CONSERVATION OF NATURAL RESOURCES FOR SUSTAINABLE HILL AGRICULTURE

1. Natural Resources and its Importance

1.1 Hill Agriculture in North East India: Status and Option for Sustainable Development

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The North East India comprising of eight states namely Assam, Arunachal Pradesh, Meghalaya, Manipur, Mizoram, Nagaland, Sikkim and Tripura has a total geographical area of 262180 km^2 which is about 8 per cent of the country's total area with a population of about 40 million. The Net sown area is highest in Assam (34.12per cent) where plains accounts for 84.44per cent of its total geographical area followed by Tripura (23.48per cent) while Arunachal Pradesh has lowest net sown area (2.06per cent). The cropping intensity is around 118per cent, highest in Tripura (160per cent) followed by Manipur (152per cent). About 1.67 million ha area is under shifting cultivation (*jhum* cultivation). Out of 4 million ha net sown area of the region about 1.3 million ha suffer serious soil degradation problem.

The region receives an annual average rainfall of 2000 mm accounting for about 10per cent (42.5 mham) of the countries total precipitation of 420 mham. The soil of the region is acidic to strongly acidic in reaction accounting 70 per cent of the total geographical area. Low soil pH is basically due to leaching of the bases under the influence of high rainfall. The aluminium toxicity in upland and iron toxicity in the valley are prevalent. Soils are rich in organic matter. Forest cover in the region is 14.2 million ha which is about 54.16per cent of total geographical area which is higher than the national average (19.39per cent). By and large, the region is characterized by fragility, marginality, inaccessibility, cultural heterogeneity, ethnicity and rich in biodiversity. Rural population (82per cent) is agrarian and depends on agriculture and allied sector for livelihood in the absence of industries, except in the state of Assam. Around 56per cent of the area is under low altitude, 33per cent mid altitude and 11per cent under high altitude. The agricultural production system is characterized by and large CDR (Complex diverse risk prone) type, low cropping intensity, subsistence farming, undulating topography and faulty land use pattern with an annual loss of soil of 46 t/ha. Fertilizer consumption in the region is only about 12 kg/ha and chemical pesticides use is also meager (0.14 g/ha). Only 0.88 mhm water is used out of 42.5 mhm and rest is lost as run-off. The food grain requirement for the region is about 7.6 million ton against the present production of about 5.96 mt. Thus the region has a food grain deficit of about 1.6 mt. Judicious utilization and conservation of natural resources is the approach in the faming system concurrent policy and research back up to increase production, add value to the produce and market management.

Rice, maize and potato are the main crop of this region and rice based cropping system is common with the exception of Sikkim, where maize based cropping system is predominant. But the yield is very low. The most efficient cropping systems identified for different area in the region are potato-rice, rice-rice, maize-ragi, maize-mustard, maize-sunflower, maize+French bean-mustard. The groundnut, which is a recent introduction in the North East region, has proved potential and can be a good substitute of uneconomical upland rice and maize or it can be grown as intercrop with r ice and maize for higher productivity and return (Panwar *et. al.,* 2003). Munda *et. al*., (1999) reported that maize (green cob)–groundnut–mustard was the most profitable cropping system in mid altitude of Meghalaya followed by French bean (Green pod) - French bean (Grain).

Strength of the Region

A. One of the 12-mega biodiversity hot spot areas

B. Abundant natural resources

➢ Geographical area	26.45 (million ha)
➢ Forest	17.11 (million ha)
➢ Agricultural land	3.91 (million ha)
➢ Rivers	19976 km
➢ Indigenous crop germplasm	3000 nos.
➢ Orchids	1600 (175 rare spp.)
➢ Medicinal plants	119 Species belonging to 09 genera
➢ Aromatic plants	05 genera
➢ Livestock population	22.62 million
➢ Poultry	28.32 million
➢ Fish germplasms including ornamental	247 fish species

- Diverse Agro-climatic conditions
    1. Alpine Zone (>3500 m)
    2. Temperate Sub-Alpine (1500-3500 m)
    3. Sub tropical Hill Zone (1000-1500 m)
    4. Sub Tropical Plain Zone: (800-1000 m)
    5. Mild Tropical Hill Zone: (200-800 m)
    6. Mild Tropical Plain Zone: (0-200 m)
- The quality rice (*joha* rice of Assam, purple rice of Manipur etc.), fruits (Pine apple of Tripura, passion fruit of Nagaland and Mizoram etc.) and spices (Ginger, turmeric, cardamom, king chilli etc.) of the region has good national and international demand.

Weakness

1. Over exploitation of forest for fuel, timber and fodder
2. Shifting cultivation on hill slopes
3. Inaccessibility, marginality and fragility
4. Improper land use practices
5. Poor infrastructural development
6. Inadequate agricultural mechanization
7. Absence of storage and agro-processing facility
8. Shortage of quality seeds
9. Lack of policy frame work for Channelisation of supply and value chain

Opportunities

1. Development of agro-ecological zone specific farming system
2. Opportunities to increase the production by 3-4 folds under valley ecosystem
3. Opportunity for extensive organic farming under upland ecosystem
4. Mechanization of hill agriculture for increasing agricultural production
5. Rain water conservation and management
6. Agroforestry intervention particularly in classified wastelands

7. Opportunity for giving a meat revolution
8. Conservation and utilization of bioresources
9. Horticultural development including apiculture
10. Value addition and export market tapping
11. ITKs for validation and utilization

Threats

1. Danger of extinction of valuable bio-resources
2. Larger areas being barren/degraded due to shifting cultivation
3. Gradual replacement of ecosystem people by ecological refugees
4. Danger of loosing biodiversity due to germplasm piracy on account of international boundaries

Where the Region Stands

The production and requirement of food grains, horticultural crops, meat and fish are presented in the Table 1-4. The deficit in food grain is about 13per cent, whereas, in fruit and vegetable the deficit is 72.5 and 60.3 per cent respectively. Similarly, the deficit in meat and fish sector are 49.7 and 55.3 per cent respectively.

Table 1. Projected food grain production and requirement in North Eastern Region

State	CGR	Production (000 ha)			Requirement (000 ha)		
		2005	2015	2025	2005	2015	2025
Arunachal Pradesh	1.3	217	246	280	220	276	348
Assam	2.58	4733	6105	7876	5234	6214	7377
Manipur	1.96	416	505	613	486	630	817
Meghalaya	1.19	215	243	273	469	608	787
Mizoram	10.37	138	-	-	157	-	-
Nagaland	6.57	381	720	1360	443	720	1169
Tripura	2.25	584	730	911	620	717	829
North East India	-	6546	8549	11315	7473	9165	11326

Source: Vision 2025, ICAR Research Complex for NEH Region, Umiam, Meghalaya, India

Table 2. Agricultural Production (Food grain as in 2005)

Area (m ha)	Production million tones) projected	Yield (kg/ha)	Requirement (million tones) projected	Deficit (per cent)
3.90	6.5	1509	7.5	13

Sources: Vision 2025 of ICAR Research Complex for NEH Region, Umiam, Meghalaya, India

Table 3. Horticultural Crops

Sector	Area (m ha)	Production (mil t)	Yield (t/ha)	Requirement (mil t)	Deficit (per cent)
Fruits	3.40	3.03	8.65	11.01	72.5

Veg.	4.95	6.02	11.98	15.16	60.3
Spices	0.69	0.44	1.57		
Plantation crops	1.15	0.10			

Source: National Horticulture Board

Table 4. Animal Husbandry and Fishery

Sectors	Production (million tones) projected	Requirement (million tones) projected	Deficit (per cent)
Meat	0.22	0.439	49.70
Milk	1.06	2.14	50.50
Egg (million no.)	902.09	7027.21	87.20
Fish	0.21	0.38	55.30

Sources: Vision 2025, ICAR Research Complex for NEH Region, Umiam, Meghalaya, India

Irrigation Status

Agriculture in the region is by and large rainfed. Currently, the area under irrigation is 832 thousand ha., which is about 22.6per cent of the total irrigation potential. Considering the net sown area, Manipur has the maximum area under irrigation (46.4per cent), followed by Nagaland (20.8per cent), Tripura (18.2per cent), whereas in other states it varies from 10 to 38.3per cent (Table 5).

Table 5. Irrigation status of different NE states

States	Irrigation potential (000ha)	Net irrigated area (000ha)	Irrigated area (per cent)
Arunachal Pradesh	266	31	20.8
Assam	2670	572	21.1
Manipur	240	65	46.4
Meghalaya	120	46	20.8
Mizoram	80	8	12.3
Nagaland	90	59	31.0
Tripura	215	51	18.2
All India	3681	832	-

Source: Sharma and Datta, (2006).

Indigenous Farming System of North Eastern India

Shifting Cultivation

Shifting cultivation is still prevalent in north east. In 1983, the Task Force on shifting Cultivation estimated the total area was 1.47 m ha and 0.44 m tribal families were engaged under this system. The Task Force reported jhum cycle of 2-10 years in Assam to 5-9 years in Tripura. Of late (1999) Forest Survey of India estimated the cumulative area of 1.73 m ha affected by shifting cultivation and maximum area affected was reported in Nagaland, Mizoram and Manipur. Sikkim doesn't have area under shifting cultivations and terraced cultivation with permanent agriculture is prevalent. The productivity of jhum land is very low (0.87 t/ha) especially where the jhum cycle is shorter (2-3 years). For higher productivity of jhum, improved practices like proper soil and water conservation measures, improved agro-techniques viz., improved variety, proper land use systems through integrated farming system and agroforestry intervention technologies, planting across the slope etc. and models of watershed based farming systems should be adopted. The ICAR Research Complex for NEH Region, Umiam, Meghalaya, India has developed 8 models of farming systems involving components to check soil erosion and rain water conservation. National Watershed Development project on Rainfed Areas and Watershed Development in shifting cultivated Areas were launched during VII - VIII five yearly plan for seven North eastern states.

Bun system of cultivation

This system of cultivation is practiced mainly in the state of Meghalaya. Under this system, the crops are grown on a series of raised beds locally referred to as "Bun" formed along the slope of the hills. The phytomass is collected on the raised beds along with the soil and burning follows after exposing and drying over a period in dry season. The "Bun" system is more hazardous than the typical slash-and-burn system from soil erosion point of view. Presently most of the farmers grow crops consecutively for two years in Bun field. In first year, generally tuber crops like ginger, turmeric, potato, sweet potato etc. and vegetables followed by upland paddy are grown. Then the Bun field is left abandoned for three to five years for natural soil fertility build-up and regeneration of vegetation. Abundance of broad-leaf vegetations in an area serves an indicator for the local farmers for good fertility status of the land. The Bun cultivation cycle was reduced to three to five years from earlier eight to ten years. The reduction in Bun cycle does not allow the soil to recoup its fertility to its potential resulting in continuous decline in productivity, increase in puts, and enhancing the rate of soil degradation and surface run off. Case studies revealed that for every tonne of potato produce through the system, the soil loss is 2 tonnes (Singh and Singh, 1981). It has been observed that as the time advances the horizontal spacing between the two raised beds (Buns) goes on increasing due to dearth of soil and the land is abandoned when soil is almost exhausted and even grasses fail to grow some times exposing the bed rocks (Borthankur, 1992). The entire Shillong plateau has been denuded by this method of cultivation.

Rice-fish system of Apatani plateau

It is a multi-purpose water management system, which integrates land, water and farming system by protecting soil erosion, conserving water for irrigation and paddy-cum-fish culture (Sarangi and De, 2005). It has been practiced in a flat land of about 30 km^2 located at an altitude of about 1,525 meter msl. In the humid tropic climate of Lower Subansiri district of Arunachal Pradesh. Local tribe "Apatani" which develop this system dominates the area; every stream rising from the hill is trapped soon after it emerges from forest, canalized at the rim of valley and diverted by network of primary, secondary and tertiary channels. The water into the plots is drawn from irrigation channel and has a check gate made of bamboo splits (huburs) at the inlet for regulation of entry and exit of water through the outlet. The farmers drain off the water from the rice fields twice, once during flowering and finally at maturity. For fish culture, a vertical pit is dug in the middle of the plot, so that the water remains in these pits even when it drains away from the surrounding fields. To prevent trashes of migration of fish, a semi circular wooden/bamboo net is installed at the inlet to reduce beating action of flowing water regulating in soil erosion; wooden strikes of planks are put at the outlet. The huburs are installed about 15 cm to 25 cm above the bed level. The water from terraces in finally drained into the river, which flows in the middle of valley.

In Manipur and Nagaland Paddy-cum-fish culture is practiced in terraced fields where a small pond is dug in the middle or corner for harvesting of fish during the harvest of paddy. Two crops of fish and one crop of paddy is commonly taken conserving water throughout the year. Technology intervention of Common Carp found most suitable in the higher altitudes grown with improved rice varieties. In the system, Grass carp is another competent fish commonly grown with rice as pre-*kharif* crop in the plain of Manipur.

Bamboo drip irrigation system

Water application on hill slopes for irrigation of plantation crops poses a serious problem of soil erosion. The tribal farmers in Muktapur, Jaintia hills district of Meghalaya have developed the indigenous technique of bamboo drip irrigation. Betel vines planted with arecanut as the supporting tree are irrigated with this system, in which water trickles or drips drop at the base of crop. In this system, water from the natural streams located at higher elevation is conveyed with the use of bamboo channels, supports to the site of plantation through gravity flow. Discharge of water up to 25 liters/min can be easily managed by manipulating the distribution system.

Alder based agriculture in Nagaland

In some pockets of Nagaland the farmers use *Alnus nepalensi*s (Alder) tree for agriculture. In this system the Alder seedlings are planted on the sloppy land intended for cultivation and the alder grows fast till attain six to ten years old. At this stage initially the trees are pollarded, the leaves and twigs are burnt and ash is mixed with soil to prepare it for raising crops. Subsequently also pollarding is done once every four to six years. Under this process coppice are cut except five to six on top of the main trunk and crop schedule is followed including fallow period of two to four years. The bigger branches stripped of leaves are used for five wood, while the root of the tree develop nodules (colonies of Frankia) responsible for fertility improvement where as spreading nature of the roots helps in preventing soil erosion in slopes.

ZABO system

"Zabo" is an indigenous farming system of Nagaland. The word "Zabo" means impounding of water. It has a combination of forest, agriculture and animal husbandry with well-founded soil and water conservation base. It has protected forest land towards the top of hill, water harvesting tanks in the middle and cattle yard and paddy fields for storage for the crops as well as for irrigation during the crop period. Special techniques for seepage control in the paddy plots are followed. Paddy husk is used on shoulder bunds and puddling is done thoroughly.

Improved resource management practices

Integrated Farming System Approach

Farming system requires integrated or holistic approach in sustaining productivity of hill agriculture. In natural resource conservation different topo-sequential cropping involving Agri-horti-silvi- pastoral system was found to be most economical with effective soil and water conservation measures in the northeast. It is also possible to integrate different components of ecosystem (land, water, plant species etc) to obtain sustained production from waste, rainfed and degraded lands to check natural hazards like floods, drought and soil erosion. Special attention is required in selecting a proper site according to slope, plant species and management of agri-horti-silvipastoral system in respect of land capability, water harvesting and cultural practices. Some of the potential farming systems of the region are discussed below:

Agro-pastoral based land use

The system was adopted on hill slope up to 50per cent with bench terrace, and contour bunding as major soil conservation measures. Land development under the system may cost about 400 - 500 man days / ha. Selection of the crop should be based on farmer's choice as well as market potentials, Hilltops should be kept under forest (fuel-cum-fodder trees, bamboo and timber trees etc.) Based on the existing farming system, agroclimatic and soil condition, the cropping are visualized are: Rice based cropping system (Rice-mustard / potato / radish): oil seed based cropping system etc. Cultivation of crops in topo-sequences is useful on hill slopes. As per topo-sequence, rice is taken in the bottom and cassava, buckwheat etc. grown at the upper terrace. Maize is grown next to rice. Dairy cow can be effectively integrated with crop production on terraced hill slopes for sustainable agriculture under the system. By product of crops and fodder raised on bunds and terrace raisers occupying about 30per cent of land provide scope for subsidiary sources of income through animal husbandry. Among perennial grasses and legumes-*Setaria sphacelata*, thin napier, Guinea and *Stylosanthes* were found good for terrace risers. Management of forage crops on the terrace risers is important. These grasses should not be allowed to grow more than 50 to 60 cm tall to avoid any shade effect on food crop. The deficit green fodder during winter can be mat by feeding leaves of broom grass and crops residues produced in the watershed. In *situ* generation of farmyard manure from livestock refuse, weeds and non-edible crops residues can be effectively utilized under integrated nutrient management to reduce the chemical fertilizer requirement (Verma *et. al.,* 2001). Analysis of sustainability and livelihood potential showed that the system incorporate the classical organic recycling and non competitive inputs, arresting nutrient in rainwater flow by growing forage crops on the terrace rises, negligible soil erosion and converting in a chain all biomass in the watershed into economic outputs (Singh *et. al.,* 1996).

Agri-horti-silvi-pastoral land use

The systems comprise agricultural land use towards the foot-hills, horticulture in the mid portion of the hill and silvi-pastoral crops in top portion of hill slopes. Contour bunds, bench terrace, half moon terrace, grassed ways are the major conservation measures. Such land uses are expected to retain over 70-90 per cent of the annual rainfall with negligible soil erosion. This is the ideal system suited to steep hill slop. Variety of agricultural, horticultural and silvi-pastoral crops mentioned in the three systems can be grown in this system. Choice of crops will vary according to altitudes. The fodder from terrace risers, horticultural portion and silvi-pastoral unit can sustain a unit of 10 goats with reproduction efficiency of 170per cent and the pigs can meet part of their nutrient requirement through succulent grasses, grains, sweet potato and radish produced in the watershed. This is an integrated system capable of providing full time and effective employment to a farm family.

Based on the studies that have been made so far a ICAR Research Complex for NEH Region, Meghalaya, India, mixed land use with agri-horti-silvi-pastoral system with appropriate topo sequence has been found to be one of the most sustainable means to provide an alternative farming system to replace jhumming. For non arable lands like B-1 class lands suitable for pasture and fodder crops, livestock enterprises like goat rearing, milch cows etc. are to be taken up with pasture grasses like guinea grasses, congo-signal, broom grass etc. In the foothill, crops like maize, groundnut, ginger, rice bean, sweet potato in *kharif* season and mustard, radish, pea and turnip in *rabi* season can be grown. In the middle portion horticultural plants mandarin, guava, Assam lemon and pineapple have been planted on contour bunds.

A model on micro watershed based namely Agri-Horti-Silvi Pastoral System established on 1.58 ha land. The area under planned land use is 1.03 ha and remaining 0.55 ha is under forest. The soil was clay loam having 41.77per cent slopes, comes under VIIe land capability classification. The system comprises agricultural land use towards the foot hills (0.20 ha land), horticultural in the middle portion (0.29 ha land) and silvi pastoral crops on the tops of the hills (0.44 ha land). The distribution of the area was on the basis of water requirement, soil condition, depth of the soil and slope of the land. Conservation measures namely bench terraces at 1.0 m vertical and stilling basin (small water pools) and contour bunds in the middle and upper portion for horticultural and silvi-pastoral crops, respectively, was used. The land in the foothills developed by bench terracing and contour bunding at one m vertical interval. The crops like maize, groundnut, ginger, rice bean and sweet potato in *kharif* season and toria, radish, pea and turnip in *rabi* season were grown and found most suitable at 1000 m altitude. Guava performs better as compared to mandarin and Assam lemon. Guava starts fruiting two and half years after planting. Pineapple planted in interspecies. After 7 years of planting, size of fruits become smaller as compared to previous years in the system as a ratoon crops. Guava reached its full bearing stage after 7 years planting and covered 90per cent of the area followed by Assam lemon. The growth of the orange was slow, 25per cent plants start flowering after 7 years but no fruiting. The average productivity of guava after 8 years was 36.7 kg / tree, Assam lemon 48.3 nos./tree. After 11 years of planting average number of fruit / tree of orange and Assam lemon was 83.4 and 40.5 respectively showed good performances.

Alder (*Alnus nepalensis)* as a silvi component and broom grass as herbaceous (pastoral) component showed better compatibility and growth performance. Broom as a pastoral component produced 17.5 q fresh and 7.72 q/ha dry weight of spikes. Leaves of broom grass were sufficient to feed a unit of 10 goats during lean winter month. Bench terracing, contour bunds, stilling basin and grassed waterways developed with the use of local resources was satisfactory, retaining 97per cent of the annual rainfall within the system. A unit of 10 goats and 05 pigs were maintained on grasses (broom grasses produced in the silvi-pastoral and guinea grasses in the horticulture portion and on the terrace rises of the agriculture portion), crop byproduct and radish and sweet potato produced in the system. The Khasi local pigs attained a growth rate of 138/day, F1 hybrid (cross of local and Hampshire) 252g/day and F2 (cross of local and Hampshire) 176 g/day. F1 hybrid was most economical breed in 12 month of feeding. Land up to 100per cent hill slopes with soil depth greater than 1m can be used for this mixed land use system for the farmers living in remote areas and requiring all the basic needs.

Table 6. Economic of micro watershed based land use system

Land use	Input (Rs./ha)	Output (Rs./ha)	Profit (Rs./ha)	Ratio
Dairy farming	34,107	65,688	31,581	1.93
Agropastoral	33,938	64,787	30,849	1.91
Agri-horti-silvipasture	33,015	68,118	35,103	2.06
Silvi-horti system	15,345	18,588	3,243	1.21

Sources: Annual Report, ICAR Research Complex for NEH Region 2007.

Promising and suitable fodder crops are identified on the basis of sustained yield fodder, fast coverage, adaptability in soil condition and palatability amongst different species of livestock are classified into different groups. Forages form the major portion of feed of cattle during June to September, which is replaced with shrubs, herbs and other tree leaves during lean season. There is apparent indication of tropical predominance grasses and other types of forages of annual and perennial types for feeding to different categories of livestock. Some improved perennial grasses have an excellent production potential in the region. Promising variety of improved perennial grasses have an excellent production potential in the region .Promising varieties of improved perennial grasses such as Setaria, congosignal, guinea and broom for pasture development to economize milk, beef and chevon production. Besides these, stylosanthes and groundnut fodder variety are promising perennial legumes. Their yield performances however, reduced during winter season due to moisture stress and cold. Rice bean, cowpea, soybean performed well and suitable annual legumes for low medium and high altitutde up to 1500 msl. Navaro, Parari, Exbucklandia and Mulberry have been found suitable fodder tree for feeding to rabbit, goat and dairy animals (Sahoo *et. al.,* 2001). The majority of tree leaf fodder are high in crude protein and desirably low to medium in crude fibre content. It has an important role in feeding during lean season when availability of grasses is scanty.

