the best option. Improvement of soil health with application of gypsum, organic manure and inorganic fertilizers is the need of hour.

It is emphasized that the soil and crop management technologies and varieties developed by agricultural universities, ICAR institutions and the state departments for sustainable and high productivity of cereals, pulses and oilseeds, fishery need a fresh look. The quality inputs *viz.* seeds, fertilizers, lime, gypsum, press-mud, fingerlings, mushroom span, fruit plant saplings etc are not easily available in the nearby markets/stores, The government should make mandatory to all the dealers/suppliers to keep lime, press-mud, gypsum along with inorganic fertilizers for easy access by the farmers.

Water Resource in Eastern India

Rainfall, a crucial resource for crop production in rainfed areas of eastern India, influences all the farm activities. Amount, distribution pattern and intensity of occurrence of the rainfall vary across location and over time. Singh *et al.* (1999) have classified rainfall pattern in Eastern India in different classes (Table 9).

They have also classified moisture availability periods taking into account the rainfall and potential evapotranspiration (PET). Under rainfed condition, the crop growth period passes under three moisture availability periods. These periods are

Table 9. Rainfall classes in Eastern India

S. No.	Rainfall classes	Rainfall (mm)	S. No.	Rainfall classes	Rainfall (mm)
1	Extremely low	<1000	5	Moderately high	1600-1800
2	Low	1000-1200	6	High	1800-2000
3	Moderately medium	1200-1400	7	Very high	2000-3000
4	Medium	1400-1600	8	Extremely high	>3000

(i) *Moist I*: This period occurs in the beginning of *kharif* season. The PET and temperature are quite high with longer day length, low rainfall and crop canopy (when PET>R>PET/2). Field preparation, direct seeding of upland crops and seedling raising for transplanted rice are done during this period.

(ii) *Moist II*: This is the period of crop mature and harvesting. The crop canopy is quite high; PET becomes low due to lowering of temperature and shortening of day length (when PET>R>PET/2). Crop harvesting and post-harvest operations are done during this period.

(iii) *Humid*: During this period, the rainfall is higher than PET (R>PET). Transplanting, weeding and intercultural operations are done during this period.

The long range rainfall and PET data analysis show that the moisture availability period varies differently in different states in Eastern India (Table 10).

Table 10. Range of moisture availability period in different states of Eastern India

States	Range of moisture availability periods in days		
	Moist I	Humid	Moist II
Assam	21-33	191-205	11-22
Bihar and Jharkhand	12-18	95-139	17-22
Chhattisgarh and Madhya Pradesh	10-16	103-147	12-21
Orissa	12-14	131-165	15-18
Uttar Pradesh	12-18	81-123	17-22
West Bengal	16-28	130-187	13-22

Source: Singh *et al.* (1999)

The rainwater, after touching the soil surface, undergoes different processes, which can be understood using following simple rainwater balance equation proposed by Sastri (2000).

$$R = DSW + RO + D + ET + M$$

where,

R = Rainfall

DSW = Soil water change (from the pre-monsoon dry soil, the soil water reaches field capacity/ saturation point during the rainy season).

RO = Run-off (when the intensity of rainfall is higher than the infiltration rate, the water runs off from that area and reaches rivers through creeks, rivulets and small canal).

D = Deep percolation (after saturation point, the excess water that goes into the soil percolates down and joins the ground water).

ET = Evapotranspiration (water over the bare soil evaporates through the surface. The soil water acts as a transporter and is finally absorbed into the atmosphere through the process of transpiration. Thus, evaporation from the soil and transpiration through the plant occur simultaneously as ET).

M = Metabolic water (a very small portion of the soil moisture which gradually accumulates in the plants as they grow).

Thus, the DSW that is stored in the soil is used for evapo-transpiration and is replenished by the rainfall. Therefore, the ET amount is the only amount needed by the plant for its growth and development. The state-wise water resource and its management practices are discussed in following sections:

Assam

Average rainfall of Assam is 2,263 mm in 144 rainy days. Major amount of rainfall (66 to 85%) is received from June to September. Pre-monsoon rainfall accounts for 20 to 30% and in dry season rainfall is < 1% in December, 2% in January, 4% in February, and 6% in March. The first spell of rainfall with high intensity occurs mostly in April. Assam is rich in surface and ground water resources. The total surface water in state is estimated at 600 billion cubic meters (BCM). About 11% of the geographical area of the state is occupied by surface water bodies. Rivers occupy 56%, *beels* (an oxbow lakes) 28%, and ponds and tanks occupy little over 7% of surface water resources in Assam. Rivers carry rain water and glacier-melted water from upper reaches to valleys. Brahmaputra is a major international river covering a drainage area of 5,80,000 km^2, out of which 33.6% lies in India. Its basin in India is shared maximum by Arunachal Pradesh (41.9%) followed by Assam (36.3%). Average width of Brahmaputra Valley is 86 km of which the river itself often occupies up to 20 km. All along its course, abundant wetlands and swamps are common in the flood plains. About 81% of the total water consumption in Brahmaputra Barak basin is used for irrigation. However, most of the water withdrawn for irrigation is lost through evaporation, deep percolation, lateral flow and runoff. Overall irrigation efficiency of Brahmaputra basin (32%) and annual potential evapo-transpiration of 1144 mm are lowest among the basins of India (Amarsinghe 2004). In addition to surface sources, Assam is rich in ground water with annual replenishable resource of 27.23 BCM yr^{-1}. Net ground water availability for the state is 24.89 BCM yr^{-1} with annual draft of 5.44 BCM yr^{-1}. Thus, the stage of ground water development is estimated at 22%. Tube wells yield ground water @ 27-59 $m^3 hr^{-1}$ in *Bhabar* zone, 80-240 $m^3 hr^{-1}$ in *tarai* zone and 20-50 $m^3 hr^{-1}$ in flood plains of Brahmaputra Valley while in Cachar district it is 50-100 $m^3 hr^{-1}$.

As per estimate of Irrigation Department of Assam, gross irrigation potential (annually irrigable area) for state is assessed at 27 lakh ha. Achieved irrigation potential up to 2003-04 was 11.26 lakh ha out of which 2.10 lakh ha was through major and medium irrigation programmes (surface flow and surface lift) while the remaining 9.16 lakh ha was through minor irrigation (ground water lift). Thus, ground water is the major source of irrigation accounting for 81% of the irrigated area. Irrigation using ground water has higher productivity potential due to controlled release of water. Ground water resource has been utilized mainly through operation of shallow tube-wells with average command area of 2 hectares per shallow tube-well. Shallow tube-wells account for more than 60% of the irrigated area. The achieved potential of 11.26 lakh ha accounts for 27.55% of gross cropped area (40.87 lakh ha), indicating a major chunk of 72.45 % area as rainfed.