A fodder block at 32per cent slopes on hills has been developed in a watershed under dairy/small ruminant based farming system. The area under terrace was put under annual fodder cultivation of maize, rice bean and soybean in *kharif* and oat in *rabi.* The risers and bunds were put under perennial grasses like Sectaria (*S. sphacelata*), Guinea (*Penicum maximum*) var. Hamil, Makunia, Hybrid NB-37 and Congosignal (*Brachieria* rosenensis) etc. that contain better DCP (7.5-8.5 per cent) and TDN (60-65 per cent) than native pasture and yielded more than 20 t/ha DM. The Broom grass was planted on the top area of watershed to fulfill the green fodder requirement during lean season. The Pararii (*Schefflera wallichiana*) fodder trees were also planted on the boundary lines of the watershed for feeding to small ruminant during lean season. The palatability of broom and parari leaves in goats is good and can be meet the maintenances nutrient requirement during lean season. The ruminants were fed on with produced perennial grasses during rainy season however, broom and fodder tree leaves were offered winter season along with concentrate feed. Total 40 t (25 t for rainy and 15 t for winter) fodder will be required for feeding to 30 goats in a year.

Intensive Integrated Farming System

Intensive Integrated Farming System (IIFS) is based on the principle that ‘there is no waste’ and ‘waste is only a misplaced resource which can become a valuable material for another product’. Here as many number of component possible are integrated to utilize the available resources effective. It is generally considered relevant to benefit small and marginal farmers. All the components of the agriculture like crop-livestock-fishery-horticulture are integrated in complimentary mode. Soil and water conservation measures are also given due importance in IIFS. Thus IIFS may provide the environmentally sustainable and economically viable technology that encompasses rational utilization rather than maximization of individual element in the system. Considering the importance, IIFS were developed to achieve food and nutritional security at household level. The energy output: input ranged from 1.38 to 1.83 in IIFS compared to 1.23 in control where no integration was done. Amongst various IIFS, chicken-crop-fish-duck-horticulture showed highest energy output: input ratio (1.83) followed by crop-fish-poultry – multipurpose trees (MPTS). The monetary input reveled that crop-fish-mushroomvermicompost-horticulture had maximum input followed by chicken- crop- fish-duck-horticulture.

Organic farming

In view of increasing consumption of fertilizers and insecticides and its deteriorating effect on soil productivity and soil/animals/human health, the concept of organic farming is gaining importance throughout the world. In most of the Eastern states fertilizer consumption is less than 12 kg/ha (excluding Manipur and Tripura), which accounts for roughly 15per cent of the area of the country. Firstly, the use of inorganic fertilizers and chemicals are meager in the region. The farmers of the region, in general and hill farmers in particulars are having apathy towards use of agro-chemicals. Secondly, the fruits of green revolution could not benefit the farmer of the hills as the system of production in the hills remained low input-low risk-low yield technology based and the average yield of most of the crop remained far behind the national average. It is assumed that the differences in production gap due to adoption of organic agriculture is expected to be negligible; rather there is scope for enhancing productivity with good organic management and the organic premiums would boost earning of he hill farmers. Thirdly, it is an added advantage that all the households are maintaining livestocks (pig, poultry, cattle, goats, etc.), producing sufficient quantity of on-farm manures, which could be efficiently used for organic agriculture. Moreover, the eastern states being the one of the mega-biodiversity rich in plant biomass viz., weeds, shrubs, herbs and forest litters. Most of these species could be efficiently used in organic production. The region as a whole having a potential of 46 mt of manure, which almost equivalent to the requirement for organic production in identified areas (Bujarbaruah, 2004). Vermicomposting, green manuring, growing of leguminous hedge row species viz., *Crotolaria, Feringia* sp. in the bunds, farm fences and terrace/risers, recycling the pruned biomass in to the filed improves soil and health and productivity.

In-situ residue management

The land locked narrow valley lands are generally rich in organic matter and nutrient contents are they receive a lot of run off from surrounding hillocks, which bring a considerable amount of nutrient to the field. The local farmers grow rice without any external nutrient application or in some rare cases very low quantity of organic manure is used once is 3-4 years times. Crop residues like rice straw etc. which contain a good amount of essential nutrient are either removed for selling as fodder for cattle or burnt in the field. Effective management of residues, roots, stubbles and weed biomass can have a beneficial effect on soil fertility through addition of organic matter, plant nutrient and improvement in soil condition. Incorporating of crop residues not only improved the crop yield but also increased the nutrient uptake besides improving the physico-chemical and biological properties of the soil which provide better soil environment for growth and development. In a study at ICAR Research Complex for NEH Region, Umiam, Meghalaya, India, after harvesting lowland rice, five vegetable crops viz. tomato (*Lycopersicon esculentum* Mill), potato (*Solanum tuberosum* L.), French bean (*Phaseolus vulgaris*), cabbage (*Brassica oleracea* L var. *capitata*) and carrot (*Daucas carota* L.) were recommendable to be grown during pre-*kharif* season on temporary raised beds. Among the five cropping sequences, rice-tomato gave highest rice equivalent yield (214.40 q/ha) followed by rice- carrot (206.4 q/ha). Highest net return (Rs. 66,635/ha) was recorded in rice-potato sequences. Weed biomass production in different sequences ranged from 37.5 q/ha with rice-tomato to as high as 50.6 q/ha in case of rice–fallow. Soil fertility in terms of available NPK status was found stable in all the crop sequences except rice-cabbage, where fertility status declined slightly. The soil biological properties like population of *Rhizobium*, bacteria, phosphorus solubilizing microorganism and earthworm activity all were found remarkably higher in experimental field compared to other adjacent plots that are managed inorganically. It was concluded that vegetables like tomato, carrot, potato etc. could be profitably grown after *kharif* rice, if residues are managed effectively under temporary raised beds without deteriorating soil fertility.

Alley cropping/Hedge row intercropping

It is a type of intercropping where arable crops are grown in between the alleys (interspace) formed by the two hedge rows or leguminous shrub rows. It is also called as hedge row intercropping. Depending upon the slopes, plant species involved, the alley width may vary from 2-5 m. In north east India, legumionous shrubs like *Crotolaria, Tephrossia, Casia, Acacia, Cajanus cajan, Flemingia, Indigofera spp.* etc. are suitable as alley crop or hedge row crop. Ginger, turmeric, maize etc are grown in between the alley (Plate 1). The alley height is generally maintained at about 1 m by pruning periodically and the pruned biomass is either used as mulch or incorporated in to the soil as a source of nutrients. Intercropping in interspaces of hedgerow is a proven and sustainable technology for the NEH Region. The hedgerow grown in the contours helps in developing natural terrace in few years time. The green biomass (leaf, twigs etc.) of such hedge row species are very rich in essential nutrients especially N, P and K. The nutrient content of some important hedge row species are given in Table 7. This system of cultivation reduces erosion and conserves soil moisture and nutrients. On an average, pruning of N fixing hedgerow species added 20-80, 3-4 and 8-38 kg/ha/year of N, P and K, respectively. Addition of leaf biomass from hedge row species resulted a significant improvement in fertility status of soil (Laxminarayan *et. al*., 2006).

Plate 1. Maize grown in between *Tephrosia* hedge rows

Table 7. Production of total pruned biomass and nutrient content in different hedge-row species

Hedge species	Total pruned biomass (per cent)	Nutrient concentration in green biomass (per cent)		
		N	P	K
C. cajan	8.94	3.29	0.67	1.43
C. tetragona	19.55	3.47	0.48	1.63
D. rensonii	7.06	3.63	0.48	1.56
F. macrophylla	4.70	3.23	0.45	1.26
I. tinctoria	12.02	3.83	0.81	1.63
T. candiada	10.86	3.57	0.32	1.67

Source: Bhatt and Bujarbaruah (2005)

The similar concept has been also tested under lowland condition for in-situ biomass generation for soil fertility management and to reduce dependence on external inputs like fertilizer. Hedge row species like *Tephrossia spp, Cjananus cajan* etc were grown on the alternate raised bunds in low land rice field. A good amount of biomass has been generated to supplement nutrient requirement of rice crops.

Conservation tillage system

Conventional tillage leaves no land unploughed and leaves no residues in the field**.** On contrast, **c**onservation tillage disturbs the soil to the minimum extent necessary and leaves up to 30per cent residues on the soil. Zero tillage, minimum tillage and stubble mulch tillage are the components of conservation tillage. Conservation tillage can reduce soil loss by 50per cent and conserves soil moisture to a great extent. Zero tillage consists of one pass operation which places seed and fertilizer into an undisturbed seedbed, packs the furrow and retains adequate surface residues to prevent soil erosion. It involves planting seeds into soil that hasn't been tilled after the harvest of the previous crop. The crop germinates on residual water left by the previous crop, saving up to a million liters of water per hectare. Zero tilled crops were sown by hand dibbler. In case of pea crop, which has been taken as succeeding crop followed by rice, better crop performance found under 75per cent rice stalk retention as compared to 50per cent rice stalk retention and complete removal of rice crop.

Zero-tillage technology can produce higher yields, reduce production costs up to ten percent, save on diesel for tractors, and the fertility and structure of the soil are improved. The zero tillage not only favourably moderates the soil rhizosphere and produces higher grain yield in long term aspect but also improves the water economy during dry periods by permitting downward movement of water across the root boundary. Thus this technology may provide greater opportunity for low cost crop cultivation through better management practices for sustaining crop production in the hilly eco-system.

Watershed approach

Watershed as a tool for soil and water conservation measures as well as for socioeconomic development of community is already a widely accepted fact. ICAR Research Complex for NEH Region, Umiam, Meghalaya has adopted 18 watershed in different states of the NEH Region. To mention a few successful watershed are Mawlangkhar watershed, West Khasi Hills, Meghalaya, Mawpun, Ri-Bhoi, Meghalaya, Jalukie, Nagaland. Through these watershed, the Institute has taken the important technologies develop by the Institute in the farmers field. The components of these watershed includes, socio-economic survey for analysis of resources status, water harvesting structure, construction of bench and half moon terrace along with other agronomic measures for soil and water conservation, introduction of HYV crops, introduction of fruit/vegetable, introduction of improved milch cow, pigs and rabbits, poultry and duckery unit, composite fish culture, small processing units, training on crop production and animals husbandry etc.

Jalkund-a micro rainwater harvesting structure

The *Jalkund* (a rainwater harvesting structure in India) technology was developed at the ICAR Research farm, Umiam and validated at farmers filed. The steps for making *Jalkund* are a 5 x 4 x 1.5m pit, leveling the sides and corner of *Jalkund*, smothered of walls *Jalkund* by plastering with mixture of clay and cow dung in the ratio of 5:1, cushioning of *Jalkund* with dry pine leaf/hardy grass etc. @ 2 to 3 kg/m^2 and finally laying out LDPE Agrifilm (250μ) for covering the *Jalkund*. The stored water stored should be covered to avoid the evaporation loss of water particularly during off season (November to March.). Covering of *Jalkund* with thatch (5-8 cm thick) made of locally available bamboo and grasses reduces about 75 to 80 per cent evaporation loss of water. The use of neem oil @ 10 ml Jalkund over water surface after each weekly watering is also effective to minimize the evaporation loss of the water. 111 such Eastern Hills part of India provided to farmer in four states (Meghalaya, Manipur, Nagaland and Tripura). Some farmers are growing high value crops like strawberry at stored water. Most of the farmers at the upper ridges are using stored water for livestock components. Farmers at high hills, used barbed wire to fence the *Jalkund* and using the water for Livestock, vegetables production as well as for domestic purposes. The feedback from farmers' field indicated that the water stored in a *Jalkund* is sufficient for irrigating 200 tomato plants, rear 5 piglets, two ducks or 50 poultry birds during the dry season of November to March.

Land configuration for increasing cropping intensity

In North East India due to very high rainfall the proper drainage is a problem especially during rainy season. Many a time crop plants suffer from poor drainage leading to crop failure. The hill and mountain topography of the region further aggravates the situation. The excess water from such topography comes down as runoff and creates temporary floods in valleys. Even in winter season the water table in valley foot hills remain high mainly because of seepage from surrounding hillocks and uplands. Therefore especially in lowland after *kharif* (rainy) season rice, it practically becomes impossible to take a second crop. However, experiment conducted at the ICAR Research Complex for NEH Region, Umiam, Meghalaya proved that simply by adopting proper land configuration, it is possible to take a second crop. Depending upon the type of soil, amount of water logging, resources available with the farmer and crops to be grown various types of configuration have been developed. The configuration may be permanent or temporary as per farmer's wishes and labour cost. In permanent raised and sunken beds, the raised area is used for cultivation of vegetables and other remunerative crops, whereas sunken area is used for double cropping of rice. The land utilization is 100per cent in these systems. For temporary system, after harvesting *kharif* rice, temporary raised beds are constructed to cultivate vegetables. This system is suitable for the area where marshy soil depth/waterlogged soil depth is less. The width of raised bed may be 3 m and the drainage/sunken bed may be 1m. In temporary system the sunken area is not used for cultivation. The wastage of land is therefore range from 25 to 50 per cent. The soil from sunken area in this system is used for raising the height of raised area by cutting and filling method. Under mid altitude condition of Meghalaya it was possible to achieve 300per cent cropping intensity on raised beds (tomato/potato/frenchbean/carrot–Bhindi–Frenchbean/black gram) and 200per cent cropping intensity on sunken beds (rice transplanted–rice ratoon/lentil/pea).

SRI -an alternative method of rice cultivation

In India, SRI technology started picking up. States like Andhra Pradesh; Tamil Nadu has done a good progress in this technology. Even in North East India also a lot of works are undertaken in SRI and ICM. In Tripura on an average about 20per cent higher yield are obtained from SRI compared to conventional practice. The state has covered about 15per cent of its area under SRI. These practices can improve rice productivity by 15-20 per cent over conventional practices. In Garo Hills, Meghalaya also similar results were obtained. Under mid hills condition of Meghalaya, SRI and ICM gives 10- 20per cent higher productivity compared to conventional practices. The significant aspect of these practices is that the crop duration gets shortened by about 10-15 days. However, since the region falls under high rainfall zone, no systematic study on water economy is yet undertaken.

Issues and Strategies

Amelioration of environmental constraints

- Liming**:** 33 per cent of the area (1.33 m ha) per year liming to double the productivity per hectare. Soil health card
- Softwares indicating soil status
- Integrated nutrient management including minor elements: packages to counter low availability of Zn and P.
- Management of aluminium toxicity in upland and iron toxicity in lowland: tolerant varieties to such soil conditions.

Natural resource conservation

- Organic food production in shifting cultivated areas polarizing adoption of soil and water conservation in the form of farming system models: suitable varieties of rice, maize and pulses and adopting farming system models
- Regional sensitization programme: Regional sensitization programme on land tenure system

Food and environmental security

- One million tons deficiency in rice can be compensated by increasing productivity from 1.8 t/ha to 2.2 t/ha with the adoption of altitude specific varieties, double cropping, irrigation and appropriate packages of practices.
- Breeder seed production to facilitate seed availability. Varieties for shifting cultivated areas to achieve yield of 1.5 t/ha from present level of 0.87 t/ha.
- Maize as cereal crop for human and animal (QPM) and horizontal expansion under maize.
- Diversification with other cereal and pulse crops e.g. wheat, rice bean, ***rajma***, letil, pigeonpea, urd bean, pea etc. and provision of irrigation covering 2.0 lakh hectares per year.
- Bioresource- inventorization and utilization through sharing informations, data base for future use and protection of IPR, integrated resource management for medicinal aromatic plants, ornamental plants, bioparks.
- 50 per cent of jhum lands under organic agriculture
- Managing the effect of global worming/climate change.
- Harnessing the benefit of plant-animal and fish biotechnology.
- Validating ITKs in agriculture and allied sectors.

Horticulture development

- Fruit development: Replacement by high yielding varieties, quality planting materials, technology mission post harvest processing and value addition, marketing through IT data base data base development.

- Vegetable sector development: Target of 15 t/ha from present level of about 11t/ha
  Spices development: Gingerer and turmeric having processing qualities and production maximization.

Animal sciences and fisheries development

- Backyard cross bred pig and improved poultry birds, artificial insemination technology, local resource based feed formulation, health aspects etc.

Common issues

- Intensive Integrated Farming system (IIFS)
- Water harvesting structures
- Soil health rejuvenation
- Precision farming
- Post harvest handling
- Sanitary and phyto-sanitary issues
- Strengthening women in agriculture.
- ICT in agriculture

Prospects of Crops Production in Eastern Region of India

- Higher productivity and self-sufficiency as well as economy of the farmers of the Eastern Region of India can be attained by the adoption of modern technology and ideal land use system.
- Double cropping of rice including ratooning of pre-*kharif* rice and other crops is possible in low valley land with adequate minor irrigation development.
- High yield potential crops like groundnut, soybean, sunflower, arhar, urd bean etc. could be substituted unproductive upland rice.
- Viable, sustainable and socially acceptable natural/organic farming could be done to make the region self-sufficient of food grains without deteriorating the soil health and environment
- On-farm research and demonstration of improved package of practices using identified HYVs of crops recommended doses of fertilizers and use plants protection measures should be emphasized.
- Identification of crops and their management under moistures stress and low temperatures conditions along with organic/natural farming need to be stressed.
- Integrated plants nutrient system (IPNS) in crop production exploiting the use of Azolla (biofertilizer) weeds (*Eupatorium, Ambrosia spp*), trees (*Alnus*) etc.
- Suitable intercropping of filed crops such as soybean, urd bean, groundnut, cowpea etc. with rice and maize as well disease; pest management technology is essential in Eastern Region of India**.**
- On–farm perfection of locally available technology is essential to boost up the productivity and economy of the farming community in general and the region in particular.
- The terrace risers, which constituted 37-40 per cent of the total area, should be utilized for growing perennial fodder grasses and will provide enough fodder to have sources of income through rearing of animals besides binding soil.

- Development of eco-friendly sustainable agro-practices which can improve the productivity under shifting cultivation area. As a long range objective, the shifting cultivation should be diverse with the alternate farming system based on settled agriculture, keeping in view, the tribal social system, preferably through farmers' participatory approach.
- Development of integrated approach for efficient management of soil, water and other natural resources based on watershed management approach.
- Evolving agro-techniques for improving fertilizer and water use efficiency soil and water conservation rainfed and hill technology and watershed management techniques without the purview of the existing system popularizing them.
- Diversification of area from less remunerative and less sustainable cropping system to remunerative crops/cropping system through effective substitution programmes wherever required.
- Phased eradication of shifting cultivation through introduction of terracing/settled cultivation with appropriate agro-techniques and support systems.

Conclusion

Crops production in the North Eastern Region of India is mostly consumption oriented to meet the needs of the farmers. Use of local varieties, low consumption of fertilizers and pesticides low moisture retention capacity of upland soil, undulating terrain with varying altitudes and slopes low temperature, poor drainage in valley land during monsoon and lack of irrigation facilities during winter months, low sunshine hours along with traditional management practices have resulted have resulted into low productivity and low cropping intensity. Rice, wheat, barely, millet, soybean. French bean, black and green gram, mustard vegetable (cabbage, carrot, bean and potato) ginger and turmeric are the principal annual crops grown in the Eastern Region. The productivity efficiency based on yield and spread index of major crops showed that maize, wheat, oilseeds, and millets are the most efficient crops in Arunachal Pradesh rice in Manipur, maize, potato tapioca, ginger and turmeric in Meghalaya and rice, maize, oilseeds, cotton and ginger in Mizoram, while in Nagaland rice, pulse, oilseed and potato and in Sikkim maize, wheat, millet, pulse and ginger are the most efficient crops. The most efficient cropping system identified for different are/farming situation in the region are potato-rice, rice-rice, maize ragi, maize-mustard, maize-sunflower, maize + frenchbean - mustard. The groundnut, which is a recent introduction in the North East, has proved potential and can be a good substitute of uneconomical upland rice and maize or it can be grown as intercrop with rice and maize for higher return and improved quality. Adoption of improved agro-techniques can improve the crop productivity substantially in the region. Adoption of watershed approach, Integrated farming system approach, land configuration for increasing cropping intensity, organic farming, conservation tillage etc. are identified as potential resource conservation measures for the region for sustainability in agriculture.

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1.2 Natural Resource Management: An Overview

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During last three decades India has witnessed appreciable growth in food grains, horticultural crops, animal husbandry and aquaculture. It is now realized that the commodity centered technologies developed in green revolution have led to bypassing the fruits of this revolution in poor endowed and fragile resource systems, viz. rainfed, mountain, coastal and arid systems. We must appreciate that these systems through poor in physical resource, are quite rich in biodiversity. On the other hand, land and water use in the country is inappropriate and unscientific. Prime agriculture lands continue to be diverted to non-agricultural use. Productivity of agricultural land is decreasing due to biotic and abiotic stresses (Anonymous, 2000). Water is treated as a free commodity leading to unsustainable exploitation of the resource. The time is not far off where water should be one of the most scarce commodities, and agriculture would have to manage with less of it because this sector may not be able to pay as much as other sectors would be able to pay. Our rich and bountiful biological endorsement is also showing sign of erosion. It is important to preserve the genetic variability in agriculturally valuable species so that they continue to be useful under prevalent biotic and abiotic pressures.

Natural resources in India

Soil resources and land use scenario

The geographical matrix of India (Table 1) is based on the reported area of 305.01 M ha. And is broadly grouped into three sections (i) agricultural sector (59.27 percent) consisting of net cultivated areas, current follows, other follows and cultivable wastes; (ii) ecological sector (33.56 percent) comprising forests, miscellaneous, barren and uncultivable waste, and (iii) non agricultural sector (7.17 percent)not includes land under non-agricultural uses. About 130.77 M ha have effective land cover through out the year in the form of (i) permanent vegetation in the areas of dense forest stand and intense cropping, and (ii) non agricultural uses. These areas are supposed to be free from erosion- mediated land degradation.

The predominant soil groups of India are: red (105.5 million ha), black (73.5 million ha), alluvial (58.4 million ha), laterite (11.7 million ha), desert (30 million ha) and hill and terai soils (26.8 million ha). The per capita availability of land for cultivation is constantly declining (estimated to decrease to 0.17 ha in 2000 to 0.14 ha by 2025) and there is very little scope for horizontal expansion of net cultivated area.

The soil degradation map of India, prepared by using GLASOD methodology shows that an area of about 187 M ha, almost 57 percent of the total geographical area of the country has been affected by various land degradation problems, induced largely by human interventions. Water erosion is major problem causing loss of top soil and/ or terrain deformation in about 148 M ha (representing 45 percent) of the total area through the country. Wind erosion is dominant in the western regions, covering 13.5 M ha (representing 4.1 percent) of the total area. It causes loss of top-soil in 1.9 percent, terrain deformation in 1.2 percent and over blowing and shifting of sand dune in 0.5 percent of the affected area.

Table 1: Geographical matrix of India

Land Use	Area (M ha)	Effective covered area/year (M ha)
A. Geographical area	328.73	-
B. Reporting area for land utilization	305.00	130.27
i) Ecological sector		
a) Forest	68.00	50.29

b) Permanent pasture and grazing lands	11.30	5.42
c) Miscellaneous trees and hedges	3.67	2.06
d) Barren and uncultivable wasteland	19.38	-
ii) Ecological sector		
a) Net cultivated area	142.51	51.2
b) Current fallow	13.91	-
c) Other fallow	9.65	-
d) Cultivable waste	14.64	-
iii) Non- agricultural sector		
a) Under non-agricultural uses	21.9	21.9

Source: Anonymous (2000)

Emergence of multi-nutrient deficiency

The emergence of multi-nutrient deficiencies in soils owing to adoption of indiffeerent nutrient management practices is always debated but the quantitative assessment of its nature and extent of complexity is rarely done. Database generated and soil fertility maps developed so far deal with individual nutrients in isolation. Thus, it is not known if a soil assessed deficient in nutrient X is simultaneously deficient in nutrient Y and Z. or not The studies conducted in collaboration amongst PDCSR Modipuram, IARI New Delhi and IPNI, India Programme under different Agro-ecological regions and results obtained clearly indicated that the multi-nutrient deficiency are propping up differentially in number and spatially in agro-ecological zones, depending upon soil type, rainfall, and cropping systems. In North Gujarat Plains, 80 percent of the soils were found deficient in either NPKS/ NPK/ NKS/ NK, whereas only 6 percent soils were found deficient in NPKSFe. Similarly, in Rohilkhand, Awadh and South Bihar Plains 96 percent soils showed the deficiency of elements. The 38 percent soil were found deficient in NPKSZn, followed by 22 percent NKZn, 18 percent NPK and 18 percent in NK. These investigations highlights the significance of need-based application of nutrients instead of (may be one, two or more number of macro and micro nutrients) balanced application of NPK only for enhancing productivity but a substantial saving can be made through location specific soil test based nutrient management.

The agricultural production can be sustainable if it promotes practices that:

1. Improve soil quality, while reducing erosion, Salinization and other forms of degradation to achieve greater resilience to drought, better fertilizer efficiency, and reduced greenhouse gas emissions.
2. Minimize the use of pesticides and herbicides by applying integrated pest management, crop rotation and crop diversification .
3. Employ environmental management systems to ensure proper treatment of solid waste, manure and waste water.
4. Ensure the safe storage, application and disposal of agricultural chemicals

5. Maintain habitats to support wildlife and conserve biodiversity.

Therefore, there is need to develop agricultural techniques that are ecologically sound, economically viable, and socially responsible. Activities should focus on environmental sustainability across agricultural supply chains and multi-use landscapes. Sustainable agriculture in the context of development helps to achieve production efficiency, protect ecosystem functions, enhance resilience to climate change, ensure healthy communities, and satisfy basic needs.

Water resources and irrigation potential

Water is the most critical inputs for enhancing agricultural productivity, and therefore,expansion of irrigation has been a key strategy in the development of agriculture in the country.

Water resources

Items	Details
Annual rain water received in India	400 M. ha m
Irrigation potential of India	139.5 m. ha
Major and medium schemes	58.5 m. ha
Minor irrigation schemes	15.0 m. ha
Ground water exploitation	66.0 m. ha
Utilization of irrigation potential	78.5 m. ha
Net irrigated area	57.24 m. ha
Gross irrigated area	76.34 m. ha

India has created an irrigation potential of about 84.9 M ha against the ultimate irrigation potential of 113.5 M ha (now revised to 139.5 M ha). As assessed by different irrigation commissions, with increase targets for minor irrigation and ground water the ultimate irrigation potential shall be about 130 million ha. Broad assessment places the required potential at 180 M ha, indicating additional potential of about 50 M ha, which has to come from additional major and medium irrigation projects, where 21.1 M ha is utilized out of the 32.3 M ha and 58.5 M ha of created and ultimate irrigation potential, respectively. It is estimated that even after achieving the full irrigation potential, nearly 50 percent of the total cultivated area would remain rainfed. The share of major and medium irrigation is higher, by 3.2 M ha, as compared to that of minor irrigation. Ground-water schemes contribute more than 72 percent of the total ultimate potential through minor irrigation. Uttar Pradesh and Bihar are two states along with Madhya Pradesh, Andhra Pradesh and Maharashtra, which account for 58 percent of the total ultimate potential of major and medium irrigation in the country. In spite of abundant water resources in the country, several problems are anticipated. Some of the apparent constraints are given below:

- Water resources in the country are not distributed uniformly. For example, 29 per cent of the water resources are available in the Brahmaputra basin, which constitute only 6 per cent of the country’s area.

- Southern and western regions have much lesser water resources than the national average in some areas of the southern regions; for instance, availability is as low as one- fourth of the national average.
- Pollution of surface/ ground water resources may not leave all our water resources potable.
- In the year with abnormal rainfall (low), the water resources scenario may become quite serious.

Vegetation resources

Due to large heterogeneity in the climate of different regions, cultivated as well as natural vegetation are also highly variable. Currently an area of 70 million ha is covered by forest in India. Of these 24.93 million ha has lees than 40 percent crown density. Per capita forest availability is only 0.07 ha. Deforestation has been one of the major causes of land degradation, with for reaching consequences to humanity. The poor quality of forest cover has not only accelerated the problems of environmental degradation but has also led to the deficit of fuel and fodder, 76 million tonnes dry fodder (Anonymous, 2000). During 1993, the country faced a deficit of 570 million tones green fodder, 276 million tones dry fodder, 9 million tones of timber, 6 million tonnes of pulp wood and 80 million tonnes fuel wood. MPTs (multipurpose tree species) in agricultural fields and wasteland play a significant role in augmenting the fodder, fuel and small timber resources.

Climate/ weather resources

Country has number of physiographic regions exist with highly variable temperature and rainfall patterns.

Climate and weather resources

Items	Details
Rainfall	Average annual rainfall- 1200 mm Large part of the country receive annual rainfall of 1000 mm
South west monsoon rainfall (June – Sept)	74% of annual rainfall
Temperature regime	28^0 – 29^0 during monsoon season 15^0 or less in winter season
Sunshine	Least in NE region- 5.8 hours Highest in Rajasthan- 9.1 hours

With such a vastness, the nation is endowed with a diverse climate, characterized by good rainfall in larger part of the country, abundant sunshine and moderate temperature regimes. This support and promotes diversified vegetation and cropping patterns in different regions. However, due to monsoonal pattern of rainfall, occurrence of drought in some parts is a common phenomenon. But rapid and uncontrolled industrialization has had an adverse impact on the climate at global level. The temperature in the regions are likely to record increase in this region by 0.1 to o.3 ^{0} C during coming years. Coupled with increase in CO_2 level, three is likely to be significant change in the amount and the distribution pattern of rainfall, which will influence all agriculture- related activities.

Issues of global warming

In order to maximize the overall production, a careful planning is needed taking into account minimum disturbance of the ecosystem so that sustained production activities are ensured. Another issue having long-term implication would be the global warming. If the current trends in emission of green house gases continue, the earth's temperature is expected to rise by additional 0.5 to 2.0 ^{0}C by 2030 AD as compared to 1980. This wills result in warming of the globe by 1.5–4.5^{0} C. the thermal expansion of ocean water would lead to rise in global sea levels by about 0.3 to 1.2 m. As a consequence, inundation of large low-lying coastal areas and intrusion of saline water into the adjoining aquifers will occur.

Management of natural resources for sustained productivity

According to World Bank report, if 4% growth in irrigated agriculture is to be sustained, productivity per unit area will have to be doubled by 2015. A very large proportion of area under food grains falls in the low productivity category (area with productivity lower than the national average). According to Paroda (1994), the share of low productivity area varies from 57% in coarse cereals to 92% in oilseeds. The most disturbing fact is that such a large area falls under the low productivity class in respect of wheat, 78% of which is irrigated. In rice, 32% of the irrigated area is of low productivity. These could be areas, which offer the first and maximum possibility in stepping up the yield level relatively with ease.

System productivity of predominant cropping systems and yield gaps

Productivity of predominant cropping systems under different agro climatic-regions at on-station research conducted under AICRP-CS (Average of 03 years from 2004-05 to 2006-07), and average potential yield either derived through simulation modeling (1, 29, 21) and/or taken from maximum yield research trials of AICRP are depicted in Fig 1. Yield gaps in terms of rice equivalent yield (REY) and gross return between state average and on-station research average, and between state average and potential yields revealed that there is need to put excessive efforts to bridge these yield gaps.

Productivity computed in terms of REY was highest ranging between 8.46-12.04 t ha^{-1} for rice-wheat system, 8.61-11.35 t ha^{-1} for maize-wheat system and 5.84-7.46 t ha^{-1} for pearl millet-wheat system in Trans Gangetic Plains. While lowest system productivity of rice-wheat system (4.72-8.73 t ha^{-1}) and maize-wheat system (4.35-9.34 t ha^{-1}) was in Western Himalayan region. Assessing yield gap in terms of REY for various cropping systems varies from 0.88-7.54 t ha^{-1} in different Agro-climatic region (ACR). Further, yield gap between state average and on-station research average varied from cropping system to cropping system and from region to region within a system (12). Averaged over the ACR, the yield gap was is 3.87 t ha^{-1}, which indicates towards achieving 50 per cent of the gap on 50 per cent cultivated area in different agro-ecological zones would give the additional production of 136.6 million tonnes of rice equivalent yield. Though such hypothesis can only come under reality after solving institutional, economic, social and physical constraints of the region. Other viable options for vertical productivity improvement are efficient input management such as balanced nutrient application, use of quality seed, and efficient crop protection measures in conjunction with increasing the irrigation facilities/infrastructure.

Tillage and crop establishment

Rice

Despite the proven advantages of puddling in rice, its adverse effect on subsequent wheat is not unlikely. Destruction of soil structure during puddling and consequent increase in sub-surface soil compaction and bulk density leads to an environment that is not congenial to wheat growth. As a result, in continuous rice-wheat system wheat yields start declining in excessively puddled plots.

Alternative crop establishment techniques that exclude puddling and transplanting have also been evaluated. On station experiments indicated direct seeding of rice under dry seedbed conditions as a promising rice establishment method, which not only produced rice yields similar to transplanting but also mitigated the puddling-induced yield decline in wheat (Table 2). While adopting direct seeding of rice, the most important concern is weed control. With an effective weed control by way of stale seed-bed perpetration or use of herbicides, direct seeding may prove a better alternative to transplanting in terms of annual productivity as well as economic returns.

Table 2. Grain yield (t/ha) of rice and wheat as influenced by rice crop establishment practices

Crop establishment practices in rice	Rice	Wheat
Transplanting	3.60	3.01
Direct Seeding (dry/line sowing)	3.70	3.37
Direct Seeding (puddle/broadcast)	3.50	3.27
Direct seeding (Puddled /dibbling)	3.30	3.20
CD at 5%	0.14	0.12

Source: PDCSR Annual report, 1997

Mechanization of rice transplanting

Use of self-propelled transplanter for rice planting is a relatively new agro-technique. Field experiments have confirmed the superiority of mechanized transplanting over other methods in terms of grain and biological yields, and economic returns (Table 3).

Table 3. Comparison of economic returns under different methods of rice planting

Planting method	Grain yield (t/ha)	Straw yield (t/ha)	Cost of cultivation (Rs./ha)	Gross return (Rs./ha)	Net return (Rs./ha)	Benefit : cost ratio
Direct seeding of sprouted rice	3.28	4.54	12,135	19,452	7,317	1.60
Direct dry seeding	3.90	4.86	11,420	22,806	11,386	2.00
Manual transplanting	4.34	4.72	13,518	24,966	11,448	1.85
Mechanical transplanting	5.34	5.52	11,005	30,546	19,541	2.78

Source: PDCSR Annual Report, 2002

Wheat

The new concepts of resource conservation tillage (RCT) and developments in machinery make it possible to raise a good wheat crop with minimum or even no tillage (Hobbs and Gupta, 2003). The machinery named strip-till drills and zero-till drills meant for wheat sowing are now available in market. Whereas strip-till drill pulverizes the soil in strips leaving other area untilled, zero-till drill opens slits for seed and fertilizer placement. With these machines wheat sowing and fertilizer placement (basal) is completed in one operation and no tillage equipments are needed. On-station as well as on-farm studies revealed that wheat sowing by strip-till drill produced similar or greater yield than the crop sown with conventional tillage, and the performance of zero-till drill was also satisfactory (Table 4). The strip- and zero-till drills are gaining popularity amongst farmers, for ease in handling and completion of wheat sowing in one operation. In Middle and Lower Gangetic Plains, where turn-around time between rice harvesting and wheat sowing is less and the field left after rice is not immediately fit for tillage due to excess moisture, a large-scale adoption of these machines may help in timely sowing of wheat.

Table 4. Grain yield of wheat (t/ha) under different tillage and fertilizer N levels

Tillage	**Nitrogen levels (kg/ha)**		**Mean**
	120	150	
Conventional tillage	5.32	5.83	5.57
Reduced Tillage	5.49	6.06	5.78
Zero tillage	5.17	5.73	5.45
Mean	5.33	5.88	-

Source: PDCSR Annual Report, 2002

Integrated and balanced nutrition

Integrated nutrient management

Green manure, FYM, and rice and wheat crop residues are the important IPNS ingredients used to supplement chemical fertilizers. Result of extensive studies undertaken during past two decades, revealed the possibility to substitute 25-50% of fertilizer NPK in rice, with the use of FYM or green manure on equivalent N content basis. Results from long–term experiments (LTEs) have established that the high productivity of rice-wheat system cannot be sustained with fertilizer only but integrated use of chemical fertilizers with organic sources such as farmyard manure [FYM], green manure [GM] and crop residues incorporation. 50% N substitution during *kharif* season with organic manures as stated above helped in attaining highest system productivity across the zones. Another study conducted at Modipuram indicated that a decomposed sulphitation pressmud (SPM) gave even better performance over FYM in increasing the yields of rice and wheat.

Residue Recycling

Recycling of crop residues back to fields helps to build stable organic matter in the soil, as also to sustain yield levels. Studies in AICARP suggested that in some areas incorporation of crop residues made it possible to curtail 25% of fertilizer NPK requirement of rice. Application of 10-20 kg N ha^{-1} at the time of incorporation of residues hastened the rate of decomposition, and consequently increased the beneficial effect in terms of grain yield and soil fertility build-up (Table 5). Since 70-80% of K taken up by these crops is retained in straw component, residue recycling may be the best option to replenish K to the soil and avoid the mining of soil K reserves. Efforts are underway to develop direct drilling and stubble mulching machinery to overcome this problem (RWC 2002). A novel, promising approach recently developed and tested by Australian and Indian collaborators is the "Happy Seeder", which combines the stubble mulching and seed drilling functions into the one machine. The stubble is cut and picked up in front of the sowing tines (which therefore engage bare soil) and deposited behind the seed drill as mulch.

Table 5. Effect of rice and wheat crop residues incorporation on productivity of the system and soil health

Treatment	Mean grain yield (t/ha)			Soil fertility after 6 cycle		
	Rice	**Wheat**	**Total**	**OC%**	**Av P (kg/ha)**	**Av K (kg/ha)**
R. S. Pura (06 years)						
Rec. N, no N at CR addition	4.31	3.39	7.70	0.38	11.5	90
10 kg rec. N at CR addition	4.21	3.45	7.66	0.43	13.2	96
20 kg rec. N at CR addition	3.98	3.33	7.31	0.48	14.5	93
Rec. N+ 10 kg N at CR addition	4.61	3.73	8.34	0.48	15.2	99
Rec. N+ 20 kg N at CR addition	4.46	3.90	8.36	0.46	13.2	96
Kanpur (06 years)						
Rec. N, no N at CR addition	4.41	4.03	8.44	0.29	21.4	188
10 kg rec. N at CR addition	4.29	4.07	8.36	0.33	22.6	190
20 kg rec. N at CR addition	4.23	3.99	8.22	0.31	24.8	195
Rec. N+ 10 kg N at CR addition	4.56	4.36	8.92	0.36	25.8	200
Rec. N+ 20 kg N at CR addition	4.69	4.14	8.83	0.34	26.5	198

Initial values of OC, Available P and available K were 0.43 and 0.10%, 10.4 and 18.4 kg/ha, and 91.5 and 218 kg/ha, respectively at R. S. Pura and Kanpur.

Source: Yadav, 1997

Inclusion of legume in system

Research evidences suggest that a large scope exists for inclusion of legumes in rice-wheat system as catch crop, green fodder crop or as green manure. Alternatively, in a long-term prospective, one of the cereal crops can also be substituted with a legume crop which generally acts as a soil health restorer on account of its ability to fix atmospheric N and utilize soil nutrients from deeper layers through their tap root system, which in turn saves N requirement of succeeding crop. Studies under AICRP-CS indicated that recycling of summer green gram residues after picking the pods was as effective as *Sesbania* green manuring in terms of yield gain in rice and wheat (Hegde, 1992). Experiment conducted at Modipuram revealed an appreciable increase in the use-efficiency of N and P fertilizers in rice-wheat system with the inclusion of summer cowpea (forage) (Table 6).

Table 6. Recovery efficiency of N and P fertilizers in rice-wheat system as influenced by inclusion of summer forage cowpea.

Fertilizer NP rate (kg/ha)	Rice		Wheat	
	Summer Fallow	**Summer Cowpea**	**Summer Fallow**	**Summer Cowpea**
Recovery efficiency of N (%)				
$N_{120}P_0$	34.8	35.3	42.3	38.3
$N_{120}P_{60}$	36.4	41.2	54.5	61.7
Recovery efficiency of P (%)				
N_0P_{26}	11.6	15.6	11.2	12.6
$N_{120}P_{26}$	22.7	25.0	27.9	30.4

Source: Dwivedi *et. al.,* (2003)

Site-specific nutrient management vis a vis balanced nutrition

Site-specific nutrient management (SSNM), considering native nutrient supply of the soil and productivity targets is an strategy that may provide sustained high yields on one hand, and assure restoration of soil fertility on the other. Studies conducted with SSNM in consideration of all deficient nutrients for high yields targets reveals a marked crop response for rice-wheat and rice-rice cropping system (Table 7). Such results obtained under SSNM indicate that yield stagnation of the intensive cropping system can be breaked and a production target of 15-18 tonnes of rice –wheat and rice- rice system may be attained.

Table 7. Effect of site-specific nutrient management on maximum economic yield ($kg\ ha^{-1}$) of rice-wheat cropping system

Sites	Crop	SSNM	State average
R S Pura	Rice	8555	1689
	Wheat	4746	1325
	Total	13301	3014
Ludhiana	Rice	10410	3545
	Wheat	6548	4532
	Total	16958	8077
Modipuram	Rice	9950	2120
	Wheat	5940	2755
	Total	15890	4875
Kanpur	Rice	8341	2120
	Wheat	5685	2755
	Total	14026	4875
Ranchi	Rice	7027	1480
	Wheat	4057	2056
	Total	11084	3536

Source: Tiwari *et. al.,* 2006

Efficient water management

Water shortage is a major constraint to sustaining and increasing the productivity of rice-wheat systems in South Asia. Groundwater levels are declining rapidly in the NW IGP. In the eastern IGP delayed onset of rains and near lack of ground water development during the monsoon season delays rice nursery and transplanting operations to set-in a vicious cycle of late planting of crops. Irrigation water requirement of rice and wheat has been studied at different locations in the IGP under the All India Coordinated Research Project on Water Management**.** The total water requirement for wheat has been estimated to fluctuate from 238 mm in Bihar to 400 mm in Punjab. The total water requirement of rice is estimated to vary from 1144 mm in Bihar plains to 1560 mm in Haryana. Thus, a total of 1382 mm to 1838 mm water is required for the RW system at different locations in the IGP, accounting to more than 80% for the rice-growing season. Thus to save on water, saving must be effected during the rice growing season, the major water user in the RW system. Many technologies appear to save substantial amounts of water through reducing irrigation water requirement, but whether these are true water savings is uncertain, as components of the water balance have not been quantified. Such technologies include laser levelling, direct drilling, raised beds, non-ponded rice culture, stubble mulching and irrigation scheduling. However, moving away from puddled ponded to more aerobic rice culture sometimes brings new production problems.

For zero-tillage, farmers report about 25-30% water savings (Table 8). This comes in several ways. First, zero tillage is possible just after rice harvest and residual moisture is available for wheat germination. In many instances where wheat planting is delayed after rice harvest farmers have to pre-irrigate their fields before planting; zero tillage saves this irrigation. Savings in water also comes from the fact that irrigation water advances quicker in untilled soil than in tilled soil. That means farmers can apply irrigation much faster. Because zero-till wheat takes immediate advantage of residual moisture from the previous rice crop, as well as cutting down on subsequent irrigation, water use is reduced by about 10 cm-hectares, or approximately 1 million liters per hectare. One additional benefit is less waterlogging and yellowing of the wheat plants after the first irrigation that is a common occurrence on normal ploughed land. In zero tillage, less water is applied in the first irrigation and thus yellowing is not seen.

Table 8. Wheat yield and water saving with zero-till technologies in farmer participatory trials

Parameter	Paired planting@	Controlled traffic**	Zero till	Conventional tillage
Water saving, %	26.2	30.8	35.4	#
Yield (q/ha)	65	58	57.8	51.9

\#   Compared with conventional tilled wheat planted a week later (*);

** One row behind each tractor tyre not sown;

@ Spacing between set-rows (14 cm); and between paired sets (25cm).

In bed planting, farmers commonly mention 30-45% water savings in this system in wheat. More number of irrigation are required in bed planting but total water requirement is less than flat bed planting in wheat.

Input water savings of 35-57% have been reported for dry seeded rice sown into non-puddled soil with the soil kept near saturation or field capacity compared with continuously flooded (~5 cm) Puddled transplanted rice in research experiments in. However yields were reduced by similar amounts due to iron or zinc deficiency and increased incidence of nematodes. Farmer and researcher trials in the IGP suggest irrigation water savings of 12 to 60% for direct seeded (DSRB) and transplanted (TRB) rice on beds, with similar or lower yields for TRB compared with puddled flooded transplanted rice (PTR), and usually slightly lower yields with DSRB (Gupta et al. 2002).