Issues

Inspite of enormous water resources, the availability of water does not match with the demand in terms of quantity, quality, time and space. Whereas some river basins/watersheds are water-surplus and under-exploited, others are extremely water-scarce. Erratic distribution of rainfall causes floods and droughts. Ground water is contaminated with high fluoride content in Karbi Anglong district, high iron content in North Bank Plain Zone and arsenic is found in some ground water samples of Karimganj district. In Assam, the cumulative irrigation potential created by the Irrigation Department was 4.95 lakh ha in 1999-2000, out of which the utilization was only 1.19 lakh ha (24.1%). This has decreased over years to 13.1% in 2003-04. The low irrigation potential utilization is due to old cropping patterns, lack of awareness of water use, poor repair and maintenance of irrigation schemes, non-energisation of pump sets, irregular supply of electricity and reluctance of farmers to pay for the water charges.

Bihar

State is quite rich in water resource. The main source of water is rainfall (1000-1400 mm) and rivers *viz.* Ghaghra, Gandak, Burhi Gandak, Kamala, Balan, Adhwara, Kosi Mahananda, Sone, Punpun, Paimar and Chandan flowing from different states and passing through the southern plains. North-west alluvial plains are flood-prone having large surface and ground water, but the gross cropped area under irrigation is only 27%. The exploitation of ground water is very low. Recurrence of floods in large areas and consequent water-logging are major problems in north-east alluvial plains. Irrigation facilities are very poor and the irrigated area is only 21% in the zone. South Bihar alluvial plain has a very good canal and shallow tube wells irrigation net work. Barring *Tal* and *Diara* lands, majority of area is under irrigation (72.7%). The zone faces low water use efficiency in some command areas due to lack of proper technology for the efficient use of irrigation water to check the rise of water table.

Issues

The crop loss due to floods in *kharif* can be compensated by good harvest in *rabi* and *zaid* seasons by exploiting ground water in North Bihar if regular supply of electricity and diesel is assured as majority of farmers have installed the shallow tube wells. In Gandak command area good drainage system should be developed to reduce the effect of salinity. Technologies for efficient use of irrigation water should be demonstrated on large scale in North Bihar.

Chhattisgarh

Major source of water in Chhattisgarh state is rainfall (1200-1600 mm). Estimated surface water flowing through rivers with 75% dependability is 59.90 BCM and due to various geographical and interstate constraints the usable surface water in the state is 41.72 BCM. Currently, only 9.2 BCM surface water is being used. Estimated ground-water in the state is 13.68 BCM and present utilization is 2.79 BCM. With an ultimate aim of achieving 75% irrigation, the state has taken up many important projects and is also expediting many ongoing projects. As per the Water Resource Department’s report 2006-07, Chhattisgarh state has already achieved about 1.771 Mha (30.6%) irrigation potential at the end of March 2007. The major source of irrigation in the state is canals (70%), open wells/tube-wells (18%), tanks (5%) and other sources (7%). The water use efficiency of canal system is less than 30%.

Issues

There is a need of demonstration of on-farm reservoir in different topo-sequences with farmers' participation. Land consolidation in the state should be given priority, which will facilitate in developing community ponds for water harvesting and irrigation.

Jharkhand

The major source of water in Jharkhand is precipitation (1300 mm: based on 50 years average in 90 rainy days) during monsoon months. Major amount of rainfall (80%) occurs from June to September in 60 rainy days. Pre-monsoon rainfall accounts for 7.3% in March-April, 3.8% in January-February and post monsoon rainfall accounts for 6.7% in October-December months. The 10-year mean rainfall of 22 districts is given in table 11.

Table 11. District-wise mean rainfall (10 years mean) in Jharkhand

S.No.	Districts	Rainfall (mm)	S.No.	Districts	Rainfall (mm)
1	Bokaro	1145.3	12	Jamtara	1328.8
2	Chatra	1078.7	13	Kodarma	1125.1
3	Deoghar	1420.7	14	Latehar	1329.9
4	Dhanbad	223.5	15	Lohardaga	1137.4
5	Dumka	1358.5	16	Palamu	1257.1
6	East Singhbhum	1321.6	17	Pakur	1730.1
7	Garhwa	1237.4	18	Ranchi	1388.6
8	Giridih	1095.3	19	Sahebganj	1371.4
9	Godda	1100.2	20	Saraikela	1276.9
10	Gumla	1521.5	21	Simdega	1381.8
11	Hazaribagh	1138.2	22	West Singhbhum	1253.4

The rainwater either accumulates in ponds, reservoirs, check dams, paddy fields or out-flow through the rivers (Swarnrekha, Damodar, Sunkh, South Koel, North Koel, Ganga, Mayurakshi, Barakar and Konar) into the sea. The river systems are spread in 1800 km length. The state is having number of reservoirs for electricity generation and irrigation purposes and total area of reservoirs is 108,001 ha. Under irrigation development programme, number of check dams (20,000 ha) and ponds (29,000 ha) have been constructed. In spite of so much rain water and water resources, only 10% area is under irrigation. The major constraint of non-availability of irrigation water is the run-off loss.

Issues

Construction of small check dams in depressed area, concrete structure across the creeks, ponds along the creeks and open wells of 20 feet diameter can expand the irrigated area many-fold in the state.

Orissa

Precipitation is the main source of water that supports requirements of agriculture, drinking and industry in the state. The average rainfall is 1497 mm out of which 80% is received during monsoon months. The pre-monsoon rainfall contributes 11% as against 12% during post-monsoon period. However, large spatial and temporal variations in precipitation cause drought, flood, and water congestion making crop cultivation during *kharif* an uncertain venture. An analysis of rainfall revealed that there were about 12 to 23 years of drought and equal number of flood years during 1901 to 1975. The frequency of droughts is more in Sambalpur, Sundargarh, Phulbani, and Kalahandi districts. During the period from 1950 to 1973, dry spells for 7–10 days had occurred in six years in September and 10 years in October. The rainfall data from 1977 to 1986 revealed that annual rainfall of the state exhibited a decline of 169.60 mm from the normal 1482.20 mm. The surface water available in the state of Orissa is 95 lakh ha-m and ground water 20 lakh ha-m which can irrigate about 5.9 Mha of cultivated area. On the other hand, out of 6.17 Mha of cultivable land only 2.58 Mha is covered under irrigation but assured irrigation is available only in 1.96 Mha. About 0.47 Mha under minor irrigation provides only supportive life-saving irrigation in *kharif* season depending on the rainfall situation.