Weed management

During post green revolution era expansion of rice-wheat cereal based cropping system has promoted a kind of monoculture of cereal-cereal cropping, ignoring the basic principles of crop rotation. Hence build-up of weed population has emerged as one of the major constraints threatening the sustainability of rice-wheat system. Wherever, high productivity levels and assured irrigation are used, weed problem becomes the single major factor responsible for low yields. The loss in crop yield due to weeds especially in transplanted rice has been reported to vary from 15-20%, whereas it is 30-35% in direct-seeded puddled rice. In wheat the yield losses are 15-30% depending upon the intensity and the type of weed flora present. In rice-wheat system, the major weeds of rice are *Echinocloa* spp, *Cyperus rotundus*, *Fimbristylis* and *Eclipta alba*. In wheat, the predominant weed species are *Phalaris minor*, *Avena* spp, *Chenopodium album*, *Lathyrus, Melilotus indica* and *Vicia sativa*. Chemical weed control reduced the weed population in both rice and wheat. Application of butachlor @ 2 kg/ha at 2 to 3 days after rice transplanting and that of isoproturon @ 1- 1.25 kg/ha 30-35 days after wheat sowing gave better efficiency. For broad-leaved weeds in wheat, post-emergence application of 2, 4-D sodium salt at 1 kg a.i./ha appeared promising. Among the cultural techniques of weed control, introduction of legumes as a break crop (a legume grown to substitute one of the cereal crop at fixed interval) has shown promise. In long-term studies at Modipuram, substitution of wheat with berseem and that of rice with forage cowpea at an interval of 03 years helped minimizing the weed population in both the crops (Table 9).

Table 9. Effect of nutrient and crop management strategies on weed intensity in rice-wheat system

Treatment	Rice	Wheat
Continuous rice-wheat cropping	23	232
Every 3rd wheat substituted with berseem	13	190
Every 3rd rice substituted with cowpea	09	164

Source: Singh and Dwivedi (2006)

Crop diversification

The present agricultural scenario, especially in irrigated areas, is dominated by monoculture of certain crops, as more than 80% of food comes from about 10 crop species. Crop diversification may prove to be of paramount importance in mitigating the problems arising due to monoculture. For instance, diversifying rice-wheat system with crops such as berseem, mustard, sugarcane etc. effectively minimizes *Phalaris minor* infestation, whereas inclusion of legumes for grain, fodder or green manure improves the fertility and soil physical health. In fact, introduction of new crops with greater economic viability often prove advantageous, as these crops spread faster and adapt well due to proper technology packages. Most significant examples of crop diversification in past few decades are introduction of rice in Punjab and Haryana, wheat in West Bengal, groundnut in Gujarat, soybean in Madhya Pradesh and winter maize in Bihar. Besides, cultivation of pulses and oilseeds in rice-fallows of eastern India and that of french bean in northern plains are likely to make sizeable difference. What is important is to identify promising crops and cropping systems that have higher and stable yield and profit under irrigated and water scarce situations, so as to suggest need-based diversification of existing cropping systems.

Crop diversification under assured irrigated situations: Choice of a crop combination by the farmer is greatly influenced by factors like profitability, household needs, competitiveness of the product in the market, resource base, input supply etc. Hence the alternative crops or cropping systems have to be carefully examined in the light of these factors prior to recommendation. Studies taken up under the aegis of All India Coordinated Research Project on Cropping Systems (AICRP-CS) have suggested some high intensity crop sequences in major agro-ecologies, that have sown marked advantage over existing cropping systems (Table 10). Introduction of an entirely new cropping system, or diversification of one or more component crops resulted in enhanced annual productivity ranging between 25 and 117% over the existing cropping systems at different AICRP-CS research centers.

Table 10. Efficient intensive cropping systems for different agro-ecosystems

Cropping systems			**Mean yield (t ha^{-1})**			**Rice yield equivalent (t ha^{-1})**
Kharif	***Rabi***	**Summer**	***Kharif***	***Rabi***	**Summer**	
			Arid ecosystem			
S.K. Nagar (03 year averaged)						
Pearlmillet	Potato	Groundnut	0.69	21.42	2.47	18.39
[*]Castor	Castor	Pearlmillet	2.72	-	2.97	8.72
Siruguppa (02 years averaged)						
Rice	Rice	-	4.56	6.21	-	10.77
[*]Rice	Sunflower	-	4.63	1.03	-	7.19
			Semi-arid ecosystem			
Indore (03 years averaged)						
Soybean	Wheat	-	2.38	4.26	-	8.57
[*]Sorghum	Wheat	-	2.35	4.16	-	6.11
Junagadh (02 years averaged)						
Castor	Castor	Groundnut	1.50	-	1.77	7.68
[*]Groundnut	Maize (f)[1]	Groundnut	0.19	29.5	0.57	3.75
Ludhiana (02 years averaged)						

Rice	Potato	Groundnut	5.20	21.67	2.24	22.60
Maize	Potato	Groundnut	3.54	23.71	2.29	21.53
*Rice	Wheat	-	5.48	4.94	-	10.42
			Sub-humid ecosystem			
Palampur (02 years averaged)						
Maize	Toria	Potato	5.08	0.68	15.16	14.11
*Maize	Toria	Gobhisarson	4.55	0.31	0.86	6.34
Varanasi (02 years averaged)						
Rice	Mustard	Greengram	4.56	2.13	0.58	10.69
*Rice	Wheat	-	4.08	3.94	-	8.02
			Humid ecosystem			
Kalyani (02 years averaged)						
Jute	Rice	Potato	2.23	3.89	16.89	16.20
*Rice	Rice	Mustard	2.96	3.59	0.59	7.92
			Coastal ecosystem			
Navsari (02 years averaged)						
Rice	Safflower	Cowpea	3.79	1.32	0.75	8.05
*Rice	Sorghum (f)	Groundnut	3.92	10.76	0.77	6.46

*Existing cropping system; [1]fodder

Source: Annual Report (1997-98), PDCSR, Modipuram, Meerut, India

Crop diversification under water-scarce conditions: In rain fed areas or in those having limited water availability, efficient crops have been identified, which produced a significantly higher yield compared with the traditionally grown crops (Table 11). Substitution of cotton by sorghum at Bellary, wheat by chickpea at Varanasi, and by taramira at Hisar, for instance, brought many fold increase in the total productivity. As a thumb rule, crops having higher water requirement should not be included in the crop production systems, unless assured irrigation is available.

Table 11. Productivity of traditional and efficient crops under limited water availability

Region	Traditional crop	Yield (t ha^{-1})	Efficient crop	Yield (t ha^{-1})
Bellary	Cotton	0.20	Sorghum	2.67
Varanasi	Wheat	0.86	Chickpea	2.85
Ranchi	Upland rice	2.88	Maize	3.36
Indore	Greengram	1.18	Soybean	3.33
	Wheat	1.12	Safflower	2.42
Agra	Wheat	1.03	Mustard	2.04
Hisar	Wheat	0.32	Taramira	1.61

Udaipur	Maize	2.20	Sorghum	4.40
	Wheat	1.25	Safflower	1.71

Source: Singh and Vijayalakshmi (1992).

Inter-cropping is one of the important ways to increase the productivity and provide income stability under limited soil moisture conditions. Extensive studies carried out under AICRP-CS have helped in identification and standardization of several highly profitable inter-cropping systems. Some of the promising inter-cropping system are maize + black gram at Palampur, Ranchi and Banswara; maize + soyabean at Ranchi, maize+ cowpea at Karjat; sorghum + soybean at Sehore; sorghum+ pigeon pea at Indore, pigeon pea +green gram at Bichpuri and Hanumangarh; rice+ soybean at Kalyani and Jabalpur; and wheat + rapeseed at Indore. Most of these inter-cropping systems have been evaluated on farmers' fields and found to be highly remunerative (15-200%) over the sole crops (Table 12). It was generally observed that both the component crops should be fertilized at recommended rate, to achieve maximum benefit from a diversified inter-cropping system.

Table 12. Proven inter-cropping systems on farmers' fields

Inter-cropping system	District	Per cent additional benefit over sole crop
Pigeonpea+groundnut	Singhbhum	199
	Sangrur	50
	Mayurbhanj	69
Pigeonpea+blackgram	Aligarh	42
Pigeonpea+maize	Ghazipur	11
Pigeonpea+pearlmillet	Ghazipur	20
Sorghum+pigeonpea	Wardha	100
	Bidar and Bellary	103
Sorghum+soybean	Wardha	25
Groundnut+blackgram	Tiruchirapalli, Pudukkottai and South Arcot	35
	Chengalpattu	25
Groundnut+greengram	Salem	10
Maize+soybean	Periyar	9
	Pithoragarh	19
Maize+blackgram	Bilaspur and Hamirpur	53
	Ghaziabad	30
	Dungarpur	38
Chickpea+mustard	Dungarpur and Jhunjhunu	12
	Rohtak and Jind	35
Wheat+mustard	Rohtak, Sirsa and Jind	22

Source: AICRP-CS Reports

Farming system approach

As discussed earlier, this approach involves either introduction of an altogether new enterprise on the farm to replace the existing one or use of one or more enterprises as a complement to the existing enterprise. Whereas at a resource poor marginal to small farm, a sudden shift of enterprises is unlikely, an integrated use of two or more enterprises is very common. Under dry land conditions, a judicious integration of farm-enterprises, e.g. agro-forestry, agri-horticulture, agri-silviculture or silvi-pasture produced a higher benefit: cost (B: C) ratio compared with arable cropping (Table 13).

Table 13. Benefit: cost ratio of different alternate land-use systems under dryland conditions, Hyderabad, India

Farming systems	Years averaged	Benefit: cost ratio
Agro-forestry (with sorghum+pigeonpea)	10	1.65
Agri-horticulture	30	5.53
Silvi-agriculture (with castor intercrop)	10	1.99
Silvi-pasture	10	2.45
Arable farming	1	1.34

Source: Solanki and Newaj (1999)

In other studies also, integration of aquaculture with wetland rice systems has been advocated. The integrated farming systems involving azolla, green manure and fish culture along with rice registered higher B: C ratio and net income over the rice-rice system, irrespective of N management practices. At Coimbatore, enterprise integration i.e., crop production (rice-rice system)+ aquaculture + poultry, pigeon or goat made it possible to increase the productivity by two or three fold, and net return by three fold compared with existing rice-rice cropping system (Table 14). The B: C ratio, per day return and employment generation was also higher under integrated farming systems. Amongst various enterprise combinations tested in these studies, rice-fish culture along with goat rearing appeared most advantageous. All these indicate the thereby the superiority of an enterprise-mix involving crop production, dairying and sericulture and related enterprises.

Table 14. Productivity (rice grain equivalent yield), economics and employment generation under different integrated farming systems (mean over two years)

Farming systems	System productivity (kg ha^{-1})	Net return (Rs ha^{-1})	B: C ratio	Per day return (Rs ha^{-1})	Employment generation (man days)
Cropping alone	12223	36190	2.45	167	369
Crop+fish+poultry	31859	114665	3.60	436	515
Crop+fish+pigeon	32355	118462	3.74	443	515
Crop+fish+goat	39610	126564	3.41	493	576

Source: Jayanthi, C. *et al*., (2001)

Conclusion

Considering the issues of sustainability, global worming, land degradation, livelihood of the rural poor, sustaining productivity of agriculture and availability of natural resource in India the following strategies should be developed for managing the natural resources of India:

- Inventory, characterization and monitoring of natural resources, as adequate information is lacking on characterization of soil and water resources and climatic parameters at micro level, which is very essential for efficient land-use planning and resource deployment.
- Development of efficient and sustainable land-use plans for each agro-ecological zone or sub-zone of the country, considering their resource base, potential productivity, risk factors and social acceptability at micro-level. It will help in creating essential infrastructure to support the system for yield maximization and its commercialization without causing ecological threats.
- Development of location-specific watershed models in rainfed areas to enhance the average productivity from 0.8 t/ha to 2.0 t/ha.
- Development of integrated farming systems, specific to different farming situations prevailing in the country.
- Development methodologies for improvement in agro-met advisory services and their effective use in mitigation of adverse effects of aberrant weather conditions on agricultural production systems.
- Improving the agronomic practices ;
    (a) Improvement in fertilizer-use efficiency by 8-10% over the current level of 30-40%.
    (b) Increasing cropping intensity by about 20-30% over the current level. The intensity of cropping at present for the country is 1.36, whereas that of Punjab is 1.7. Therefore, by increasing the cropping intensity and productivity, total food grain production can be substantially increased. In irrigated areas there is a potential to enhance cropping intensity through sequential and intercropping systems.
    (c) Multi-purpose tree components for different agricultural production systems to be identified to augment the supply of fodder, fuel, industrial wood and timber in rural areas.
    (d) Enhancing the contribution of organics and bio-fertilizers to meet about 1/3 of the plant-nutrient needs and development of appropriate technologies for improving their efficacy and integrated nutrient-management systems, which may also help in increasing the use efficiencies of other inputs.
    (e) Irrigation-system management and enhancement of water productivity by about 10% from the current level
    (f) Development of technologies for efficient and safer utilization of poor-quality waters for crop production, as the share of water allocation to agriculture in anticipated reducing by 10-15%.

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1.3 NEH Region Land Resources Degradation and Restoration

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Land is the basis of life support systems, through production of biomass to provide food, fodder, fibre, fuel, timber, and other biotic materials for human uses, either directly or through animal husbandry including aquaculture and inland and coastal fishery. The land resources (vegetation, water and soil) are responsive to human intervention for the development. Present conditions of land in many areas of north-eastern hills are the result of a combination of both its natural and genesis and human influences which are still active. The human influences such as agriculture in Apatani plateau of Arunachal Pradesh, building of terraces for wheat cultivation by Monpas tribes of Arunachal Pradesh, terraced wet-rice cultivation by Angamis and Chakesang of Kohima district of Nagaland, and terraced agriculture in Sikkim hills may be the result of positive human action. The prevalence of shifting cultivation (*jhum*) is the result of human negligence or lack of knowledge and foresight that resulted severely eroded hills without good vegetation. In NEH region, the farmer's immediate concern is crop yield improvement, diversity of crops, and enhancement of basic income to meet the individual needs. The basic social concept of sustainable management of land is based on balance among the different segments of the society as well as a balance between individual and institutional values. The land of this region is suffering from various kind of land degradation as a result of different activities to meet the increasing demand of population.

Natural resources (economically referred to as land or raw materials) occur naturally within environments that exist relatively undisturbed by mankind, in a natural form. A natural resource is often characterized by amounts of biodiversity existent in various ecosystems. Natural resources are derived from the environment. Many of them are essential for our survival while others are used for satisfying our wants.

Natural resource management is the management of natural resources such as land, water, soil, plants and animals, with a particular focus on how management affects the quality of life for both present and future generations. Natural resource management is interrelated with the concept of sustainable development, a principle which forms a basis for land management and environmental governance throughout the world. It is an interdisciplinary subject drawing on sciences, economics, and the practice of natural resource management. Habitat conservation is a land management practice that seeks to conserve, protect and restore, habitat areas for wild plants and animals, especially conservation reliant species, and prevent their extinction, fragmentation or reduction in range.

Geography and geology

The North Eastern Hills (NEH) zone starts from Singalila range and covers the entire seven sister states including Sikkim and Darjeeling hills of West Bengal. It lies between 21.50^o and 29.50^o N and 85.5^o - 97.5^o E, represents a distinct agroclimatic area of our country. The hill states having a total geographical area of 183,813 km^2 (5.63% of India) and is populated by 1.13 per cent of the country. The great Himalayan range includes Sikkim, Darjeeling hills and eastern most border of Arunachal Pradesh. The north-eastern ranges, the spurs of great Himalayas has two major sections- the Mishmi hills of Arunachal Pradesh and Patkai ranges run to the east and south of Assam along the Indo-Burma border. They are known under different names in different parts of Assam (Karbi Anglong and North Cachar districts), Arunachal Pradesh, Nagaland, Manipur, Mizoram and Tripura and are collectively called *Purvachal* (*Purva*, east and *anchal*, mountain). It includes low hills, plateaus and even plains. The Mishmi hills contain the loftiest ranges of NEH with many summits rising above 5000 m and also many peaks of the Patkai ranges rise between 2000 and 3000 m. The Meghalaya plateau is really an eastward extension of the massive block of peninsular India to the east of the great gap of Achaean terrain. The central plateau of Khasi and Jaintia hills cover about 5000 sq. km area, and its outer limit is defined roughly by a 1500 m contour line. Among the 7 hill states of northeast, Arunachal Pradesh has the maximum geographical area and least in Sikkim. However, both have the continental climatic zones in this region.

Morphologically north eastern hills are marked by the development of a series of ridges and valleys, terraces, scraps, several geomorphologic or planar surfaces at different elevations (15 to 5000 m and above) etc. Only permanent snow cover exists around 28 and 7 per cent of the total geographical area of Sikkim and Arunachal Pradesh, respectively. Rivers pouring water from the adjoining hill states primarily constitute Brahmaputra drainage basin. The Himalayan (Sikkim and Arunachal Pradesh) rivers originate from the snow-clad mountains while from other states originate from the alive hills. It is very difficult to generalize the direction of the rivers. However, the rivers of Arunachal Pradesh and Sikkim are usually flowing from the north to south.

The soils of North Eastern Hill Region have developed in situ on different types of rocks of geological ages starting from Paleozoic to recent formation. The old rocks are inter-layered with tertiary and quaternary formations. Disang, Barail, Surma, Tipam and Duptila series represent the rock formation in Nagaland, Manipur, Mizoram and Tripura. Both Jaintia and Disang series are overlain by very thin thick Barail series, which is of considerable economic importance as it contains thick seams of coal. Manipur valley soils have developed from the transported material formed from shale. The North Eastern and Western portion of Sikkim is made up of hard massive gneiss rocks, and the gneiss of south Sikkim is highly micaceous, muscovite and biotic being present.

Climate varies from subtropical to alpine, and even frequently from place to place at short distance in Arunachal Pradesh and Sikkim caused by rugged terrain and rapidly changes of topography. The climate of Arunachal Pradesh and Sikkim varies from sub-tropical to extreme alpine type and in other states, almost limited to subtropical to temperate. The major part of this region receives annual rainfall from 2000-4000 mm. The hill slopes facing south-western monsoon currents receive large amounts of rainfall than the enclosed valleys. All the botanical zones from tropical to alpine are found in these states due to its geographical situation, climate and altitude. These states are veritable storehouse of medicinal and economically important plants. Arunachal Pradesh and Sikkim are renowned for its Rhododendrons and orchids and for high altitude Primulas, Meconopsis and Blue poppies.

Soil

Knowledge of land resources and its potential is an essential prerequisite for planning of optimum land use and subsequent long-tern economic development. In NEH the physical factors of land like topography, slope, drainage density, geological materials and forest cover are solely responsible and directly are indirectly related to soil properties. The steep slopes, high relative relief feature and higher density of drainage of the mountain and hill areas stimulate soil erosion risks with higher degree of sediment loss and also decrease the fertility of the soil of the land scape.

The National Bureau of Soil Survey and Land Use Planning (NBSS & LUP) and Regional Centre, Jorhat and Calcutta surveyed the soils of the hilly states of this region based on three tier approach (land form analysis, field survey, laboratory investigation, and cartography and printing), soil resource map of the state (on 1:250,000 scale) has been prepared for optimizing land use but also form an important base for delineating agro-climatic zones at the state level for analogous transfer of agro-technology.

The soils of these hilly states were classified into 5 orders, 22 great groups and 45 sub groups and distribution of soils orders in different state are given in Table1. Thus the soils of this region are quite variable depending on the variability of climate, physiographic, parent materials and native vegetation. The depth of soils at different places varies considerably because of differences in physiographic position and slope. Geographical erosion generally exceeds soil formation except under forest cover. Mass movement of soil in the form of slips, glides, and mud flows and solution forms are common in this region due to high rainfall, *jhuming* on sloppy lands, deforestation, faulty methods of cultivation and road construction.

Table 1. Major soil types of North Eastern Hills Region

Soil order	**State (per cent of geographical area)**						
	Meghalaya	**Manipur**	**Sikkim**	**Tripura**	**Nagaland**	**Mizoram**	**A. P.**
Alfisols	3.6	0.2	-	5.0	4.8	2.6	0.3
Entisols	10.7	23.1	43.0	8.0	4.0	21.5	35.6
Inceptisols	45.7	38.4	33.4	80.0	76.0	37.3	37.3

Mollisols	-	-	23.6	-	-	38.6	-
Ultisols	40.0	36.4	-	7.0	17.2		14.2
Misc. land		1.9					12.6

Source: Velayutham and Bhattacharya (2000)

The soils are formed in situ excepting at foothills and near the rivers and streams, which are colluvial and alluvial in origin. The soils on steep slope in the upper part of the hills are varying shallow to very shallow. On hill terrain the soils are light coloured, highly leached, poor in bases low cation exchange capacity with low active clays. The soils are quite rich in organic carbon with decreasing trend as the depth of soil increased. Soils in the valleys and thick forest are fairly rich in organic matter and well drained. Most of these acidic soils possess high amount of exchangeable Al^{3+} throughout soil column with almost increasing trend, indicating that they are still have preserved some weatherable minerals which liberate Al ions from the edges of clay mineral through weathering processes. The soils developed on Bomdila group of rock are rich in clay content as compared to others. ***Jhum*** (Shifting Cultivation) has resulted in heavy loss of organic matter from the soil that suffers from erosion hazards. The amount of clay and soil pH tends to decrease as the elevation increases with an increase in sand, organic matter and cation exchange capacity of soil. Steep slopes accelerate the removal of soil separates and exchangeable cations through various agencies like high intensity of rainfall, hill agriculture and movement of human being and animals etc. Clay Content is invariably low in the narrow valleys, because run off sediments do not get chance for setting and are ultimately diverted to the main drainage. However, in wide valleys, poorly permeable or poorly drained soils are heavy in texture or colluvial of alluvial origin formed from the adjoining hills eroded material as noticed in Manipur valley with shale and sedimentary parent rock. The adjoining hills are acidic in reaction while valley soils are acidic to neutral in reaction due to deposition of bases brought by surface runoff water and eroded materials.

Soil Productivity Problems

The major soils problems of the region are soil degradation, soil acidity and soil erosion due to shifting cultivation. Most severely affected states in the NEH region includes Mizoram (about 89% of the land area is degraded), Nagaland (about 60% is degraded land), Meghalaya (about 54% is degraded land) mainly due to water erosion and soil acidity and about! 60% land area of Tripura is degraded on account of water erosion, water logging/flooding along with soil acidity (Table 2). Soil acidity in general and subsoil acidity in particular are the major limiting factors for low productivity potential of these soils. The management of acid soils in this region should aim at either liming to neutralize exchangeable Al^{3+} or selection of Al-tolerant crops.

Table 2. State-wise soil degradation status of the NE

State	Water erosion	Water logging/ Flooding	Soil acidity	Complex problems	Total deg. area	TGA of State	Degradation Area (%)
Assam	688	37	612	876	2213	7814	28.2
Arunachal Pradesh	2372	176	1955	-	4503	8374	53.8
Manipur	133	111	481	227	952	2233	42.6
Meghalaya	137	07	1030	34	1208	2243	53.9

Mizoram	137	-	1050	694	1881	2108	89.2
Nagaland	390	-	127	478	995	1658	60.0
Tripura	121	191	203	113	628	1049	59.9

Source: Gajbhiye (2006)

The soil productivity related constraints limiting the productivity are briefed below:

- Soil acidity and related fertility constraints.
- Flooding/waterlogging in valley land, depression in foot hills.
- Sand deposition in Brahmaputra and Barak valleys on fertile lands.
- Loss of top-fertile soil through runoff water on sloppy lands and exposure of acidic poor fertile soils.
- Prevalent of shifting agriculture (*Jhum*) of short cycle of abandoned period (3-5 years) on sloppy hills resulting land susceptible to erosion devoid of vegetation and poor recycling of nutrients.
- Scarcity of water for crop production during *rabi* crop.
- Low use fertilizers and its low efficiency.
- Low status of soil available phosphorus cause by acidic soil reaction limiting the productivity after soil acidity.
- Low rate of improved agricultural practices adoption such as improved varieties, fertilizers, pesticides, weed management, cultural operations, sowing methods, etc.
- Stoniness and limiting soil depths in places for hill agriculture.

Soil acidity is one of the most important factors affecting the productivity of crops and NEH soils occupy 54% of the total country acidic soils having pH below 5.5 in this region (Table 3). Under such type of soils (pH below 5.5), acidity plays major role in determining the nutrient availability to plants and in many instances by specific mineral stress problems. Acid soil infertility is a syndrome of problems that affect plant growth in soils with low pH. This complex of problems arises from toxicities and deficiencies in acid soils are related to:

1 Presence of the toxic concentration of Al and to a lesser extent Mn toxicity in many species,
2 Deficiency of bases (Ca, Mg, K) and their poor retention power,
3 High P fixation capacity of soil caused by highly active Al and Fe surfaces, rendering it unavailable to plants,
4 Deficiency of Mo, especially for the growth of legumes,
5 Reduction of soil biological activities,
6 Impairment of N_2-fixation by legumes caused by poor survival of microsymbiont and inhibition of nodulation,
7 Fe and Mn toxicities in submerged rice.
8 Bacterial growth is inhibited by nutrient toxicities and low nutrient availability in acidic soils, and
9 Soil acidification changes the decline balance between groups of living organisms in the soil, due to the preference of soil fauna for specific pH environment. Generally, soil fauna has tolerate the soil acidity to cope with large changes in soil pH, however, most macrofauna including deep burrowing species such as worms and termites tend to decrease in abundance in acidic soil conditions.

In majority of the acidic soils, the P deficiency may limit the crop productivity after soil acidity. In the acidic soils, the availability of phosphorus is reduced due to high P fixation capacity and/or precipitation of P to less soluble Fe- and Al-phosphates. Moreover, Al can immobilize P on root surfaces, cell walls, and in the free spaces of plant roots as insoluble Al-P, preventing the translocation of P from roots to shoots and limit the uptake of relatively immobile P in the soil to plants.

Table 3. Extent of the acid soil in NE region (million hectares)

States	pH <5.5	pH 5.5.-6.5	Total acid soil	Geog. area	% Geog. area of acid soil
Arunachal Pradesh	6.52	0.27	6.79	7.786	81.08
Assam	2.33	2.33	4.66	7.844	59.41
Manipur	1.87	0.32	2.19	2.233	98.07
Meghalaya	1.19	1.05	2.24	2.243	99.87
Mizoram	1.27	0.78	2.05	2.208	97.20
Nagaland	1.60	0.05	1.64	1.658	99.50
Sikkim	0.60	-	0.60	0.710	84.51
Tripura	0.81	0.24	1.05	1.049	100.00
Total NE	16.19	5.04	21.23	26.219	80.97
India	30.00	58.94	89.95	328.726	27.36
% NE of India	53.97	8.41	23.60	7.97	6.45

Source: NBSS&LUP

Land use

The land use of NEH is the result of techniques and customs by different ethnic groups before their migrations as well as of their later adaptation to the location specific nature of soils and landscapes of settlement. The land use pattern of NEH region is strongly influenced by the elevation, climate and mountainous terrain, especially in the field of agriculture and forestry. Forest is the main land use in these states (Table 2) under varying forest cover densities followed by alpine barren land, snow and glaciers. Excepting Sikkim and Tripura, all states had the forest cover above 70% of geographical area. (Table 4). However, reserve forest area is below 60% of the reported area in most of states excepting Arunachal Pradesh and Mizoram (above 70%). The net cultivated area varied widely from 3.37 (Arunachal Pradesh) to 26.41% (Tripura) and is approximately 6.8% of the total reported area of the states (Table 2).

Land Degradation

Degraded lands are those land, whose conditions has deteriorated to such an extent that it can not be put to any productive use, except current fallow due to various constraints. Soil degradation is the reverse of soil health, resulting persistent decrease of soil potential productivity and loss of environmental regulatory capacity. Degraded lands and stress sites can be categorized into the following:

1. Ecologically degraded lands
2. Land degraded as a result of developmental activities

Land under first category includes degraded forestlands, severely gullied and eroded lands, and areas affected by shifting cultivation. The second category consists of mined land, waterlogged areas and industrial wastelands.

Land degradation indicators

Indicators are instrument to help us monitor whether we are on the path towards or away from sustainable land use systems. The visual indicators for the different types of land degradation are given below. These types of land degradation are interrelated. Land degradation manifest itself chiefly in the form of water erosion, followed by wind erosion, and chemical deterioration. The causes of land unproductively are various. Barren and wasteland are generally called unproductive land which is at present not use for production because of their unfavourable conditions for production. Wasteland has become unproductive as a consequence of human interference with nature resulting in degradation of the soil.

Visual indicators of land degradation

1. Rills
   Gullies
2. Pedestals
3. Armour layer
4. Accumulation of soil around clumps of vegetation or upslope of trees, fences or other barriers
5. Exposed roots or parent material
6. Muddy water/mudflows during and shortly after storms
7. Sedimentation in streams and reservoirs
8. Dust storms/clouds
9. Sandy layer on soil surface
10. Parallel furrows in clay soil or ripples in sandy layer
11. Bare or barren spots
12. Efflorescence
13. Soil particles unstable in water
14. pH
15. Nutrient deficiency/toxicity symptoms evident on plants
16. Increased incidence of plant disease/morphological irregularities (e.g. stunting)
17. Decreasing yields
18. Changes in vegetation species
19. Plough pan
20. Restricted rooting depth
21. Structural degradation, including compaction
22. Poor response to fertilizers
23. Decrease in organic matter (light coloured soils)
24. Increased sealing, crusting and run-off, reduced soil water
25. Decrease in number of earthworms/ants and similar

   In addition to above indicators following four indicators are also identified as core land quality indicators.

1. Water quality
2. Forest land quality

3. Rangeland quality
4. Land contamination/pollution

Causes of Land Degradation

The land degradation has been degraded mainly due to over exploitation of forest for fuel, timber and fodder surrounding human settlement, shifting cultivation on hill slopes, improper land use practices, population explosion including livestock, infra-structure development and mining without proper changes in land management caused by land tenure systems of different ethnic tribes. In NEH, there are high percentage of area under wasteland due to shifting cultivation (*Jhum*) in Nagaland, Assam hills, Manipur, Meghalaya and Mizoram (Table 5) and in Sikkim and Darjeeling hills is caused by degraded forest. On such lands, soil erosion through running water is the main agent of land degradation devoid of vegetative cover. The existing community/private land system has been excessively exploited for survival and realization of short-term objective without taking care of soil health. The major cropland areas of hill agriculture are eroding faster than natural processes and have been significantly degraded.

Landslides during monsoon adversely effect utility services such as roads, power generation, reservoirs, human settlements, trade, tourism and other developmental and economic activity parameters effecting on-site slope processes. This process not only affects the land/soil but also cause loss of bio-diversity including base resource itself, and human life. The main causes, which are leading towards the land degradation in this region, are briefed below.

Deforestation: The deterioration in the productivity of the mountain environment has now been defined as a function of vegetative cover of uncultivated land. As per government policy two-thirds of the hills should be under forest cover to prevent land degradation for the stability of fragile hill ecosystem. All the hill districts of Assam, Arunachal Pradesh, Manipur, Meghalaya, Mizoram and Nagaland had the forest cover more than 66%. Forest ecosystems of hills are being threatened by a number of factors namely;

(a) Loss of forest lands to agriculture (mainly for shifting cultivation), industries, infrastructures and human settlements.
(b) Loss of forestland due to multipurpose projects, construction of roads, transmission lines etc., quarrying, and encroachments.
(c) Degradation causes by illicit felling, lopping for fodder and fuel wood, overgrazing, removal of forest floor litter, forest fires, over felling etc.
(d) Population explosion and encroachment of forest land.

The deforestation causes the:

- Loss of flora and fauna
- Loss in soil organic matter
- Soil erosion
- Increase in run-off and formation of sheet, rill and gully erosion
- Rise in atmospheric temperature

The deforestation of hill slopes has resulted increased sediment load of rivers emerging from the hill and mountains, causing the greater sedimentation load in Brahmaputra and its tributaries as compared to Ganges and local damage being proportionate to angle of slope.

Increasing population pressure: The population density in mountain areas has moved from low to very high following the introduction of modern health care. If population of 2001 is taken into number of people per hectare of arable land; it is found that densities would greatly exceed those of the progressive plain lands (e.g. Punjab and Haryana). In that area double/triple cropping has become widespread, that is not practiced at higher elevations due to low temperature. The increased population in subsistence mountain society has led to: (a) reduced amount of land per family, (b) deepening poverty, (c) massive deforestation, and (d) cultivating marginal sloppy lands leading towards more degradation.

Cultivation along the steep slopes: Most of the land belongs to VI and VII classes of land capability and being used for agricultural crops production along the slope. Continuous increases in population has resulted in further extension of cultivation on steeper slopes with much less fertile soil is one of the major cause of the degradation of land productivity. The loss of soil through runoff on such lands varied from 10.8 t/ha to as high as 62 t/ha depending upon land use for different types of agriculture (Prasad *et al.,* 1986). The loss of topsoil reduces the inherent productivity of land through the loss of nutrients and degradation of the physical structure of the soil. It also increases the cost of food production.

Livestock growth: The livestock population has also put tremendous pressure on forest and pasture resources. Fodder is either available directly in the form of grasses, which is grazed by livestock or collected by the livestock owner or in lean season (November to February/March) produced by lopping of leaves and twigs of certain trees and shrubs. Under the present system of unrestricted grazing of animals during the some part of the year on village common land or on government land causing no cast to the farmers and resulting regression of the natural cover to sparse inferior grasses and unpalatable weeds. Over grazed forest results (i) damage of ground vegetation by overgrazing and trampling, (ii) compact the soil and increases in run-off, and (iii) accelerates the top soil erosion.

Shifting cultivation: In the northeastern hill region of India, shifting cultivation is a common practice on hill slopes and it is the single largest factor for the loss of forest cover in this region (Table 6). This practice is known as *'Jhum'*. Quantum jump of population pressure of tribal societies practicing shifting cultivation and declaration of reserve forests by government, have shortened the fallow periods, which on an average presently is 3-5 years compared to 25-30 years half a century ago. The loss of soil under shifting agriculture has been reported in the tune of 5 to 83 t/ha depending upon crops grown and slope of the land (Prasad *et al*., 1986). The productivity of lands under shifting cultivation are directly dependent on the rest or fallow periods, during which such lands rebuild their store of organic matter, essential nutrient for remunerative agricultural yields predominantly stored in forest ecosystem rather than the soil.

Road construction: Earlier Himalayas were, for most part, accessible on foot along trails the only road led to famous hill stations. The Chinese invasion in 1962 and its military presence on the Himalayan frontier prompted a massive road construction in great haste for military purposes outweighed concern for careful planning and sound engineering. After road construction, the extensive slope instability resulted in the production of enormous volume of debris, usually dumped on road and further down slope during heavy monsoon storms in the form of debris flows, rock falls, rockslides and mudflow. The annual debris production per linear kilometer of roadbed for three specific roadways calculated as (Valdia 1987).

Western Himalayan: Jammu and Srinagar	724 m^3
Central Himalayas: Tanakpur - Tawaghat	411 m^3
Eastern Himalayas: Arunachal Pradesh	719 m3
Mean	550 m3

Thus road development causes destruction of downslide vegetation cover as well as the agricultural terraces of local subsistence farmers, who are usually not compensated for their losses. It is assumed that landslides produced by road construction are responsible for increase of suspended load in the local head streams of Brahmaputra. However, the development of road has also produced a major socio-economic impact, which includes greater accessibility of hither to remote forests to commercial logging, ease of movement of people both from the mountains to cities of the neighboring plains and from the plains to the mountains.

Mining activities: Open cost mining results loss of productive cover, soil loss and serious environmental degradation. Land after mining generally does not remain conductive to tree growth. The extensive surface excavation of sloping land not only damages the ecosystem within the periphery of mined area, but also sets a chain of ecological disturbances for beyond, down the watersheds. The recklessness of uncontrolled and irresponsible development of open coal mining and limestone quarrying is a most shattering impression to the Jaintia Hill of Meghalaya.

Land tenure system. In most of north eastern hill states, the land belongs either to community chiefs or village headman. The tenancy system is as such that most of the cultivators have no land right and the temporary piece land for cultivation is being decided by the heads. This has resulted the loss of soil productivity because tenants have the short term linkage to that piece of land without taking the care of soil building processes.

Restoration of degraded lands

Understanding the processes, factors and causes of land degradation is a basic prerequisite towards successful restoration of the productivity of degraded lands. Knowing the category of soil degradation is an important stage to restore the soil quality and its productivity by preventing soil erosion, promoting high biological activity, increasing soil organic matter content and increasing rooting depth of plants. The prevention, conservation of resources and restoration of the productivity of degraded soils in the northeastern hills can be successfully restore to some extent following the mechanical approaches and ecological approaches.

Mechanical approaches

Mechanic approaches are used in cases of extreme degradation, where other approaches are not possible or slow. Mechanical measures include: check dams (masonry, stone, loose rock, log check dams, etc.), level bench terraces, stone terracing, contour drains, contour bunds, earthen dam/reservoirs, gabion, stream channeling, etc. to absorb most of the surface water into the soil before reaching to streams. By adopting terracing and protected waterways, the steep slopes could be cultivated safely and profitably. The terrace risers can be planted with local grasses to protect the soil loss and produce forage for cattle. Fords culverts and bridges are needed in large enough for crossing small streams, sediment, debris etc. to remove the water before it has a chance to concentrate and cause erosion. During construction of road, to avoid mass movement of soil, the best way is to place the culverts to the natural stream channel as closely as possible.

Ecological approaches

Contour ridges; check dams and bench terraces involve high cost of construction and maintenance, which poor farmers cannot afford to invest. Ecological measures are more effective when used in combination with engineering techniques. Many terrace areas have failed not because of design or construction, but owing to negligence in protection and maintenance. Mechanical methods of soil conservation are acceptable to farmers where these are the part of traditional culture (e.g. terracing in Nagaland and Sikkim for the cultivation of irrigated rice). Slope stabilization includes re-vegetation and other engineering measures to control surface erosion on road cut and fill slope and waste and borrow areas. Wattling and staking is a combination of mechanical stabilization and re-vegetation on road fill banks and similar areas of base slopes for building new roads in the hilly terrain. It helps to reduce the run-off and its velocity, barrier or buffer strip for controlling soil and conservation of moisture for stake growth.

Ecological approaches include vegetative barriers on field boundaries, contour bunds and ridge, appropriate agroforestry practices, vegetative filter strips, live checks etc. to promote in-situ moisture conservation. In brief the objectives of ecological approaches to restore land degradation are:

i) to stabilize slopes and control of sedimentation in the stream,
ii) to establish dense and diverse vegetative cover to provide ecological stability to the site and act as soil amendments,
iii) to ensure nutrient cycling and enrichment of soil,
iv) to fulfill fuel, fodder and other requirements of local people, and
v) To enhance the ameliorative value of the site.

The main ecological approaches are described in brief for the sustainability of land.

Stabilization of landscape: It can be done through the grading of slopes before surface treatment and re-vegetation or cut-off-ditches with a variety of terraces. With an effective vegetation cover, the establishment of plants may control gradients without supplemental mechanical measures in protecting the landscape against water erosion. Catastrophic events (such as land slides) cannot be altogether prevented, but management action can be implemented to reduce the frequency of events by preventing human occupation, economic development therein and planting of deep-rooted trees and/or shrubs on steep slopes.

Restoration of mined areas: Land after mining generally does not remain conductive to tree growth. The ecological rehabilitation can be attempted by using plant species of economic value to local population and also compatible to the degraded sites must have the following characteristics.

1. species capable of colonizing degraded sites,
2. species capable of foxing atmospheric nitrogen as well as conserve the soil,
3. species capable of producing fuel, fodder, fibre for local population, and
4. Species, which are of aesthetic value.

Maintenance of soil fertility for crop productivity: Usually the relationship between soil erosion, nutrient runoff losses, organic matter depletion, and beneficial effects of conservation and management practices occur simultaneously. Soil conservation not only includes control of erosion, but also recognizes equally the importance of soil fertility maintenance. The management practices include the maintenance of soil fertility, soil quality and productivity. Soil fertility remains at an optimum level if regular doses of manure and fertilizers are added to it and soil pH adjusted to 5.5 to eliminate the aluminum toxicity (Patiram *et al.* 1994). Multiple cropping, inter-cropping, relay cropping, inclusion of legumes in rotation, strip cropping etc. ensure better crop productivity, besides maintaining soil fertility. Plant nutrients in crop residues, litter from forests cattle manure and domestic-waste composts comprise the working capital of plant nutrients because farmers can transfer and allocate those nutrient sources to a particular crop in a crop rotation and to a particular plot. The legumes in farming systems are essential to ensure and sustain agriculture with a moderate level of agricultural output. The integrated plant nutrient system (IPNS) is a step in the direction of sustainable agricultural development through necessary modification of the conventional technology to improve soil health by adopting the best time, method and source of application and utilizing sources other than chemical fertilizers such as organic manure, bio-fertilizers etc. to meet part of the nutrient needs of crops and cropping system. This region is very much favourable for the agricultural development based on biomass production as a result of humid climate. Efforts are needed for its adaptability at farmer's level, because in most of the cases farmers have the availability of organic manure and biomass available around the habitat with the limited purchasing power of households for fertilizers.

Forestation and Agroforestry: Forests, hydrological and from the erosion control point of view, provide more protection due to closed system as long as they are maintained as forest lands. Open/degraded forest land + forest blank + scrubs in reserve forest and alpine scrub can be restore with an integrated approach through afforestation to change the unpleasant look into pleasant view of the site. Restoration or afforestation makes the unproductive lands to productive by minimizing erosion and rebuilding of nutrient budget. In the initial stage severely eroded lands, require complete forest cover of local origin coupled with protection from grazing. The local perennial tall tufted grass species Amliso (*Thysanolaena agrostis*) can reclaim and protect the degraded land, terrace risers, water ways, land between trees, and vulnerable points, provides fodder to animals in winter and spikes for brooms.

Agroforestry is a combination tree and crops, offers the viable alternative to arrest the degraded land. In this region, tribal people were/are surviving directly or indirectly tree based farming system. Agroforestry has a long tradition in this region, where in grain crops, rhizomatous crops, pineapple, coffee, tea, spices and vegetables are being taken with a number of fruit and other trees, such as pine, pear, plum, areca nut, mandarin, guava, coconut, jackfruit, banana, large cardamom with trees (mainly *Alnus nepalensis* and *Schima wallichii*), fodder trees (*Erithrina* sp., *Ficus* sp., *Bauhunia* sp., *Artocarpus lakooch*, *Litsaea polyantha*, etc.) in the different agroclimatic zones. The land not suitable for agriculture due to high slope can be used for grasslands or forestry. The agroforestry practices enhanced the soil productivity by improving (i) pumping up of nutrients from subsoil by deep-rooted perennials, (ii) reduction in leaching losses through the capture of mobile nutrients by the well developed deep, spreading root systems of perennials, (iii) maintenance of soil organic matter through the supply of above- and belowground litter and pruning of tree leaves and branches, (iv) addition of nitrogen through biological N-fixation by nitrogen fixture, (v) protection from soil erosion, and (vi) maintenance or improvement of soil physical properties. In NEH region, Nagas use the *Alnus nepalensis* for fertility rejuvination of *jhum* land. Appropriate agro-forestry systems have the potential to check soil erosion, maintain soil organic matters and physical characteristics, augment nitrogen buildup through nitrogen fixing trees and promote efficient nutrient cycling. Where trees are integrated extensively with crop and livestock production. Large cardamom with shade trees on hill slopes unsuitable for crop production, an integral part of the farming system in Sikkim is ecologically sustainable (Patiram *et al.*1996). The combination of trees, grasses, herbs and shrubs along with large cardamom plantation arrest the flow of water; reduce the risk of soil erosion and water pollution hazards. Bamboo thickets along the drainage channels on steep slope and earth works, grasses on terrace risers and on marginal land to stabilize the soil against degradation, fodder trees around the settled agriculture, and intercrops under fruit trees and forest give production from land occupied. The multistory homestead gardening possesses the inherent capacity to arrest land denudation. *Thysanolina maximum* on degraded lands for broom and fodder, minor forest produce such as food, fibre, and medicine, wild animals for hunting etc. The positive interaction among components (trees/shrubs and crops/animals) to obtain a more diversified and/or more sustainable production from the available resources and physical environments that is possible under socio-economic conditions. The variation of climate due to altitude further provide ample scope for growing a variety of agricultural crops, multipurpose tree species and fruits of tropical to temperate climates for the effective utilization of land under agro-forestry for its sustainability.

Proper land use planning on watershed basis: The planning of an area development can be best tackled on a natural drainage unit called 'watersheds' with a view to develop resources in such a manner so as to get maximum benefits to the people by maintaining ecological balance through continued long-term efforts and commitments for example maintenance of infra-structure, protection and judicious use of land, water and forest resources to meet the continued demands, etc. The land use planning is the systematic assessment of physical, social and economic factors in such a way as to encourage and assist land users in selecting options that increase their productivity with sustainability and meet the needs of society (FAO 1993). In order to implement the land use planning at catchment for the hilly terrains should have following objectives of:

1. Optimization of production from agriculture, forests, plantation (large cardamom), mixed farming systems and others on a sustained yield basis for self-sufficiency in basic needs.
2. Control of land degradation to their primary production potential.
3. Development of wasteland for profitable biomass production.
4. Exploitation of important mineral resources with proper planning for rehabilitation of mined areas.
5. Efficient utilization of perennial water resources by reducing run-off and sedimentation.
6. Provide the security for food, fodder, fibre, fuel, timber etc.
7. Protection of scenic beauty, natural vegetation, wildlife and birds of montane region for appreciation to next generation.
8. The modification of indigenous knowledge based on latest technical know-how by inter-generations wisdom of local inhabitants of the region through native means to suit their conditions.