The ground water reserve in the state is about 20 lakh ha-m out of which 3 lakh ha-m is used for drinking, industry and other committed uses while 17 lakh ha-m is available for irrigation. But only 10% of ground water is used for agriculture. The quality of ground water in Orissa is good and suitable for drinking as well as for irrigation purposes. Electrical conductivity more than 1.0 dS m^{-1} has been recorded in dug well waters located in coastal districts of Ganjam, Jagatsinghpur, Balasore, Kendrapada and Puri. Flouride concentrations greater than 1.5 mg L^{-1} have been observed in the isolated patches of Khurda, Nuapada and Angul districts. Nitrate concentrations greater than 45 mg L^{-1} have been observed in some pockets of Ganjam, Kalahandi and Bolangir districts. Higher concentration of iron (>1 ppm) have been recorded in the tube wells in the coastal tract and also in iron-ore belt of Keonjhar, Maurbhanj and Sundargarh districts.

Issues

Irrigation being the key input in increasing crop production as well as crop intensification, the state has embarked on a massive drive to create river lift-irrigation systems and also trap the individual and captive irrigation sources like wells, bore wells and open wells.

Uttar Pradesh

The major source of water in the eastern UP is rainfall and water flowing in the perennial rivers due to snow melting in Himalayas. The water is being lifted from different rivers and supplied through canal to the farmers' fields. Underground water is used for irrigation by the farmers by using mechanical devices. In north-eastern plain zone average annual rainfall ranges between 1400 and 1500 mm with small amount received in winter and pre-monsoon months. Rapti, Burhi Rapti, Gandak, Burhi Gandak and Ghaghar rivers are the main source of surface water. Eastern plain zone is full of under-ground water in addition to rainfall. The *rabi* and *zaid* crops are grown using underground water. The average annual rainfall in this zone ranges from 1000 to 1200 mm, and 90% rainfall is received during monsoon months. Failure of rains or less rainfall may create havoc due to low water table in winter and summer months. Vindhyan zone (Mirzapur, Sonebhadra and parts of Chandauli districts) receives lowest annual rainfall (800 mm). The surface run-off loss of water is the major constraint due to sloppy undulating topo-sequence of the hills. The total irrigated area in this zone is 2.42 lakh ha (Table 12).

Table 12. Irrigated area under different sources of irrigation in the eastern U.P.

S. No.	Zones	Area (ha) under different sources of irrigation						
		Canals tube wells	Govt. tube wells	Private tube wells	Other lakes and ponds	Tanks, sources	Other irrigated area	Actual
1.	North eastern plain zone	192325	150231	952143	23084	52217	17672	1432107
2.	Eastern plain zone	544966	147374	1268857	2620	1287	579	1965683
3	Vindhyan zone	150880	28563	43421	8708	3330	6458	241360

Source: Uttaranchal and Uttar Pradesh at a glance, district wise statistical overview, 2005. Published by Jagran Research Centre, Jagran Building, 2 Sarvodaya Nagar, Kanpur

Issues

The ground water exploitation for irrigation by installing shallow and deep tube-wells is a major concern. Most of the village open wells are redundant and have dried up due to intensive use of ground water by tube-wells and even majority of open wells are not getting fully recharged during monsoon months. Similar is the fate of village ponds. Ancestors in every village had dug water ponds/tanks for domestic, animal and agricultural use. These ponds have either got silted with eroded soils or are being filled up slowly and slowly by the farmers for making agricultural use. Scientifically, these ponds were source of recharging of ground water and open wells in the village. The large scale felling of trees is one of the major reasons for occurrence of droughts and low ground water table in the state. Construction of check dams, digging of ponds for recharging the ground water, and sustainable supply of electricity and diesel for operating pumps are the priorities for ensuring higher productivity.

West Bengal

Rainfall and water inflow from many rivers are the major sources of surface and ground water supply in the state. The mean annual rainfall varies from 2500 to 3500 mm in hill, 2100 to 3300 mm in *tarai* and *Teesta* alluvial, 1400 to 1900 mm in old alluvial, 1650 mm in new alluvial, 1200 to 1400 mm in red and lateritic and 1600 to 1900 mm in coastal saline zones. Water received from rainfall either recharges the ground water or runs off through creeks, *nallahs* and rivers in to the sea. The ground water availability is minimum in hilly zones (6,700 ha) followed by coastal saline (11,800 ha), *tarai* (16,400 ha), red and lateritic (76,800 ha), old alluvial (98,000 ha) and new alluvial (162,700 ha) zones. With plenty available surface and ground water, only 5-7, 35-40, 50-60, 60-70, 28-35 and 25-30% area is irrigated in hill, *tarai*, old alluvial, new alluvial, red and lateritic and coastal saline zones, respectively. The major source of irrigation in the state is natural stream in hills; shallow and deep tube-wells in *tarai*; canal, shallow and deep tube-well and lift irrigation in old alluvial; shallow and deep tube-wells and lift irrigation in new alluvial; ponds, canals and shallow and deep tube-wells in red and lateritic; and pond and deep tube-wells in coastal saline regions.

Issues

The water-related problems are different in different zones. In hill zone, aberrations in distribution and volume of rainfall, fast water run-off, water deficit for *kharif* crops at late growth stages and water scarcity for *rabi* crops are the major issues. Water run-off, waterlogging/stagnation, impeded drainage, inadequate hydraulic capacity of silted rivers and reservoirs and water deficit for *kharif* crops at late growth stages and water scarcity for *rabi* crops are problems in *tarai* zone. Old and new alluvial zones face surface run-off, water stagnation, river water intrusion during monsoon, sudden water release from upstream reservoirs, siltation in rivers and reservoirs and water scarcity for winter crops. In new alluvial zone, unscientific/reckless ground water exploitation, water surplus in monsoon and deficit in *rabi* and ground water contamination are additional problems. Red and lateritic zone receives low, erratic, and unevenly distributed rainfall. It suffers from excessive run-off, inadequate storage/collection facilities and water deficit at different stages of crop growth and the coastal saline zone faces non-availability of quality irrigation water. Soil salinity, waterlogging, drainage congestions, intrusion of saline sea water and poor quality of ground water due to excessive withdrawal for irrigation, are major constraints faced by the farmers and other users inhabiting the coastal saline zone.

Rainwater harvesting by constructing check dams/ponds/open wells/percolation tanks at different slopes is the best option. With public partnership, desiltation work of village ponds, reservoirs and canals should be given priority for accumulating more rain water during monsoon months. Irrigation water lifted by energy pumps must be delivered directly in the field using PVC pipes to avoid transportation loss. Farmers should be advised through the well conducted demonstrations to use optimum level of irrigation water for realizing higher crop yields

Management of Rain Water

Recurring droughts and floods are the major constraints limiting the production of farming and cropping systems in the Eastern India. Due to non-availability of water, the farmers use lower amount of production inputs, and grow only a crop in a year. Other constraints are no crop diversification, poor animal health, poverty, hunger, unemployment and out-migration and exploitation of the male population. Water harvesting in the farm ponds at different topo-sequences in Chhattisgarh, Orissa, Jharkhand, parts of Bengal and UP are the future needs. Water storage is done by bunding the fields works only in a normal rainfall year and it does not take account of the rainfall variation. The benefits of these existing rainwater management systems are limited to big farmers. The model developed at IGKV Raipur and depicted in figure 1 may help rainfed farmers to a great extent.