. The preservation of natural ecosystems, scenic areas and wildlife habitat represents another dimension of many watershed projects. According to established practice, climate, soil, landform, hydrology etc. of an area, the human intervention should be restricted to the choice of a crop, a livestock or a forest type. Information on soil and related properties can be obtained from soil survey and geological information system (GIS) to delineate the soil and land suitability for different useful purposes depending upon the household and community needs for sustainable hill ecosystem.

Integrated mountain development: Integrated mountain development includes a policy approach in development planning of all sectors of energy, transport, tourism, industry, agriculture, horticulture, social issues of population policy, public health, education, and resource conservation techniques. It is a process where by optimum use of mountain resources can be sustained over several generations in the context of available technology. It also includes preservation of gene pool, augmentation of the well being of the local people, controlled and acceptable downstream effects. Major efforts are needed to diversify the mountain economy and living standard of people with emphasis on hill environmental protection and sustainable development.

Transformed shifting agriculture: The intelligent application of modern low cast, and energy techniques could be expected to increase the yield crops under shifting cultivation without affecting the viability of the system. Improved fallow with woody and herbaceous legumes with primary purpose of fixing N as a part of short fallow (2-3 years) to increase the accumulation of large quantities of N and to provide a residual effect to two or three subsequent crops. The introduction of plantation and horticultural crops like rubber, coffee, tea, banana, citrus, black paper, cashew, spice trees, pineapple etc. on *jhum* fields on sloppy hills are the promising alternatives, provided free food for some time to cultivators to gain confidence. The locals without breaking their traditions can achieve this through a reasonable share of profits after processing and marketing.

Farming system approach: The appropriate hill farming system is the need of hour, which would permit continuous sustainable production and the same time well, adapted to the requirements of farming community. Within an agro-ecological zone, several farming systems are found in the hills with variation in resource endowment, preferences, and socio-economic position of the specific family. Sound soil conservation and soil management practices should be an integral part of such farming system, to suit the specific location conditions of the varying elevations of hills. In economic terms, there is great potential for the development of commercial production of tree and perennial crops (large cardamom, tea, coffee, black pepper etc.) on the slopes for export market.

Artisan manpower development: Traditional handicrafts represent the physical manifestation of tradition, whose value transcends the economic and on the other hand hold the potential to create a vibrant rural economy. The indigenous handicrafts and handloom along with other rural development initiative would not only generate jobs, but also keep alive the land resources, its biodiversity for protection.

Eco-tourism: This region has the congenial environments of tourism and friendly, hospitable multi-coloured people. At higher elevations above 2000 m eco-tourism is the other way to meet the people's needs through alternative employment opportunities leaving the land in natural way to maintain the beauty of hills. State government is providing facilities for the attraction of tourists in these states.

Conclusion

In the north-eastern region of fragile hill environment, inappropriate planning of infrastructure, deforestation, cultivation on hill slopes, population pressure per unit of arable lands, intensive utilization of available natural resources and prevalent of shifting cultivation, together are responsible of land degradation. Soil erosion through running water is the main cause of land degradation devoid of vegetation on hill slopes and often subjected to landslides during rainy season (May to September). Shifting cultivation on hill slopes is the major cause of loss of forest cover in these hill states. Mountain areas need to be protected, rehabilitated and developed as much as any other ecosystem or economy. The priority should be given to techniques and practices that can enhance production without damaging the environment. Contour ridge; check dams and bench terraces involve high cost of construction and maintenance so ecological measures with combination of engineering technique can be used to protect the hill environment. The integrated mountain with holistic approach viz., transformation of *jhum* lands, horticulture, livestock based farming with stall feeding, proper infra-structure development, artisan man power development, eco-tourism, and organic farming are the sound economically alternatives or options in the existing systems to achieve the desired results.

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Table 4. Land use pattern of northeastern hill states ('000 ha) (State of Forest Report 1999)

Land use	Arunachal Pradesh	Manipur	Meghalaya	Mizoram	Nagaland	*Sikkim*	Tripura
1.Geog. area	8374	2233	2243	2108	1658	710	1049
2.Reporting area	5495	2211	2241	2109	1538	710	1059
3. Forest	5154 (93.79)	602 (27.23)	935 (41.72)	1598 (75.77)	863 (56.11)	257 (36.20)	606 (57.77)
4.Misc. tree, crops & groves	44 (0.80)	24 (0.09)	159 (7.09))	0	129 (8.39)	5 (0.70)	27 (2.57)
5.Not available for cultivation	48 (0.87)	1445 (65.36)	244 (10.89)	65 (3.08)	61 (3.97)	270 (38.02)	133 (12.68)
6.Permanent pasture and grazing land	N*	N**	0	0	0	69 (9.72)	0
7.Culturable waste land	N*	N**	473 (21.11))	174 (8.25)	70 (4.55)	1 (0.14)	1 (0.10)
8.Fallow land except current fallow	36 (0.66)	0	165 (7.36)	163 (7.73)	85 (5.53)	9 (1.27)	1 (0.10)
9.Current fallow	28 (0.51)	0	69 (3.08)	0	105 (6.83)	4 (0.56)	5 (0.38
10. Net sown area	185 (3.37)	140 (6.33)	216 (9.64)	109 (5.17)	225 (14.63)	95 (13.38)	277 (26.41)

N* and N** included in misc. tree crops and groves and non-agricultural uses, respectively; () indicates percentage

Table 5. Cumulative area from 1987-1997 affected by shifting cultivation (m ha) (State of Forest Report 1999)

State	Area affected
Arunachal Pradesh	0.23
Assam	0.13
Manipur	0.36
Meghalaya	0.18
Mizoram	0.38
Nagaland	0.39
Tripura	0.06
Total	1.73

Table 6. Loss or gain of forest cover (sq. km) in 1997 assessment as compared to 1995 in the north-eastern states (States of Forest Report 1997)

State	Forest cover		*Loss*			Gain			Net
	1995	1997	Sh.C.	Others	Total	NRSC	Others	Total	Change
Arunachal Pradesh	68,621	68,602	75	-	75	56	-	56	-19
Assam	24,601	23,824	257	159	416	163	16	179	-237
Manipur	17,558	17,418	603	-	603	463	-	463	-140
Meghalaya	15,174	15,657	75	2	77	20	-	20	-57
Mizoram	18,576	18,775	292	-	292	491	-	491	+199
Nagaland	14,291	14,221	573	-	573	503	-	503	-70
Tripura	5,538	5,546	-	3	3	4	7	11	+8
Total	164,359	164,043	1,875	164	2,039	1,700	23	1,723	-316

Sh.C. and NRSC = Shifting cultivated and natural regeneration in shifting cultivation.

1.4 Oilseed *Brassica* Germplasm: Status, Utilization and Priorities

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Brassica is a genus of the Brassicaceae (Cruciferae), commonly known as the Cruciferae family. The family Brassicaceae, includes about 3,500 species and 350 genera, is one of the ten most economically important plant families (Warwick *et.al.,* 2000). *Brassica* contains about 100 species, including cabbage, cauliflower, broccoli, brussels sprouts, turnip, various mustards and weeds (Willis, 1973). *Brassica* crops are among the oldest cultivated plants known to humans with written records dating back to ca. 1500 BC (Prakash, 1980) and archaeological evidence of its importance dating back to 5000 BC (Yan 1990). The important members of this group are: *Brassica napus, B. rapa,* and *B. juncea* -sources of canola and industrial oil. Oilcake is used as an animal feed. Further, *Brassica* species have several medicinal uses. The utilization of oilseed Brassicas is steadily increasing. Rapeseed-mustard comprises a group of seven cultivated oilseed Brassicas of tribe Brassicae within the family Brassicaeas. They are the main source of edible oil in Indian diet after groundnut. The different species are, Indian mustard (*Brassica juncea* (L.) Czern. & Coss.), toria (*B. rapa* L. ssp. *toria)*, yellow sarson (*B. rapa* L. ssp. *yellow sarson)*, brown sarson (*B. rapa* L. ssp. *brown sarson)*, gobhi sarson (*B. napus* L.*),* karan rai (*B. carinata* Braun.) and taramira (*Eruca sativa* Mill.*)*. Oilseed Brassicas represent a rich diversity (Table 1), which are being cultivated in 23 states and union territories (Misra and Kumar, 2008). However, much of diversity is concentrated in the Indo-gangetic plains and sub-mountain Himalayas.

Table 1. Diversity in rapeseed-mustard and related species (*after Kumar and Misra 2007*)

Species	Genome	Chr. No (*n*)	Mating system
Mustard			
Brassica juncea	AB	18	Self compatible*
Brassica carinata	BC	17	Self compatible
Brassica nigra	B	08	Self incompatible
Brassica tournefortii	T	10	Self incompatible
Sinapis alba	S	12	Self incompatible
Rapeseed			
Brassica rapa (syn .B. campestris)			
ssp. *toria*	A	10	Self incompatible
ssp. *yellow sarson*	A	10	Self compatible
ssp. *brown sarson*	A	10	Self incompatible
Brassica napus	AC	19	Self compatible
Eruca sativa	E	11	Self incompatible
*Brassica oleracea***	C	09	Self incompatible

**Out crossing 5-15per cent, ** =Vegetables*

The Brassicaceae, is distinguished on the basis of the presence of conduplicate cotyledons (i.e. the cotyledons are longitudinally folded around the radical) and/ or two-segmented fruits (siliquae), which contain seeds in one or both segments, and only simple hairs, if present (Misra, 2008a). Three characteristics separate the mustard family from all other plant families:

- The stamens are tetradynamous, meaning there are four long stamens and two short stamens in each flower.
- The flowers have four petals that form a cross, hence the alternate family name *Cruciferae*.
- The pods have a thin translucent, frame-like inner membrane, the replum, that separates the two sides of the pod and to which the seeds are attached, called siliqua.

Importance of oilseed brassica

Brassicas play an important role in the world agriculture as oilseeds, vegetables, forage and fodder, green manure and condiments. Indian mustard, is predominately play important role the oil seed economic A large proportion of mustard oil is used directly in cooking, the oil is also used in the manufacture of salad dressage and table oils, confectionery fats and shortenings which is two are used in making cakes, biscuits, pastries and many other products. It is also of great importance in the manufacture of margarine. The fatty acids and their derivatives are widely used for industrial purpose. Oils may not be used directly in the preparation of paints, linoleum or inks, due to its semi-drying nature. However, its derivatives and fatty acid can be used for this purpose. It is also used in production of rubber, tanning industries, as lubricants, and manufacture of soaps, detergents and bonding compounds. It seems likely that many new uses will be found for oil in future, such as medium for pesticide application, as herbicide additives and as fuel in the form of biodiesel. Oilseed cake or meal is a byproduct during the extraction of oil from the seeds. It is an important source of protein for animals and it's currently being considered as a potential supplementary source for human beings. The cake has 35 to 40percent crude protein depending upon the variety as well as condition of growing and processing. The amino acid content is comparable well with soybean meal, but it is richer in sulphur amino acids and poorer in lysine. The fiber content in meal is very higher, as compared to soybean meal, which lead to a lowering of the metabolically and digestible energy values and decrease in the bioavailability of minerals. The low glucosinolate meal is good food for young ruminants and lactating cows, piggery and poultry purposes (Kumar *et. al.,* 2004). The economically most important product is oil. The mustard oil contains substantial amount of unsaturated fatty acid and the low concentration (around 7 percent) of saturated fatty acid. In unsaturated fatty acid it contains oleic acid (8-40percent), lenolenic acid (5-10 percent), linoleic acid (10-29 percent), eicosinoic acid (5-12 percent) and erucic acid (40-55 percent). The *Brassica* seed meal (oil cake) contains: protein (36-38 percent), carbohydrate (14-16 percent), fiber (10-15 percent), moisture (6-8 percent), ash (4-6 percent), mineral (3-4 percent), vitamins (0.7-0.9 percent) glucosinolate (2-3 percent), phytic acid (3-6 percent), sinapine (1-1.5percent) and 1.6-3.1 percent of tannin (Agnihotri and Kumar 2004).

Area, production and yield of oilseed brassicas

Rapeseed- mustard crop is grown in subtropical and tropical countries and total production in world was 46.27 mt from 26.79 m ha with yield of 1730 kg/ha during 2006-07.The major rapeseed-mustard producing countries are China, India, Canada, Germany and France. In the world India ranked second and third for area and production, respectively. In India, rapeseed-mustard crops accounted for 29.1 percent of the total oilseeds production and 26.1 percent of the total oilseed area during 2005-06. Globally, India accounts for 26.5 percent and 16.6 percent of the total hectarage and production of rapeseed-mustard, respectively (Anonymous 2007). In India, oilseed crop and rapeseed-mustard group of species accounts for 14.1 and 3percent of the gross cropped area, respectively. Among the oilseed crops, rapeseed- mustard ranked second after groundnut in total oilseed production in India. Rapeseed-mustard is the major source of income for the marginal and small farmers in rainfed areas. Because of its less water requirements (80-240 mm) and thus fits well in the rainfed cropping system. The average yield of these crops in India varies from 900-1200 kg/ ha. This crop occupying about 6.18 m ha area and 7.36 mt production with 1190 kg/ha average yield during 2008- 09, of this around 35percent area is under rainfed. Among the cultivated oilseed *Brassica* over 75percent of area and production is of Indian mustard (Misra 2004a, Misra 2008a). It is predominantly cultivated in Rajasthan, Uttar Pradesh, Haryana, Madhya Pradesh, Gujarat, Himachal Pradesh, Bihar, Assam, West Bengal, Orissa. Rajasthan ranked first in term of production with acreage and production around 40percent (Misra 2008a). In Rajasthan, Bharatpur region ranked first in of area for production followed by Alwar, Sawai Madhopur, Karoli, Sriganganagar, Jhunjhunu, Jaipur, Ajmer, Siker and Tonk.

Brassica germplasm

Plant genetic resources or germplasm are the key point of any agriculture production system. Genetic resource provides basic raw materials to crop improvement programmes. The success as well as pace of varietal development programmes depends upon available genetic variability for utilization. Germplasm constitutes reservoir of genes for resistance to various biotic and abiotic stresses. The sum total of all allelic sources influencing a wide range of characters constitutes the plant genetic resources of a crop. In broader sense plant germplasm resources is the sum total of genes in a crop species. However, "Biodiversity International" (formerly known as IPGRI: International Plant Genetic Resource Institute, Rome) the genetic resource defined as genetic material of plants, animal and other organisms that is of value for present and future generations of people and genetic diversity defined as the genetic variation present in a population and species. Therefore, both germplasm and genetic diversity are essentially required for undertaking successful crop improvement programme.

For strengthening genetic resources management; evaluation, conservation and documentation of germplasm, exchange under appropriate quarantine measures and distribution of germplasm for utilization as well as medium and long term conservation of valuable germplasm in national gene bank (in India located at NBPGR, New Delhi) for posterity of mankind are essential activities. Characterization and evaluation are important activities under plant genetic resources programmes. Characterization is the basic morphological description of accessions while a preliminary evaluation work is carried out in the course of rejuvenation. Germplasm should preferably be evaluated for important morpho-agronomic traits under different agro-climatic conditions and the systematic evaluation for various morpho-agronomic, quality traits, biotic and abiotic stresses, resulted in the identification of donors for use in the varietal improvement programme (Misra, 2008b).Worldwide, there are more than 90,000 accessions of *Brassica* conserved in 140 germplasm banks.

According to Boukema and Hintum (1999) five countries share nearly 60 per cent of Brassica germplasm holdings. They are China (17 per cent) followed by India (15 per cent), UK (10 per cent), USA (9 per cent) and Germany (8 per cent). Presently more than 57,700 accessions of different oilseeds are available in the country. NBPGR maintains over 21,700 accessions of various oilseed crops at its headquarters and regional stations. Of theses 9644 (till March 2009) belongs to rapeseed- mustard (Table 2). NBPGR has also instrumental for collecting 4095 indigenous rapeseed- mustard germplasm and introducing 3401 exotic accessions during 1986-2006 (Sharma and Singh, 2007). In our country we have over 14000 rapeseed – mustard germplasm accessions (Kumar and Misra, 2008).

Table 3. Status of germplasm at national genebank (till March 2009)

Type of germplasm	**Total Acc.**
Indigenous	9042
Exotic	246
Wild	65
Released/ farmers/ folk varieties	254
Genetic stocks	37
Total	**9644**

Table 3. Status of working germplasm collections in India (till July 2009)

Name of species	Total Acc.
Indian Mustard	9720
Brown Sarson	478
Yellow Sarson	1064
Toria	1918
Taramira	578
Gobhi Sarson	595
Karan Rai	243
Other	126
Total	**14722**

For effective utilization of oilseed Brassicas diversity concentrated efforts have been made. The systematic evaluation for various morpho-agronomic, quality traits, biotic and abiotic stresses, resulted in the identification of donors (Misra, 2008b) for use in the varietal improvement programme and subsequently resulted into release of 181 improved varieties and in addition to this 37 germplasm lines have been registered for utilization in crop improvement programmes till 2009. These include several varieties developed by utilizing direct selection of germplasm, hybridization with local germplasm and exotic germplasm (Misra and Kumar, 2008, Kumar *et.al.,* 2004). The improvement of quantity and quality of oils and oilseeds greatly depends on available genetic resources and their exploitation through conventional plant breeding methods and biotechnological techniques.

Germplasm collection and introduction

To collect indigenous variability of oilseed Brassicas, systematic efforts were made by erstwhile Plant Introduction Division of the Indian Agriculture Research Institute, New Delhi, under PL 480 scheme on “Collection, Evaluation and Maintenance of Brassica Germplasm" during 1960s and over 2000 accessions of rapeseed-mustard and allied genera were collected from north-eastern plains and hills, and north-western plains and central plateau. Sporadic efforts were made in 1970s to collect Brassica germplasm under multi-crop explorations. With the establishment of the Germplasm Management Unit in the Project Coordinating Unit (Rapeseed-Mustard) by the Indian Council of Agricultural Research at the CCS-Haryana Agricultural University, Hisar in 1981 and its subsequent shifting into the National Research Centre on Rapeseed-Mustard at Bharatpur (renamed as Directorate of Rapeseed- Mustard Research in 2009) in 1993, efforts were made to collect the indigenous as well as to introduce exotic germplasm of Brassica and its wild allies (Kumar *et.al.,* 2004). At present over 14000 working collections are being maintained /used in the country. However, under joint programme of National Bureau of Plant Genetic Resources, New Delhi and All India Coordinated Research Project on Rapeseed- Mustard (AICRP-RM), several Brassica- specific explorations were undertaken in the drier parts of Gujarat, Rajasthan, Bundelkhand region of Uttar Pradesh, parts of Bihar, West Bengal, Orissa, hilly areas of Jammu and Kashmir, Himachal Pradesh and the north-eastern Himalayas. As a result of explorations, 3677 collections of different species of Brassica were made from different states during 1976-1999. Local landraces of *B. juncea* such as ‘jatai rai’, ‘desi rai’, and maghi rai’ were collected from farmer’s fields in the areas bordering Bangladesh. In yellow sarson, dwarf and early types with pendulous siliqua were collected from Indo-Bangladesh border whereas tall, robust, multi-locular types were mainly collected from eastern UP. Diversity of *B. tournefortii* and *B. nigra* was collected from drier parts of Haryana and Rajasthan. Explorations for wild crucifers in Pauri Garwal hills of Uttar Pradesh added 22 accessions of *Capsella, Crambe, Lepidium* and *Sisymbrium* spp. Several exploration trips were conducted by the Directorate of Rapeseed- Mustard Research, Bharatpur (Rajasthan) and so far, around 800 accessions were collected from different parts of country including Assam, Haryana, Himachal Pradesh, Karnataka, Madhya Pradesh, Meghalaya, Nagaland, Punjab, Rajasthan, Uttar Pradesh, Uttranchal and West Bengal. Some of the unique collections were made, which include yellow seeded toria, dwarf mustard, dwarf and early toria, white flowered yellow sarson etc.

During the last two decades, NBPGR has introduced over 3800 accessions of rapeseed-mustard from over 25 countries, under strict phyto sanitary conditions, with specific traits like high yield, high oil content, and resistance to biotic and abiotic stresses as well as desirable quality traits. Most of the *Brassica* germplasm lines introduced from Europe and Canada are of *B. napus*. These lines are very tall, late in maturity and poor yielding under Indian conditions. However some of the lines are having superior oil quality with low erucic acid and low glucosinolate, which have been introgressed into Indian cultivars. Some of the promising introductions of *Brassica* germplasm cultivars, their economic traits and source countries have been mentioned in Table 4.

Table 4. Promising *Brassica* germplasm introduced through NBPGR

Species	Traits	Cultivar/Accession	Source
Brassica juncea	Low erucic acid	Zem 1 (EC-223759) Zem 2 (EC 223760) EC-322090-093 EC-367880-885	Australia Australia China Canada
	Low glucosinolate	EC-346016 EC-287711 BJ-1058	Canada Sweden Sweden
	High oil content	EC-264486 EC-303460-463 Donskaja	Canada UK Russia
	White rust resistant line	EC-264487	Canada
	Alternaria tolerant Drought tolerant	EC-206712 EC-333584-85	France Sweden

Table 4 Cont.

Species	**Traits**	**Cultivar/Accession**	**Source**
B. rapa	Low erucic acid	EC-226808 EC-226808	Canada Sweden
	Double zero lines	EC-302478 EC-242690-91	Sweden Sweden
	High oil content	EC-232318	Canada
B. nupus	Double zero lines	EC-271577-81 EC-200831-32	UK Canada

	Drought tolerant	EC-333586-587	Sweden
B. carinata	Improved cultivars	PGR-13221-222, EC-223405	Canada Pakistan

(Modified after Singh 1996)

Germplasm evaluation

Germplasm should preferably be evaluated for important morpho-agronomic traits under different agro-climatic conditions and evaluated for disease and pest reactions at the hot spots. Based on evaluation data crop catalogues are compiled for utilization of desirable genotypes by the crop breeders. A large number of rapeseed- mustard germplasm evaluated and characterized for various agro-morphological traits and biotic stresses (Misra *et.al.,* 2004, Misra and Kumar, 2009). Range values of various agro-morphological and quality traits in different *Brassica* spp have been given in table 5. It has been observed that variability was maximum for secondary branches per plant and least for oil and protein content. Information collected on germplasm of rapeseed-mustard in the country demonstrates the availability of valuable genetic reservoir, which could be exploited for improving the existing cultivars.