Construction of on-farm reservoirs (OFRs) in series from top to lower level, helps in harvesting excess runoff. Water harvested in OFRs also recharge the ditches, wells and ponds located in the recharge zone. System may help in drought mitigation in *kharif* and growing second crop in *rabi*. The impact of water harvesting model on crop productivity is given in table 13.

About 60% of OFR water was used by gravitational flow and rest 40% by using pumps for irrigation. In addition to good rice crop, mustard and chickpea were also grown using harvested rainwater. The cropping intensity increased from 100 to 170% with the adoption of the OFR approach. Rice-chickpea cropping was found to be beneficial in relation to water use efficiency (Table 14).

Irrigation with rainwater harvest in OFR not only increased the income and profit (Table 15) but also resulted in increased employment (>100 person-day ha^{-1} yr^{-1}); land value; opportunity for

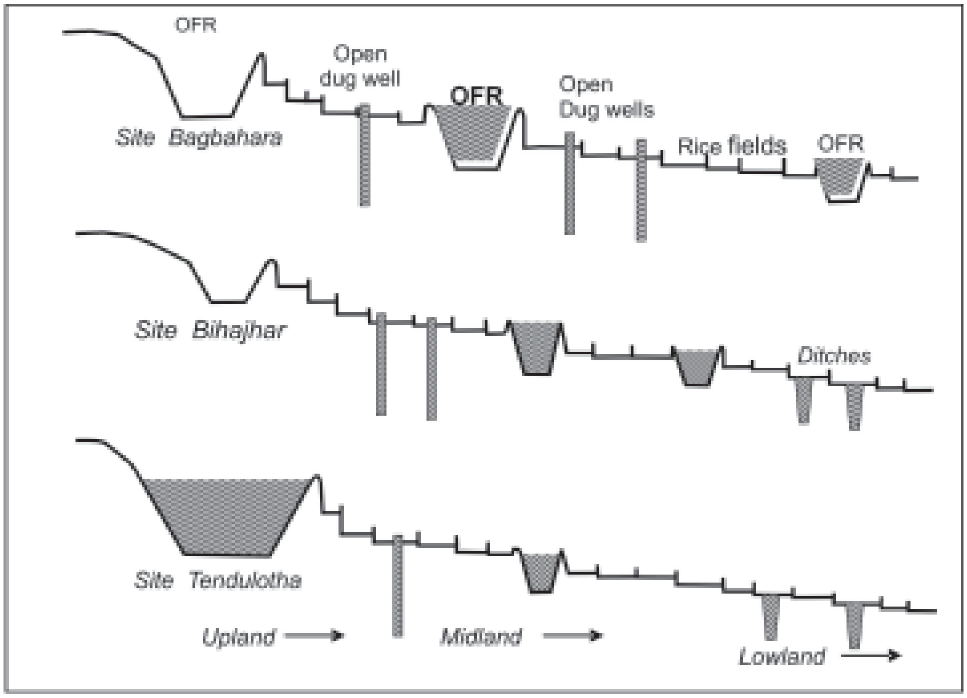

Fig 1. Location-wise on-farm reservoirs (OFR), open dug-wells and ditches at Bagbahara in Chhattisgarh (Adopted from NATP RRPS4)

Table 13. Effect of water harvesting on crop productivity and economic returns from rainfed rice production system

Year	Rainfall (June-Sept) (mm)	Area served by WHS* (ha)		Yield of un-milled rice (t ha^{-1})		Net returns over control ('000 Rs)		Net return to coston WHS(%)		Cropp ingintensity (%)	
		Rice	*Rabi* crops	Without WHS	With WHS	FP	IP	FP	IP	Without WHS	With WHS
2000-01	573	-	-	0.53	-	378	408	70	76	-	
2001-02	1144	39.6	15.4	3.20	5.62	163	567	30	105		
2002-03	452	45.4	11.8	0.24	5.12	391	759	73	141	100	126
2003-04	1359	39.6	15.0	3.04	4.86	163	380	30	70	105	138
Total/Average	40.4	11.6	1.72	5.20	1096	2113	203	392	103	128	

* Water harvesting structure

vegetable cultivation and fish rearing; groundwater recharge; reduced crop failure, soil erosion, siltation and pollution of water bodies; and also regulated stream flow and surface storage.

Most of the villages in Jharkhand are having one or more community ponds (for daily use), creeks, rivers, etc. The case study showed that in village Handio, 16 ponds were constructed along the creek (*Nallah*), flowing from upper topo-sequence (upland) to lowest part covering

Table 14. Crop productivity in watershed command area in Durg, Chahttisgarh

Farm-pond	Grain yield (t ha^{-1})							
	Kharif				*Rabi*			
	Rice		Soybean		Chickpea		Mustard	
	1996-97	1997-98	1996-97	1997-98	1996-97	1997-98	1996-97	1997-98
OFR1	3.43	4.34	-	-	1.11	0.72	-	-
OFR2	3.46	3.84	-	-	1.14	0.68	-	-
OFR3	5.48	4.97	0.65	1.27	1.34	0.74	0.88	0.57
OFP4	3.84	3.66	-	-	0.98	0.69	-	-
OFP5	3.36	3.52	-	-	-	-	-	-

Table 15. Cost-benefit analysis of the farm-ponds

Particulars	Cost and benefit (Rs ha^{-1})	
	With OFR	Traditional rainfed rice without OFR
Cost of cultivation	15,752	6,926
Cost of the system*	20,618	6,926
Gross return	31,601	10,001
Net return	10,982	3,076
Benefit-cost ratio	1.53	

*It includes repayment of principal and interest invested for construction of pond and water lifting device assuming 15 years life in addition to the cost of cultivation

about 5 km distance with the participation of NGO, Government, Central Rainfed Upland Rice Research Station, Hazaribagh and farm families (Fig. 2). The pond was connected with a small inlet with creek for inflow of rainwater flowing in creek during rainy season. These ponds' water is used for bathing, animal care, fish rearing and irrigation. With the construction of ponds along the creek, farm families became self- sufficient in food grain and exporters of vegetables round the year and got animal (fish) protein. Majority of ponds are perennial.

Farm families generally dig the open wells adjacent to the house. If rain fails in the month of September, these wells either dry up or water table goes very deep in the summer months. The farmers are advised to dig the open well with big diameter (20 ft) in the midland (Fig. 3). Open well in midland stored more water due to recharging of the well with seepage water. The farm families are having 37 such open wells charged with seepage water coming from adjacent field. It was recorded that if the water level of the wells goes down due to irrigation, it gets recharged in an hour. These wells have helped the farm families in growing more than two crops in a year.

The Damodar Valley Corporation (DVC) has developed water harvesting device in upland by constructing earthen check dam with catchment area of 266 ha with water storage capacity of 43 ha-m, command area 190 ha with open out spillway (Fig. 4). The available irrigation water changed the cropping systems, cropping intensity, crop diversification, household income, literacy rate and employment. The out-male migration from the villages to the big cities also reduced significantly.

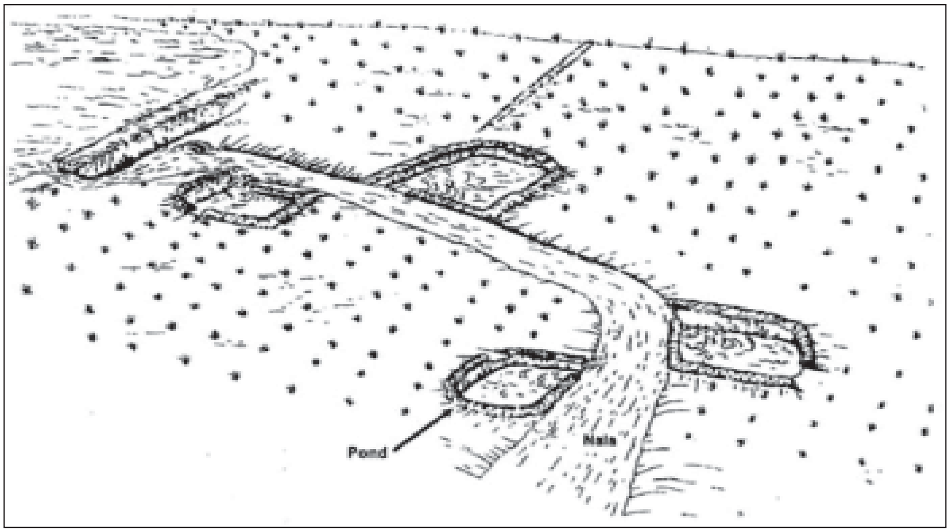

Fig. 2. Ponds along the creek (*Nallah*) (*Source:* Singh and Singh 2000)

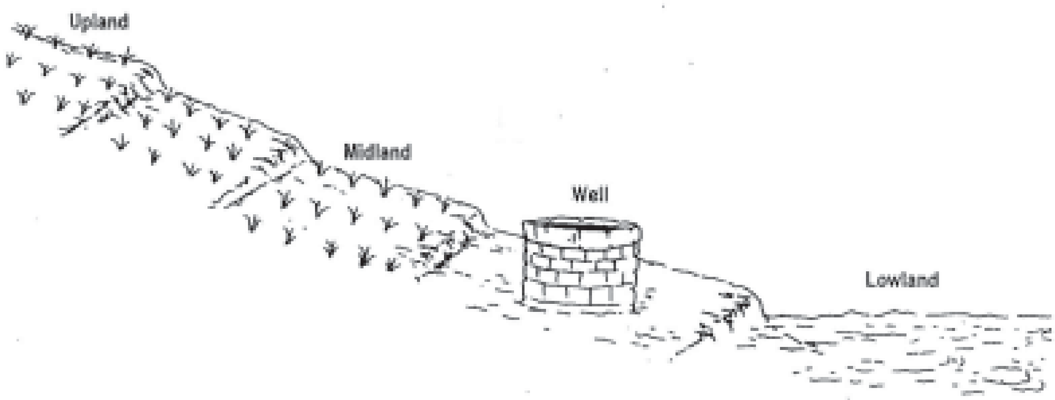

Fig. 3. Positioning open wells in undulated topography (*Source:* Singh and Singh 2000)

Fig.4. The earthen check dam in village Phuphundi, Hazaribagh, Jharkhand, Source: Singh *et al*. (2006)

Concrete Check Dam across the Creeks (Watershed Concept)

Under watershed programme, the Soil Conservation Department, Govt. of Jharkhand has constructed 10 small concrete check dams (Fig.5) across the creeks costing Rs. 1.5 to 2 lakh per check dam. The characteristics of this watershed are given in table 16.

Fig. 5. Concrete check dam across the creek in watershed area, Hazaribagh, Source: Singh *et al.* (2006)

Table 16. Characteristics of watershed developed in Hazaribagh, Jharkhand

Characters	Information
Watershed area (ha)	5,189
Number of households	2,424
Population	18,360
Working population	12,800
Catchments area (ha)	3,860
Command area (ha)	1,275
Direct beneficiary (working population)	10,000
Indirect beneficiary (working population)	2,800

Source: Singh *et al.* (2006)

Rainwater harvested in these check dams remains round the year and is used not only for the irrigation of *rabi* and *zaid* crops but is also used for the social functions in the village.

Impact

Before construction of water harvesting ponds, wells, check dams, the farm families used to cultivate only single crop either rice, or black gram or maize, or horse gram or *niger* or minor millets in upland and only rice in lowland during *kharif* and keep the field fallow in *rabi* and *zaid*. After availability of assured irrigation water, the mono-cropping has given way to multiple cropping systems. The current crops grown are

Upland

- Rice-vegetables: Peas, cauliflower, cabbage, eggplant, coriander, potato, tomato, spinach, carrot, radish, okra)
- Rice/tomato-mustard
- Tomato-vegetables
- Tomato only with staggered planting
- Tomato-wheat-vegetables
- Vegetables-vegetables-vegetables
- Maize-vegetables-vegetables

Lowland

- Rice-wheat
- Rice-tomato-vegetables
- Rice- summer vegetables (tomato, vegetables, cucumbers, beans).

Under rainfed farming, employment opportunity for working population of village was only for 4 months in a year. After rice harvest, the male members out-migrated to big cities, towns and intensive agriculture area (Punjab, Haryana and Western UP) in search of job. The rate of out-migration was more than 60%. With availability of irrigation water, the job opportunities increased to 75.7% compared to 20.2% before and the literacy reached to 38% due to the income generated by intensive agriculture. Presently 4.1% skilled educated working population only is moving out of villages in search of job. The impact of water harvesting is given in table 17.