Table 5. Range of some of the important agro-morphological traits in top 3 oil seed Brassicas germplasm accessions

Characters	**Crop**		
	Indian mustard	**Yellow sarson**	**Toria**
Plant height (cm)	72.8-232.8	53.2-188.2	36.6-155.4
Main shoot length (cm)	23.8-112.4	24.7-89.6	16.6-75.
Siliquae on main shoot	12.0-82.2	10.0-78.6	13.6-77.8
Siliquae length (cm)	2.4-6.5	2.8-7.9	2.4-7.7
Seed per siliqua	6.1-23.8	8.6-44.6	8.1-24.4
1000-Seed weight (g)	1.1-8.2	1.4-6.9	1.0-4.8
Oil content (percent)	26.1-44.5	35.1-47.0	35.7 - 45.6
Harvest index (percent)	4.7-37.7	3.7-39.0	13.6 - 41.1

The sources for resistance to pests, diseases, salinity, frost and drought were identified and utilized in breeding programmes (Table 6). The systematic evaluation for various morpho-agronomic, quality traits, biotic and abiotic stresses, resulted in the identification of donors for use in the varietal improvement programme and subsequently resulted into release of over 180 improved varieties.

Table 6. Sources of various biotic / abiotic stresses and quality traits *(*after Misra 2004b*)*

Sources of tolerance to *Alternaria* blight
***B. juncea* :** EC-129126, EC 399301, PAB 9511, PAB 9534, RC 781
***B. carinata* :** PBC-9921 (Kiran), PC 5, Pusa Swarnim (IGC 01)
***B. napus* :** GSL-1, HNS-3, PBN-2001, PBN-2002, PBN-9501, PBN 9502

Sources of location/ race-specific resistance to White rust
***B. juncea* :** EC-399300, EC 399301, JMMWR- 941 - 1 – 2, PWR 2001, PWR 9541
***B. carinata* :** JTC 1,Kiran(PBC-9921), PC 5, PC 5-17, Pusa Gaurav (DLSC 1), Pusa Swarnim (IGC

01)
B. napus**:** GSL-441, HNS-4, PBN-2001, PBN-2002

Sources of location/ race-specific resistance to downy mildew
B. juncea **:** BIOYSR
B. napus **:** PBN-2002

Genotypes having glucosinolate content less than 30 micro mole/g defatted meal
B. juncea **:** NUDH-YJ-1, NUDH-YJ-2
B. napus **:** HNS 99(0E)3, NUDB-09, NUDB-26-11

Genotypes having low erucic acid (single low)
B. juncea **:** LES - 17 -1,LES 21, LES 38, YSRL 9- 18 -23,TERI (OE) M 21
B. napus **:** NUDB-26-11, Phaguni [TERI (0E) R 03], Shyamali [TERI (0E) R 09], TERI Unnat

Genotypes having low erucic acid (< 2percent) and low glucosinolate i.e.Canola type(< 30 µ moles / g fat free meal)
B. juncea **:** Heera, NUDHYJ- 5, TERI GZ-05
B. napus **:** BCN 14, CAN 138, GSC 5(GSC3A), TERI (00) R 985, TERI(00) R 986, TERI(00) R 9903

Early duration(100- 110days)
B. juncea **:** JD 6, Kanti, NDRE 4, Sej 2

Salt tolerance (Ece up to 10 ds/m)
B. juncea **:** CS 52, CS 54(CS 614-4-1-4), RH 8814

Yellow seeded
B. juncea **:** Basanti, NDYR 8, NDYR 10, TM 4, YRN 6

Tetralocular
B. juncea **:** Geeta (RB 9901)

High oil content (~ 45 percent)
B. juncea **:** NDYR 8, NDYR 10
Apetalous source
B. juncea **:** RC 199

The registration of germplasm and varieties was initiated by NBPGR/ ICAR in 1997 with a view to give due recognition to the plant breeders associated with development / identification of novel genotypes/ germplasm/ variety for utilization in crop improvement programmes. In this endeavor, 37 germplasm lines have been registered.

Germplasm utilization

For any crop improvement programme, a broad range of genetic resources is a must. In the past, a wide spectrum of genetic stocks of Brassicas has been assembled, which include land races as well as different varieties and related species from different countries. Based on preliminary evaluation and characterization data, promising donor genotypes have been identified. Under All India Coordinated Research Project on Rapeseed-Mustard and National Research Centre on Rapeseed-Mustard (ICAR), varietal development programme is in progress. A large number of promising varieties (Table 7) have been released for cultivation for different agro-climatic regions and some are in the pipeline for release in the coming future. Out of this 181, a total of 66 are direct selection from germplasm. In rapeseed-mustard, breeders have been working with limited germplasm. This has been one of the major bottlenecks in *Brassica* improvement. The sizeable collection of germplasm available in the country does not represent the entire variability available in the indigenous material.

Table 7. Released/ recommended varieties of rapeseed- mustard in India and selection from germplasm (till July 2009)

Crop	Number of varieties released	Selection from germplasm
Brown sarson	09	06
Gobhi sarson	12	01
Taramira	05	03
Toria	31	16
Yellow sarson	22	14
Black mustard	01	01
Karan rai	07	02
Indian mustard	94	23
Total	**181**	**66**

Status of documentation

Most of the germplasm already introduced and collected by the efforts of NBPGR as well as complemented by different AICRP (RM) centres, and have characterized and evaluated for important morpho-agronomic descriptors. The information of characterization and evaluation data have been published in annual reports, research papers as well documented in crop catalogue from time to time.

Future perspective

There is a need to intensify the research on genetic resources of oilseed brassicas in the country. The following priority areas of research have been identified:

- There is a need to broaden the genetic base; the regions of higher diversity should be explored. The exploration and collection from unexplored areas / hotspots are extensively needed.
- Exploration from the countries like Australia, Canada, China, Japan, Russia, Spain, Sweden; especially for quality, high heterosis (oil content, yield), biotic, abiotic stress and wild species.
- Introduction of germplasm of wild / weedy relatives as well as cultivated species of rapeseed-mustard from the centers / areas of rich generic diversity.
- Multi-location evaluation and characterization of germplasm, and subsequently their proper documentation is required to be strengthened.
- Molecular characterization of germplasm.

- Maintenance of gene pool for various traits such as quality, biotic and abiotic stresses.
- Participation of farmers during collection of germplasm and indigenous knowledge.
- Development of a core set of the germplasm for different traits for efficient handling and utilization of germplasm.

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1.5 Northeast India- A Potential Region for Ornamental Fish Trade

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The North East Region of India is endowed with plenty of excellent varieties of ornamental fish species. The region is recognized as one of the hot spots of fish biodiversity in the world. More than 250 fish species have been reported from the rivers, rivulets, hill streams and wet lands of the Northeast Region. Some of them have great potential to be ornamental value. Several varieties of fresh water ornamental fishes of India are well known in the international market. Majority of fresh water ornamental fish species that are being currently exported from India, do come from the Northeast Region. It is to be noted that about 58 different varieties of ornamental fishes are being exported from the region that are attractive to foreign markets. At present only fresh water varieties of ornamental fishes are exported from India. According to a report (1994-95), our major markets were USA sharing 41.12 % of the total export from our country, followed by Japan 21.17 %, UK 13.64 %, Germany 8.03 %, Nepal, Singapore, Thailand, Saudi Arabia, Belgium, France, Italy, the Netherlands, Switzerland and Sweden . Kolkata was the largest exit point followed by Mumbai and Chennai with a total number of 14 registered exporters. India's ornamental trade currently stands at only Rs. 5.5 Crores.

The ornamental fish trade is relatively new in this region. An organized ornamental fish trade is yet to be developed here. Those who are exporting ornamental fishes endemic to this region normally collect the fish species from nature through their contact fishermen. Therefore, there is always an uncertainty in the catch of a particular variety of ornamental fish species. A preliminary survey on the export of ornamental fish reveals that about 20-25 different varieties of ornamental fish of this region are caught from wild and exported to the global markets. However, if this continues further, many of the local species may become extinct in the near future. A snakehead called *Chann barca* is a good example. Therefore, there is an urgent need to conserve the indigenous ornamental fish resources through sustainable exploitation of the wild stock and through captive breeding programme.

In the Brahmaputra valley and in some of the hill streams of the northeast there are several varieties of ornamental fishes in nature. They are *Botia dario, Channa stewartii, Channa barca, Channa bleheri, Gagata cenia, Hara hara, Garra* spp., *Mystus* spp., *Somileptes gongata, Nemacheilus botia, Macrognathus aculeatus, Mastacembelus pancalus, Rasbora* spp., *Danio* spp. and many others. Some of the commonly available fish species viz. Colisa's, Danio's, Tetradon, Chital, loaches are also traded there as ornamentals.

In the lower stretches of Brahmaputra, every year during the months of November, December and January, several indigenous fish species are harvested in good number from **beel/khals/ditches** etc. when inundated water level recedes. Some of these fish species have tremendous potential for ornamental fishery. Due to remoteness of the landing centers and lack of adequate post-harvesting infrastructures, these fish species are generally utilized for local consumption and for preparation of various fish products employing traditional methods. Local fish species such as *Channa puctatus, Channa stewartii, Anabus* spp., *Badis badis, Nandus nandus, Colisa* spp., *Lepidocephalus* spp., *Mastacembelus* spp., *Puntius* spp., *Amblipharyngodon mola, Macrognathus* spp., *Esomus* spp., *Chanda* spp. are being exploited for preparation of various dried and burnt fish product. Burnt, smoked and sundried fish products are highly esteemed in the hilly states of North Eastern India. However, it is causing a serious threat to the local ornamental fishery. Therefore, the urgent need is to create a massive awareness programme on conservation of ornamental fishery of Assam.

Potential:

- The North Eastern states have available water resources and excellent agro-climatic condition for ornamental fish aquaculture.
- Abundance of fresh water fish resource. Information is already available on North East fish resources and their current status. According to available information about 85 per cent of the ornamental fishes exported from India, originate from this region. It is to be noted that the collection and trade should be sustainable and environment friendly.
- International air service facilities from the Guwahati (capital city of Assam), the gateway of northeast India. With regular international air service facilities between the Assam's capitals, Guwahati-Bangkok sector, Guwahati can soon become a hub for ornamental fish export market. Therefore, local entrepreneurs should be encouraged to breed and rear specific varieties of ornamental fish, which could be marketed in foreign countries.
- Closeness to South East Asian countries -- the key players in the global ornamental fish trade. Countries such as China, Singapore and Malaysia represent potential nearby markets. With free trade pact within ASEAN countries, the total trade of ornamental fish is expected to rise.

Constraints:

- Major share of ornamental fishes exported from India are the wild caught varieties from the rivers and wetlands. This is rather a great threat to the fish biodiversity of the region.
- Lack of awareness in the region. Number of aquarium fish hobbyists is less in the region.
- Inadequate technical expertise on ornamental fish aquaculture within the state.
- Information on captive breeding of indigenous ornamental fishes is very scanty. Lack of suitable technologies to breed some of the important varieties of ornamental fish (that is in greater demand in the international market) under controlled conditions.
- Lack of proper transport and quarantine facilities at the ornamental fish collection centers.
- Lack of well-trained and skilled entrepreneurs.
- Lack of support from the government and financial sectors.

Protection of the aquatic habitat where these fish live and reproduce, banning export of the threatened and rare varieties of local fish, developing protocols for breeding and larval rearing of local fish, and cultivating the habit of rearing indigenous fish in home aquariums are the needs of the hour.

1.6 Rice Quality Diversity in North Eastern Hill Region (Diversity of Rice Quality and Medicinal Rice)

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Rice is the staple food of majority of the world's population. Ninty one percent of world's rice is produced in Asia. Rice provides 20% of the per capita energy and 13% of the per capita protein world wide. However, in Asia rice contributes about 35% of the energy and 28% of the protein. Besides, rice provides minerals, vitamins and dietary fiber to the rice eating people. Thus, rice plays a very important role in providing nutrients to a large segment of the world's population.

More than two thousand varieties are grown worldwide and International Rice Research Institute (IRRI) holds more than 83,000 varieties in its gene bank. India has about 705 varieties. The northeastern hill region of India comprising the states of Manipur, Meghalaya, Arunachal Pradesh, Nagaland, Mizoram, Tripura and Sikkim is endowed with rich source of rice germplasm which may be safely estimated to be about 9,000 accessions. The region is considered to be the secondary centre of origin of rice. Rice is the principal food crop of this region and grown in 72 percent of the total cultivable area in three major ecosystems, viz: upland including **jhum** land (sifting cultivation plots), lowlands and deep water conditions. The region is rich in variability of rice germplasm with distinguishable qualities such as scentedness, glutinous on waxyness, colourful, medicinal, ability to grow in deep-water conditions, etc. The region has wild rice cultivars also.

Rice has diverse uses both domestically and for export and hence require quality be evaluated according to its suitability for specific uses. Quality is very important and is determinant of market price and consumer acceptance. In the context of the north eastern hill region of India, rice quality diversity can be discussed in three categories: normal rice used for food purposes, medicinal rices and rices used for cosmetic purposes.

Food rice quality

The quality parameters to be evaluated for food rice varieties are usually hulling %, milling %, head rice recovery %, gelatinization temperature (correlated with alkali spreading value), cooking qualities including elongation ratio, water uptake and volume expansion ratio, nutritional qualities such as total crude protein, total carbohydrate, total ash, total fat, minerals, vitamins and amino acids and some special parameters like scentedness. Enormous variations in size and shape of grain exist among the rice varieties available in the world. Rice kernel length roughly varies from 5.0 to 7.5mm and breadth from 1.9 to 3.0mm. Some high yielding varieties from India had 5.2 to 6.8 mm in length and 1.9 to 2.5 mm in breadth. In USA, grain are classified into long (7to 7.5mm), medium (5.9 to 6.1mm) and short (5.4 to 5.5mm). In India grains are classified considering length, breadth and length breadth ratio into long slender(length 6mm and above, L/B ratio 3.0 and above), long bold (length 6.0mm and above, L/B ratio less than 3.0mm), medium slender (length less than 6mm, L/B ratio 2.5 to 3.0mm), short slender (length less than 6mm and L/B ratio 3 and above) and short bold (length less than 6mm, L/B ratio less than 3) types. Japonica varieties got shorter and bolder grains. Generally hulling outturn ranged from 71 to 83 percent. The varietal variation within Indian varieties in respect to hulling is observed to be small, but it is more in the case of Taiwan & Japanese varieties. Many japonica rices give hulling outturns of over 79 percent. The milling characteristic of a variety directly related to the hulling capability. Chalkiness of more than 10 percent is considered undesirable for marketing purposes. Alkali spreading value is related to amylose contain in the endosperm. More content of amylose results in lower alkali spreading value and low amount of amylose results in higher alkali spreading value. Volume expansion usually ranged from 2.0 to 4.35. When rice is coked at 70-80°C, the uptake of water is strongly influenced by the gelatinization temperature. The lower the gelatinization temperature of the variety, the higher will be its water uptake and vice versa. Rice grains contain starch as the principal component and protein as the second highest component. Milled rice has been shown to contain about 78 percent carbohydrate. Many reports on variability in protein content in rice are available. A range of 6.7 to 11 percent protein in brown rice was observed in 74 varieties from India by Guha and Mitra, (1963). Some varieties from Gujarat state of India were reported to have 6.5 to 12.5 percent protein. Waxy type rice has more protein than high amylase types and it has been hypothesized that waxy endosperm is more favorable for the accumulation of protein than high amylose endosperm. Govindaswami *et al*., (1969), reported 6 to 12.6 percent crude protein content in three hundred improved rice varieties in India. Even a wide range of 6.56 to 12.86 percent protein content was reported in 40 rice varieties grown in Kashmir. Amylose content in rice ranges from 0 to 37 percent. Higher amylase contents (about 20 to 30 percent) are associated with many south asian varieties. Lower amylase levels (10 to 20 percent) are more common in East Asia, where a more cohesive cooked grain is often preferred. Glutinous or waxy rice has no or very little amylose. The fat contents of milled rice have been reported to be about 0.2 to 2.0 percent. The japonica type (low amylose) of rice showed higher fat content upto 3.58 percent. Available report showed low protein miilled rice had 0.36 percent crude ash and high protein had 0.55 percent ash. Crude fibre content ranged from 0.6 percent to 1.1 percent in milled rice of low and high protein types.

Some rice varieties/cultivars are being used for medicinal purposes. In ancient Indian records such as Susrutha Samhitha and Charaka samhitha of about 1000 BC, there were records of using rice for medicinal purposes. Laicha rice of chattisgarh and Navar rice of Kerala in India are important examples of such rices which are used in herbal drug preparations. An extract of rice bran is used to cure beri-beri. In Malayasia an eye lotion is prepared by boiling rice greens.

The lotion is used for acute inflammation of the inner body tissues of eye. Husk is used to cure dysentery in Combodia. In China sprouted rice grains are used to aid digestion, give muscle tone and expel gas from the stomach.Rice fluids prepared from Japanese rice had in vitro antibacterial activity against Helicobactor pylori, the major causal organism of gastritis and peptic ulcer. Survey in north eastern hill region of India revealed many medicinal uses of rice mostly of indigenous glutinous types.

Food rice diversity in NEH region of India: Mostly rice is consumed as whole grain. Some of the quality parameters of rice which are used as food purposes are length, breadth, length /breadth ratio, milling percent, hulling percent, head rice recovery, cooking qualities, nutritional qualities and special qualities like aroma and glutinous.

Colour diversity: The kernel colour available in the north eastern hill region are: White, red, black dark purple upon cooking), half red and half black (reddish purple upon cooking. The majority of the rice has white kernel colour followed by red, black and half red & half black. (fig.1)

Diversity in physical characters: Length of the varieties/cultivars varied from 4.23mm to 7.25mm and breadth varies from 1.46 to 4.3mm. Majority of the cultivars/varieties belongs to long bold types (about 41.3 percent) followed by short bold (about 35.5 percent, long slender (about 13.4 percent), medium slender (about 8.7 percent) and short slender (about 1.2 percent). Majority of the cultivars/ variety belong to high value of alkali spreading value. Very less no. of cultivars/ varieties (about 3.5 percent) belongs to low alkali spreading value.

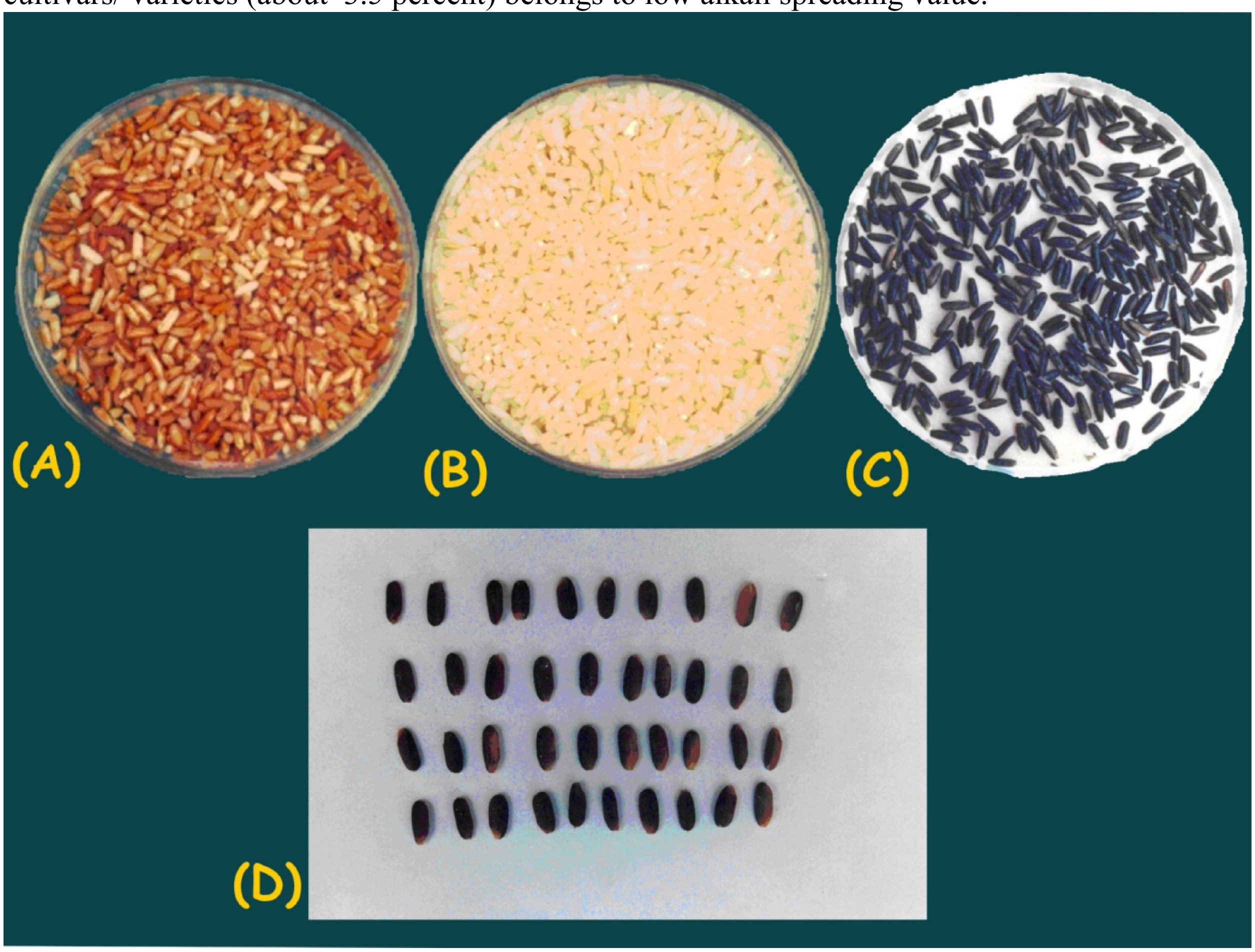

Fig 1: Kernel colour diversity in rices of north eastern hill region of India

Chalkiness of the kernel varies from 0 to 100 percent. Majority belongs to 10-20 percent chalkiness. Only 9 percent of the cultivars were observed to be below 10 percent chalkiness.

Milling quality diversity: Hulling percentage of the varieties ranged from 37 percent to 84 percent of which 54 percent of the cultivars belongs to 70 to 80 percent hulling percentage. Milling percentage ranged from 50 to 80 percent of which majority belongs to 60 to 70 percent. Head rice recovery varied from 0 to 80 percent. 52 percent of the cultivars have head rice recovery more than 40 percent.

Cooking quality diversity: Elongation ratio of the cultivars varies from 1.2 to 3.0. Majority of the cultivars has 1 to 2 elongation ratio. A few cultivars are of elongation ratio of 3.0 times. Volume expansion ratio ranged from 2 to 5 times. Most of the cultivars have 3-4times volume expansion ratio. Most of the cultivars has 200 to 400ml water uptake during cooking experiments. About 20 percent of the cultivars have about 200mL water uptake during cooking.