Table 17. Impact of watershed development on mean yield, job opportunities, food supply and household's income (average of 23 villages) in Hazaribagh district, Jharkhand

Characteristics	Values	Characteristics	Value
Mean production (t ha^{-1}) BWD*	16.4	Migration AWD (%)	4.1
Mean production (t ha^{-1}) AWD**	37.5	Food supply BWD (months)	5
Job opportunities BWD (%)	20.2	Food supply AWD (months)	11.5
Job opportunities AWD (%)	75.7	Household income BWD (Rs $household^{-1}$)	11,800
Migration BWD (%)	54	Household income AWD (Rs $household^{-1}$)	34,700

*BWD: Before watershed development, **AWD: After watershed development
Source: Singh *et al*. (2006).

Integrated Farming Systems

In eastern India farming system is by and large rice-based due to physiographic and climatic condition. Farming system constitutes households, crops and animals. In Assam rice accounts for 67% of gross cropped area and 91% of net cropped area in the state (Pathak *et al*. 2004) and rice alone accounts for 62% of the farm income (Bhowmick and Borthakur 2003). Based on field survey, Bhowmick *et al*. (1999) reported 43 farming systems, but only few are important (Table

18). Farming system activities include field crops, livestock rearing, poultry, sericulture, fruit-vegetable culture and fishery. Livestock and homestead component (*Bari* system in Assam) comprising of plantation crops, fruits, vegetables and allied activities are important for farm family in terms of farm income and employment generation at low capital investment in Assam.

Table 18. Major farming system practices in Assam

Sl. No.	Farming systems	Agro climatic zone in order of importance
1	Crop+dairy cow+poultry	CBVZ, BVZ, LBVZ, NBPZ
2	Crop+dairy cow+goat+poultry+duck	UBVZ, LBVZ, BVZ
3	Crop+dairy cow+goat +duck	LBVZ, NBPZ, CBVZ
4	Crop+dairy cow+pigeon+duck	NBPZ, LBVZ, UBVZ
5	Crop+dairy cow+ poultry+pig	HILLZ, CBVZ, LBVZ
6	Crop+dairy cow+goat +pigeon+duck	NBPZ, LBVZ, CBVZ
7	Crop+dairy cow+fishery	NBPZ, LBVZ, CBVZ
8	Crop+dairy cow+ goat +pigeon	NBPZ
9	Crop+dairy cow+poultry+fishery	NBPZ
10	Crop+dairy cow+ pigeon +fishery+pig	UBVZ
11	Crop+dairy cow+ goat + poultry +pig	HILLZ, UBVZ
12	Crop+dairy cow+ goat + sheep+poultry	BVZ
13	Crop+dairy cow +duck	NBPZ, LBVZ, UBVZ, BVZ
14	Crop+dairy cow	LBVZ, CBVZ, BVZ, NBPZ
15	Crop+dairy cow+duck+fishery	NBPZ, CBVZ, LBVZ
16	Crop+goat+ duck+poulry	UBVZ, CBVZ, LBVZ, NBPZ
17	Crop+goat+ pigeon +fishery	UBVZ, LBVZ, CBVZ, NBPZ

Note: Highlighted agro-climatic zone against a farming system indicates major farming system in the zone.
LBVZ=Lower Brahmaputra Valley Zone comprising Kamrup, Dhubri, Bongaigaon, Kokrajhar, Goalpara, Barpeta, Nalbari districts.
CBVZ=Central Brahmaputra Valley Zone comprising Naogaon and Morigaon districts. UBVZ=Upper Brahmaputra Valley Zone comprising Golaghat, Jorhat, Sibsagar, Dibrugarh and Tinsukia districts.
NBPZ=North Bank Plain Zone comprising Dhemaji, Lakhimpur, Sonitpur and Darrang districts.
BVZ= Barak Valley Zone comprising Karimganj, Cachar and Hailakandi districts

Farmers of Bihar are rearing cows, buffalos, bullocks, goats, pigs, chicks nearby their houses. These animals are used for milk, draft power, meat and income by sale of milk and meat. The by-products of these animals are used as organic manure. Animal+rice-wheat system is a major farming system in south Bihar but farmers in Patna, Gaya and Jahanabad are also following animal+vegetable+vegetable+vegetable system. This system is highly remunerative because of regular flow of income due to easy market access. In North Bihar farm families practice animal+rice-wheat farming system but due to intervention of winter maize, the farmers are also practicing animal+rice-winter maize in a vast area. After rice, tobacco cultivation is very common for high income. *Boro* rice is grown extensively wherever water is available.

Land holdings in Chhattisgarh are less than 1ha and farmers generally practice subsistence farming for continuous, reliable and balanced supply of food and cash for basic needs and recurrent farm expenditure. Farmers traditionally practice diversified farming by growing rice in mid and lowlands and oilseed and pulses in uplands with livestock. Almost every farm has a big herd of livestock, which are not productive, both in terms of draft power and milk yield.

More than 80% farmers belong to small, marginal and medium categories and they rear animals for draft power and for income in the Jharkhand state. They rear bullocks and buffaloes for draft and goats, chickens, ducks, pigeon and pigs for cash and home consumption. The major farming systems are animals + cereal crops + vegetables, animals + cereal crops + vegetables + fisheries, animals + cereal crops + vegetables + pigeon, animals + cereal crops + vegetables + chicks, and animals + cereal crops + vegetables + ducks. The vegetables and birds are main source of income in these farming systems. The majority of tribal families have jackfruit in their orchards in Santhal Pargana Division of Jharkhand. Big farmers have mango and guava orchards which are very remunerative. The one model of farming system interaction in Jharkhand is depicted in figure 6.

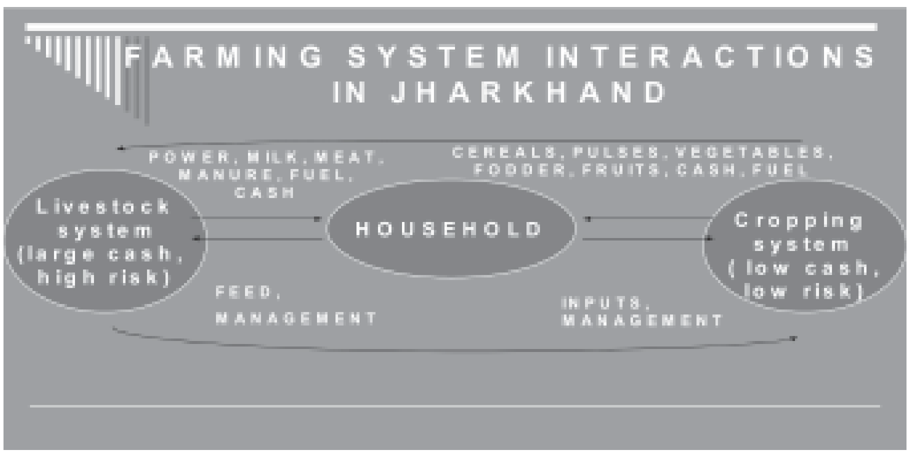

Fig. 6. Integrated farming system in Jharkhand state (*Source:* Singh *et al.* 2004)

Farming system in Orissa is a complex inter-related matrix of soils, plants, and animals and is influenced to varying degrees by economic and social forces at many levels. The farmers are integrating land-based enterprises (crops, animals, poultry and fishery). In West Bengal number of farming systems have been adopted by the farming community as per land situation, rainfall pattern, resource available and land holdings. Few of them are presented in table 19.

Eastern U.P. follows farming systems similar to those in Bihar as farmers mainly depend on rice. Major farming systems include agriculture, horticulture, agro-forestry, livestock, fisheries, poultry, goatery, piggery etc. The location-specific major crops grown are rice, wheat, sugar-cane, pulses, oilseeds and vegetables depending upon soil and water resources, market and transport. Mango, guava and banana are the major horticultural crops. Livestock rearing is common in villages. Dairy industry has not come up on a large scale but individual entrepreneurs rear several buffaloes and cows to sell milk as an alternative source of income. Poultry and fisheries are other important components of farming systems in UP to fulfill the meat requirement. Rearing of goats, sheep and pigs is a common practice in north- eastern plain zone and Vindhyan zone where majority of farmers are marginal and small. Tractors are draft power in plains and *tarai* regions but marginal or small farmers in Vindhyan region are still using bullocks as draft power.

Table19. Major farming systems practiced in West Bengal

Sl. No.	Farming system	Sl. No.	Farming system
1	Crop +dairy cow +poultry	9	Crop +dairy cow + fishery +pig
2	Crop +dairy cow +goat +poultry +duck	10	Crop +dairy cow+goat +poultry +pig
3	Crop +dairy cow +goat +duck	11	Crop+dairy cow+goat +sheep +poultry
4	Crop +dairy cow +duck	12	Crop +dairy cow
5	Crop +dairy cow + poultry +pig	13	Crop +dairy cow +duck+fishery
6	Crop +dairy cow +fishery	14	Crop +goat+ duck + poultry
7	Crop +dairy cow+ goat	15	Crop +goat +fishery
8	Crop +dairy cow +poultry +fishery		

Farming System for Different Land Holdings

In rainfed uplands in Chhattisgarh minor millets, black gram or rice are grown. Cropping systems, rice+pigeonpea and *niger*/vegetable pea-potato-tomato have been found to be economical. Raising small breeds of livestock and poultry is possible with introduction of cereal and grain legume (Singh *et al*., 1993). Income may increase by adopting cotton, black gram, sorghum, cowpeas, fodder, fruit trees (ber, custard apple, and aonla) and goat rearing on dry lands (Senthilvel *et al*. 1998). Water harvested in farm ponds increased the farm productivity, cropping intensity from 100-170% and on-farm employment. Rice-soybean-chickpea-fish and rice-soybean-mustard-fish are the best farming systems in the region (Table 20).

Table 20. Grain yield and economics of rice-fish-based systems with farm-ponds in Durg (1.1 ha farm)

Farming system	Production (q)					Gross return (Rs ha^{-1})	Net return (Rs ha^{-1})
	Rice (0.66 ha)	Soybean (0.33 ha)	Chickpea (0.99 ha)	Mustard (0.99 ha)	Fish (0.15ha)		
Rice-soybean-chickpea-fish	26.2	4.55	9.7	-	3.86	39,815	15,840
Rice-soybean-mustard-fish	26.2	4.55	-	7.25	3.86	39,590	15,620
Traditional rainfed rice system	12.5					6,875	3,080

Source: Rathore *et al*. (2001)

In mid to lowlands, agro-horticulture farming system model was tested in clayey soil at the main campus of IGAU, Raipur in a 1.05 ha with a farm pond by Rathore *et al.* (2002). The soybean and rice were sown in 0.66 and 0.30 ha area, respectively followed by chickpea as a sequence crop (total area 0.96 ha). The *ber* and drumstick were intercropped with soybean in 0.133 ha. The agro-horticulture farming system model produced 1.06 t soybean, 1.22 t rice, 0.06 t chickpea, 0.12 t *ber* and 0.29 t drumstick annually as compared to 1.1 t rice from traditional rainfed farming. The model generated Rs. 19,214 from 1.05 ha area compared to Rs. 1,550 obtained under traditional rice farming.

Farming Systems with Livestock

Only limited area of the Chhattisgarh state is having assured irrigation facilities. Tiwari *et al*. (2001) tested various models for 1.5 ha farm and suggested that crops+2 cows+15 goats+10

Table 21. Effect of mixed farming on income and employment from 1.5 ha irrigated land

Farming systems	Cost (Rs.)	Gross income (Rs.)	Net income (Rs.)	Employment generated (man-days)
Crops	14171	38264	24093	257
Crops+2 cows	34972	72640	37668	374
Crops+2 buffaloes	47257	71545	24288	390
Crops+2 cows+fish	35170	76064	40894	374
Crops+2 buffaloes+fish	47477	74969	27514	390
Crops+2 cows+15 goats+10 poultry birds+10 ducks+ fish	43311	88222	44911	380
Crops+2 buffaloes +15 goats+10 poultry birds+10 ducks+ fish	55596	87127	31531	396

Note: Rice (0.85 ha) + maize (0.25 ha) - wheat (0.85 ha) +pea and mustard (0.25 ha). Green fodder was available round the year in 0.15 ha of maize- cowpea-*jowar*- berseem

poultry birds+10 ducks+ fish model gave about Rs. 45,000 net return and generated 380 man-days employment opportunities (Table 21).

Farming system for landless, marginal and small farmers was evaluated by Ramarao *et al*. (2005). They suggested that by rearing 5 pigs + 10 goats + 10 poultry + 10 ducks, the landless farmer may earn Rs 12,520 yr^{-1} with 61 man-days employment. The marginal farmer with 1.5 acre land holding, can earn Rs. 33,076 yr^{-1} by rearing 2 bullocks + 1 cow + 1 buffalo + 10 goats + 10 poultry + 10 ducks along with crop cultivation, compared to Rs. 7,843 yr^{-1} earned from only crop production. This farming system may generate employment for 316 days in a year.

Ramarao *et al*. (2005) further evaluated six farming system models for marginal and small rainfed farmers for 0.40, 0.80 and 1.0 ha land holdings with only farm pond and farm pond with shallow dug well. The crop cultivation was done in 88% area of the farm. The rice, soybean, pigeonpea, tomato/egg plant/okra, green fodder, marigold and drumstick were grown in 33, 12, 2, 16, 10, 1 and 14% area, respectively. Twelve per cent area of the farm was for pond, shallow dug well and livestock shed. In 0.4 ha farming system model, average crop production increased to 125% and net return Rs 11,350-38,322, in 0.8 ha model by 127% and net return Rs. 24,390-72,206 and in 1.0 ha model by 137% and net return Rs. 35,689-74,238 compared to traditional rice farming (Table 22).

Study further confirmed that in lowland situation a marginal farmer can earn Rs. 11,755 yr^{-1} in 0.4 ha area in rice-poultry-fish-mushroom integration than that of Rs. 6,334 yr^{-1} following traditional farming. With integration of dairy, poultry, fishery, mushroom, biogas, etc. in 1.25 ha area, a net return of Rs. 58,367 was earned with investment of Rs. 49,286, employment for 573 man-days and resource use efficiency of Rs. 2.18 per rupee invested.

In Orissa, the water is available up to April after rainy season in lowlands. Paddy-cum-fish culture study revealed that in addition to good paddy harvest, farmers may harvest fish (1.86 t ha^{-1} 180 $days^{-1}$), with additional water available in refuge for irrigating *rabi* rice, pumpkin, green gram, and black gram. The cropping intensity may also increase from 100 to 200%. Papaya and banana are also grown in embankment of the refuges. The dikes of paddy-cum-fish farm can be utilized for fruit trees planting. Patro *et al*. (1999) suggested that by adopting fish-rice-duck/poultry-vegetable, fish-cow/pig-duck/poultry-vegetable and rice-poultry-duckery-fish-apiary-mush-

Table 22. Profit and employment opportunities from farming system models developed for small land holdings

Enterprises	Cost of cultivation (Rs)		Net return (Rs)		Employment (man-days)	
	2005-06	2006-07	2005-06	2006-07	2005-06	2006-07
			0.4 ha model			
A	5,436	4,571	11,996	9,202	84	89
B	0	16,975	0	29,120	0	118
Total (A+B)	5,436	21,546	11,996	38,322	84	207
C	2,342	2,400	2,338	2,800	60	65
D	230	900	510	1370	140	320
			0.8 ha model			
A	12,818	11,017	26,090	18,820	189	181
B	0	27,800		34,785	0	142
Total (A+B)	12,818	38,817	26,090	53,605	189	323
C	6,685	5,800	2,675	4,600	120	95
D	190	670	980	1170	160	340
			1.0 ha model			
A	20,104	16,070	41,972	31,036	268	287
B	0	29,395		42,600	0	142
Total (A+B)	20,104	45,465	41,972	73,636	268	429
C	8,356	7,250	3,344	5,750	153	135
D	240	630	1260	1280	180	320

A: Cereals, oilseeds, vegetables, fodder, flower and drum stick; B: Cow (milk), goat (meat) and fish; C: Traditional rice farming; D: Relative increase over traditional farming

room in waterlogged area in eastern India, the farmers may earn net profit of Rs. 12,038 yr^{-1} compared to Rs. 3,450 yr^{-1} following conventional cropping system: rice-rice-pulses/maize.

In Bihar vast area under *Tal, Diara, Chaur* and waterlogged conditions may be diverted for the cultivation of fish, *makhana*, *singhara*, *tinni* rice, vegetables and fruit crops on dikes. This system will not only provide more earning to the farming community, but also help them to compensate for the loss due to frequent floods occurring in the region.

In Assam, short season droughts are common after flash floods and harvested water in rice-fish system comes to the rescue. After the harvest of *kharif* rice, the harvested water in pond refuge trenches and sometimes on rice field is useful for *boro* rice and winter vegetables in Assam, Bihar, Orissa and West Bengal,. The results from 0.5 ha site at Gerua revealed that supplemental irrigation of 250 mm on 19 February and 9 March 2003 could suffice the residual water (16 cm) from *kharif* rice and rainfall during the *boro* season and the irrigation requirement was reduced by 84%. However, during *boro* 2003-04, the residual water from *kharif* rice was less due to the differential rainfall pattern. In this situation, the irrigation requirement was 500 mm and it was 33% of the requirement for a normal irrigated *boro* rice crop. Under integrated farming system, planned multistoried cropping in homesteads with arecanut, coconut, banana, lemon, pineapple, papaya, guava, and *aonla*, will add to the income. In this system tree species should not be spreading-type and root growth should be mainly vertically-oriented. Twining climber like black pepper on coconut or arecanut and hanging of climbing vegetables over fishponds are examples of intensification in space. In addition to intensification in space, wastes of poultry and duckery sheds are utilized as fish feed when hanged over fishponds. Existing land space in each homestead and pond should be made more productive by growing fodder, fruits, fish, fowls, ducks etc. Piggery and goatery are options for willing farmers. Improvement in milch cows, feed and fodder components in crop enterprise is required for animal-based farming systems. Ponds and tanks in homesteads as well as community village ponds need renovation and desiltation to accommodate small scale fish farming in addition to its role as source of water. Fish-pig, fish-duck and fish-fruits are profitable. Fish-pig enterprise yielded 6,000-7,000 kg fish and 3,000-5,600 kg pig from one hectare using 30-40 pigs (Pathak et al. 2004). Results of integrated rice-fish farming system model at Gerua (Assam) revealed that gross annual income during the period from 2002-03 to 2005-2006 ranged between Rs 62,948 to Rs 92,828 ha^{-1} with employment generation of 700 man-days. Gross income from sole rice cropping was Rs 25,000 to 30, 000 ha^{-1} with employment generation of 100 man-days.

Summary

Water-soil-farming system-related problems in eastern India and their specific management strategies are need of the hour to produce more grains, meat, milk, fodder and fruits, to meet the demand of growing population of country. The conservation of natural resource base for sustainable crop and livestock production and high productivity is the most important strategy for agricultural development. Protection of soil, conserving rain water, and developing natural ecosystem like swamps, *beels*, *tal*, *diara*-lands, *chaur* land, waterlogged areas should be given priority.

Integrated water and nutrient management should go hand in hand. Eastern India has tremendous ground water potential of shallow tube and deep tube wells. More shallow tube wells can be installed to utilize available natural water source with few problems in Assam, Bihar, West Bengal and Eastern UP. Integrated use of surface and ground water resources is the necessary for sustainable high production-oriented agriculture. The inherent problems of government departments can be overcome through public-private partnership. Water User Associations (for example Pani Panchayat in Orissa) should be formed to take care of these problems. Maintenance of government irrigation schemes and supply of regular electricity should be ensured. Entrusting the maintenance work to water user associations may be one option to overcome the inherent problems of government departments.

Our studies showed that there is a need of sincere efforts at all the levels to refine the existing farming systems in the village with integration of models developed by scientific institutions. The input supply is an other major constraint. The modalities should be developed with the participation of policy makers, scientists and farmers for smooth supply of quality seeds, fertilizers, lime, gypsum, pyrites, electricity and diesel at nearest point from where the farmers can purchase easily.

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