Diversity in amylose content: Most of the cultivars/varieties of this region are of intermediate amylose content (10 to 25 percent). Very little of the cultivars/varieties belong to high amylose types (25 percent and above). Some varieties/cultivars are of glutinous types.

Nutritional quality diversity: Total crude contents in the local cultivars/varieties raged from 3 to 15 percent on dry weight basis of the milled kernel. Most of the cultivars have 6 to 9.8 percent protein. There are about 20 high protein type rice available in the local germplasm which have more than 10 percent total crude protein in the kernel. Total carbohydrate contents of the local rice cultivar ranged from about 70 percent to 85 percent. Most of the cultivars have 70 to 80 percent carbohydrate. This value quite agrees with the other varieties available in the world. Total ash content ranged from 0.1 to 1.5 percent and crude fibre contents varies from 0.1 to 0.9 percent. Total fat content ranged from 1.0 to 4.0 percent. Majority belongs to higher fat group ranging from 2 percent or more.

Aroma: About 110 cultivars were found to possess aroma having 13 strongly aromatic cultivars.

Glutinous: Fourteen glutinous or waxy cultivars are found in the local cultivars.

Table 1. Nutritional profile of the indigenous cultivars

Sl. No.	Parameter	Range	% of total cultivar studied so far
1	Total crude protein (%)	3-5.9 6-9.9 10- 15	12 83 05
2	Total carbohydrate (%)	80 and above 70-79.9 60-69.9 50-59.9	25 59 06 10
3	Total fat (%)	0.1-1 1-1.9 2 -4 Unclassified	28 24 38 10
4	Ash (%)	0.1-0.9 1 and above Unclassified	32 58 10
5	Crude fibre (%)	0.1 to 0.9	100%

Medicinal rice diversity in NEH region of India: Some rice varieties and cultivars are being used for medicinal purposes in this part of India (Table 2).

Table 2. Ethno-pharmacological uses of uses of rice in north eastern hill region of India

Sl. No.	Disease	Predominant cultivar of rice used	State	Preparation	Mode of application
1	Dysentery	Sticky rice cultivars e.g., Moirangphou, Phouren, Chahou amubi, Chahou poireiton.	Manipur	Rice kernel is roasted on pan and powdered with pine resin	The powder is given orally
2	Muscular sprain	Sticky rice varieties	Manipur	Sticky rice is cooked. Wood charcoal is powdered and smashed with the coked rice	The paste resulting from this mixture is applied on the area, covered with banana leaf and bound to fix and left overnight
3	Dog bite	Any local cultivar	Manipur	Raw polished rice is chewed	Chewed rice is applied on the bitten area. Then one silver coin is placed on it for sometime
4	Reduced eye sight	Any local cultivar	Manipur	Rice husk is rubbed with ripe banana, the resulting paste is strained through muslin cloth	The filtrate is soaked in cotton and applied on the eyelids
5	Mouth ulcer	Chahou amubi, Moirangphou and sticky cultivars	Manipur	Chewing	Raw milled rice is chewed
6	Hypersens itivity of teeth	Chahou amubi, Moirangphou and sticky cultivars	Manipur	Chewing	Raw milled rice is chewed
7	Easy labour and healthy baby	Chahou poireiton	Manipur	Cooked rice	Cooked rice is included in the diet
8	Scanty lactation	Chahou amubi	Manipur	Cooked rice	Cooked rice is given orally with sugar
9	Dandruff	Sticky cultivars	Manipur	Rice water	Rice water is boiled with some herbs. Filtered and filtrate is applied, leaved

					for few minutes and rinsed with water
10	Skin allergy	Luwai	Meghalay a	Raw rice powder	Raw rice powder is applied on the area
11	Tonsillitis	Local cultivars	Meghalay a	Wine prepared from rice powder	The wine is given orally

Some medicinal cultivars are already collected and quality study is being done. Notably some of them are high iron, high methionine and high calcium. Some of them possess antibacterial activities against some pathogenic bacteria.

Cosmetic rice diversity:

Not much information is available on the cosmetic uses of rice in this part of India. Some of the uses are for wrinkle prevention by applying cooked rice paste on face and rice water based herbal shampoos.

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1.7 Important Plant Genetic Resources of North Eastern India: their Sustainable Utilization and Conservation.

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The Northeastern India is one of the hotspot of mega biodiversity centre of the world which falls in between Eastern Himalayan belt and Indo-Burmese Region. The physiography climate and socio cultural aspects are diverse and hence the plant genetic resources and their utilization are also varies among the states that constitute the region. Due to domestication and evolution of various crops from wild to cultivated forms has contributed many crop landraces that are adapted in particular ecological condition. Many native tribes by experience also invented particular genotype of various crop landraces which are well acclimatized in different ecological niche and over the period they formed the stable landrace. These landraces are the invaluable basic materials of crop production and tools for survivality and sustainability of local people.

Hill environment, climate, crop genotype, seasonal variations, agricultural practices are quite different from plains towards any kind of crop productions. Many unknown biotic and abiotic adversities are also faced by the hill agriculture. However, hills are the treasure house of plant diversities, which are the rich resources for crop improvement as genetic material. Conservation of such resources in any form is utmost important as these are result of million years of natural evolution and many characteristics or traits are yet to be exploited from such resources.

The basic principles involves in such activities are – gene pool concept, utilization and conservation of the genotype. Once the genotype is identified for the purpose, it will lead for the enhancement of crop production. Of course, in recent years a series of complicacies and formalities have been arise in the wake of ITK, IPR issues and the intervention of PPV & FR authority regulations.

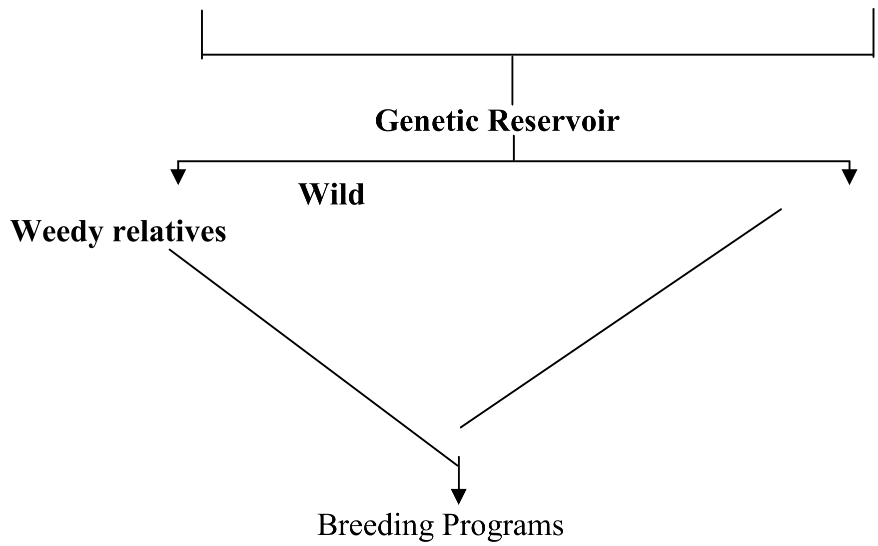
Apart from the crop biodiversity medicinal and aromatic plants have constituted a separate sector, where many wild plants are being gradually brought under the cultivation. 'Value addition' compound extracted from such material may form a strong business area on which farmers and entrepreneur's livelihood and drug development depends.

Now, the questions remain that what are these genotypes, where they are distributed? What are their source, status, potentialities and how they can be conserved for future utilization? The following model will give a comprehensive idea, based on the basic principles of Plant Genetic Resources (PGR).

Plant Genetic Resources Profile

Centre of Diversity
Primitive Cultivars
Natural hybrids
Semi domestication

Centre of Cultivation
Commercial Types
Obsolete varieties
Special purpose types



- Purelines
- Hybrids
- Genetic Stocks
- Cryopreserved materials
- Recombinant inbred lines
- Mutants
- GMO
- *In-vitro* repository material

A clear concept is necessary for different definitions in PGR which are often used. This will help the breeders to understand determine the direction of utilization and conservation of an entity material. A set of such definition of various terminologies is given below:-

- **Germplasm** **:**A set of different genotypes, material / physical basis of heredity , transmitted from generation to generation by means of germ cells.
- **Landrace** **:**Farmers developed cultivars of crop plants which are adapted to environmental conditions.
- **Gene pool** **:**Total number of genes in a plant population.
- **Genetic diversity** **:** Total amount of genetic variation present in a population of a taxon.
- **Genetic base** **:**Total number of genetic diversity within a population.
- **Cultivar** **:**A variety of a plant produced by selective breeding.
- **Cultigens** **:**Cultigens are cultivated plant species.
- **Accession** **:**Plant / Seed sample / strain or its population held in gene bank.

- **Orthodox seeds** **:**Seed that can provide low moisture and temperature without damage.

- **Recalcitrant seeds** **:** Seeds generally have short viability ranging from few weeks to a month and are sensitive to dessication and low temperature. These lose viability, if dried below a critical moisture content. (12-35%)

Crop genetic diversities of the region

The north eastern hill region of India is rich both in terms of primary and secondary crop diversities. Many exotic materials introduced by the different agencies long back which are now naturalised and cultivated. The extent of various crop diversities that are documented here in brief is not a complete picture but the latest inventorisation.

Extent of diversities in different crop groups

Cereal: It constitutes the major group that contributes the staple food. Rice, maize and barley are the common crops, while the wheat cultivation is very limited in the north eastern region. About 9650 landraces of rice **(***Oryza sativa*) occurring in the region which grows in different ecological situation. At least 7 taxa of wild relatives of rice (*Oryza*) grows in this region which includes *Oryza rufipogon ,* O. *glomerata* , O. *meyeriana*, O. *officinalis ; Leersia hexandra ; Zizania latifolia , Hygrorhiza aristata.* Wonder rice of Nagaland is a subject of future research.

Maize (*Zea mays*) is the second dominant crop in entire hill region. Lots of variability exists among the genotype in terms of Cob and grain morphology. Based on the origin, evolution, migration and introgression, Singh (1975) has identified 15 distinct races and 3 subraces. Sikkim primitive, one of the interesting land races which produces 4-6 cobs in a plant, found in the region. Nagaland and Mizoram are the major producer of the crop among the hill states. The intergeneric hybridisation also occur in this crop and the related taxa like *Coix lacryma-jobi*, *Euchlaena mexicana* and *Tripsacum dactyloides* are found in very limited cultivation.

Barley (*Hordeum vulgare*), grows in high altitude of Sikkim and Arunachal Pradesh, where Rice can not be grown , while wheat (*Triticum aestivum*) is a introduced crop in the region. This crop is confined within very limited area of Assam State.

Pseudocereals:

This group of crop covers buckwheat (*Fagopyrum esculentum*), amaranth *(Amaranth hypochondriacus)* ; chenopods (*Chenopodium album*) , jobs tear (*Coix lacryma-jobi*), millets like finger millet (*Eleusine coracana*), foxtail millet (*Setaria italica*) ; pearl millet (*Penisetum typhoides*) ; jowar (*Sorghum biceor*) and their related species also cultivated in a limited scale in their suitable and respective environmental condition. Such crops are normally grows in high altitudinal area where the other cereal crop cannot be grown. Moreover, such crop cultivation serves the alternative need of nutritive value and other requirement of local people and not for commercial purpose.

Grain Legumes

Crops belongs to this group serves the requirement of pulse and vegetable purpose. A few legumes are utilised for their tubers and not for grain purpose. Rice bean (*Vigna umbellata*) is the major pulse crop of the hills. Black gram (*Vigna mungo*) is grown in large scale only in Sikkim state in the region. Pigeon pea, lentil, lathyrus are commonly grown in Assam. Soybean, cowpea, pea, french bean, sem (*Dolichos*) , jackbean , treebean (*Parkia roxburghii*) are used as vegetable. Considerable diversities are available within these crops. Tubers of *Moghania Vestita*, *Eriosema chinense* , *Pachyrrhizus erosus* are eaten as raw by the tribals.

Oilseeds

The utilization of oil is very scanty among the hill people and perhaps due to this oilseed cultivation is very less. Oilseeds Mustard (*Brassica* spp.) only cultivated in Assam plains, otherwise leafy brassical cultivation is dominant for leaves. Bhanjira (*Perilla frutescens*) is commonly used for Chutney purpose. Systematic cultivation of this crop is lacking. Adoption of crop cultivation is depending on the food habit of the tribal community. Therefore sesame cultivation is confined in Karbi Anglong district of Assam, where a considerable amount of sesame diversity does occur. Otherwise rest oilseed crops like niger, groundnut, castor, linseed cultivation are dispersed and limited.

Vegetable

This group of crop diversities covers mainly the members of Cucurbitaceae and Solanaceae. At least 17 species of cucurbits and 12 species of *Solanums* are consumed by the local people. Many promising wild relatives can also contribute as donor member in hybridisation program. *Cucumis hystrix, Gymnopetalum cochinchinensis, Luffaaegyptica, Hodgsonia macrocarpa, Trichosanthes cordata* are the novelties of the region. Enormous diversities exist within the genera like *Cucurbita*, *Momordica*, *Lagenaria*, *Benincasa, Luffa, Cucumi , Sechium, Solanum , Abelmoschus and Capsicum* in their infraspecific levels as well as in their landraces.

Tuber Crops

This group mainly constitutes the taros, elephant foot yams and yams. A large number of variabilities are available in *colocasia* and *dioscorea*. Taxonomical and biochemical delimitation of this group is still wanting. Tribes of the region are largely dependent on these crops for their livelihood which also help them in their integrated farming system.

Fruits

The major fruits of Northeastern Hill region are Citrus, banana, jackfruit, mango, rosaceous crops and minor fruits. Among introduced crops pineapple, passion fruit, papaya and kiwi fruit are well acclimatized and naturalized. Many wild relatives of various fruit crops are also available in the region. The extents of diversities in such crops are as follows:-

i) Citrus - 17 species with their 52 varieties together with many intermediates.

ii) Banana - It constitutes both suckering (*Musa*) and non suckering (*Ensete*) group together with ornamental types (*Rhodochlamys*). All these together forms 16 species. *Musa esculenta* (A genome) and *M. balbisiana* (B-genome) has contributed many cultivars in the region.

iii) Jackfruit - *Artocarpus heterophyllus* is the only cultivated species. Three wild species (i.e. *A. lakoocha*, *A. chama* and *A. hirsuta*) are also edible.

iv) Mango - Six cultivars, two wild species i.e *Mangifera sylvatica* and *M. khasiana* do exist in the region. Manipuri dwarf mango cultivars are a novelty of the region.

v) Rosaceous-fruits species These includes *Pyrus* (2 species); *Prunus* (6 species) ; *Malus* (1 species) ; *Sorbus* (2 species) ; *Rubus* (9 species) ; *Docynia* (2 species) ; *Duchesnia* (1 species) and *Fragaria* (2 species).

Relatively less important crops includes the members of *Syzygium, Aegle , Psidium, Annona , Averrrhoa , Punica, Vitis, Litchi,* and *Zizyphus*. A few dozen of economically important minor fruits which could be cultivation (Pandey *et. at.* , 1993) . This can help the farmers to earn cash in their odd times. The potential species of this category includes the species of *Elaegnus*, *Myrica, Baccaurea, Castanopsis, Vibernum, Gynocardia, Calamus, Elaecarpus, Dillenia, Cornus, Emblica, Feronia, Flacourtia, Garcinia, Morus, Spondius, Rhus* etc.

Medicinal and Aromatic Plants:

There are about 2500 plant species in India are utilized for medicinal purpose against different ailments. The major consumption is mostly within the ethnic people who have no scope to afford and reach to modern medicine. On the other hand, various drug industries export these resources from nature through various means. Occurrence, identification and population structure of the species; effective utilization and demand of the raw material against particular ailments are the major concern to establish the importance of the material. Occurrence of the species and its population is again depending on microclimate requirement or habitat of the species. In this context, the NE Region provides a varied eco-climate and perhaps due to this, a large number plant species and their diversities exist. Altitude wise the region can be classified in to four (4) zones i.e. Tropical, Sub-tropical. Temperate and Alpine, which are the habitats for occurrence and suitable for ex-situ cultivation practice. The inventories given below are mainly for indigenous species and it has got direct relevance with the utilization and practice of ethnic people.

Environment	**Altitude**	**Species**	**Practice against particular ailments**
A) Tropical	50-500m	*Plantago erosa*	Malaria, dysentery & diarrhea
		Adhatoda vesica	Dysentery, cough, fever
		Andrographis paniculata	Jaundice
		Withania somnifera	Vigour, rheumatism
		Ocimum sanctum	Cough & cold
		Centella asiatica	Autidysentric, leprosy, asthma, bronchitis
		Vitex trifolia	Headachal, rhenumatism dyspepsia
		Aquallaria agalocha	Used in perfumery
		Tinospora cordifolia	Skin diseases and ant diabetes
		Bacopa monieri	Enhances memory power
		Pogosteman cablin	Aromatic oil for perfumery
B) Sub-	500-	*Ophiorhiza mungos*	Cancer

Tropical	2000m	*Artemisia maritime*	Malaria
		Diachroa febrifuga	Malaria
		Hydnocarpus kurzii	Leprosy
		Hedyotis auriculata	Leprosy
		Litsea cubeba	Paralysis
		Mucuna pruriens	Neurological disease
		Swertia chirata	Stomach disorder
		Rauvolfia serpentina	Reduce blood pressure
		Alpinia galanga	Rheumatism
		Clerodendron colebrookianum	Blood pressure
		Plumbago zelanica	Diarrohea & rheumatism
		Acorus calamus	Epilepsy and colic pains
		Paederia foetida	Paralysis
		Houttynia cordata	Dysentery
		Potentilla sundaica	Antidote for snake bite
		Berginia ciliate	Abortificients, cut and burns
		Dactylorhiza hatagirea	Aphrodisiac
		Acorus calamus	Diuretic
C)Temperate	2000-3000m	*Panax pseudoginseng*	Stimulant, headache, blood pressure
		Dicentra scandens	High blood pressure and diabetes
		Coptis teeta	Anti malarial
		Aconitum heterophyllum	Anti diabetes and powerful sedative
		Picrorhiza kurroa	Stomachic, dyspepsiar and fever
		Podophyllum hexandrum	Diuretic, fever, aphrodisiac
		Taxus wallichiana	Anticancerous
		Nardostachys jatamansi	Heart disease and stimulant
		Berberis aristata	Antipyretic and diaphoretic
		Valeriana wallichi	Blood disease, aphorodisiac
D) Alpine	Beyond 3000m and above	*Rheum emodi*	Tonic astringent, purgative
		Tupistra nutans	Diabetes
		Saussurea costus	Bronchial asthma, leprosy, cholera

Utilization: A vast resources of medicinal plants are available within the region. However, population is a question for some species. Demand oriented systematic cultivation and their agrotechnique is to be developed, if not available. Planting material for enhancing large scale cultivation is again a problem. Right from the species identification, to marketing is a basic need through the large scale cultivation, harvesting, storage, and marketing. Establishment of local/zonal processing centre will be helpful to extract the value added substance at least in crude form.

Plant resources conservation: There are several ways of germplasm resource conservation based on the habit, population structure and policy importance of the plant species. The ongoing strategies are:

i) ***in-situ* conservation** - Own habitat without any displacement.

ii) ***ex-situ* conservation** - → Field gene bank
→ Seed gene bank

iii) ***in vitro* conservation** - in laboratory condition following stipulated method.

iv) **Cryopreservation** - Stipulated method designated for orthodox and recalcitrant seeds.

The orthodox seeds for conservation are normally kept in Medium term storage (MTS) condition under 7-8^{o}C with 35-40% RH, which keeps longevity of seeds for 35-40% years. Seeds of particular species for their accurate longevity is again determined through the seed physiological experiment and may be kept in MTS. Accordingly monitoring of seed viability over the certain period is necessary in this method.

Vegetatively propagated germplasm materials are normally maintained in field gene bank, polyhouse, and greenhouse. Annual crop of such habit is again are to be maintained according to the crop life cycle. Perennial species is better to maintain directly in the field.

In situ conservation is primarily ecosystem based conservation. In germplasm based *in-situ* conservation. Nokrek gene sanctuary for *Citrus indica* is a unique example which is situated in West Garo Hills of Meghalaya. In similar way, NBPGR Regional Station, Shillong has identified two more large natural populations of species which warranted for their *in-situ* conservation. These are –

i)	*Emblica officinalis*	:	Parts of West Khasi Hills, Meghalaya.
ii)	*Citrus jambhiri*	:	Near Yingkiong of Arunachal Pradesh

Biosphere reserve is also a novel concept to preserve both ecosystem and species in **in-situ** condition. In north eastern region of India, the latest situation is as follows:

i)	Declared Biosphere Reserve	:	Nokrek (820 Sq.Km) ,West Garo Hills Manas (2837 Sq.Km) ,Assam Dibru – Saikhowa (765 sq km) , Arunachal Pradesh Dehang-Debang (5112 sq km), Arunachal Pradesh
ii)	Yet to be designated by MOEF, Govt. of India	:	Namdapha (Arunachal Pradesh) Kaziranga (Assam)
iii)	Yet to be designated as suggested by respective state government	:	Kanchendzonga (Sikkim)

Geographical indicators

In recent times, concept of geographical indicators of agrobidiversity important landrace and their traits are giving more emphasis for value addition. Accordingly, restriction imposition and

IPR issues are of a great concern for the respective state for benefit sharing. Examples of these categories in context of Northeastern India are as follows

1.	**'Bhoot Jalokia' of Assam / Hot Chilli of Nagaland**	:	Assam-Nagaland Border districts
2.	**'Wonder Rice'**	:	Nagaland
3.	**'Lakadong' Landrace of Turmeric**	:	Jaintia Hills, Meghalaya
4.	**Black kerneled rice (Chahao)**	:	Manipur
5.	Red kerneled rice for Zado preparation	:	Meghalaya
6.	'Komal Dhan' (Rice) for breakfast preparation	:	Assam Plains
7.	Bakhar Begena (Brinjal)	:	Sibsagar, Assam
8.	Dwarf Mango	:	Manipur
9.	Sikkim Primitive (Maize)	:	Sikkim

Conclusion

A vast and wide range of plant resources are exist both in natural condition as well as in cultivated forms in Northeastern region of India. Many of them are untapped and yet to be exploited commercially. Here are the challenges for scientists to exploit the genetic wealth that are available. When vision merges with mission, definitely one can reach at least near to the target. Roy Pat Mooney, a Canadian economist once said – 'Farmers in the third world, who have been cultivating today's major food crops for over 10000 years by observing the natural process of mutation and the careful selection, have developed an astonishing range of crop variability. All these diversities have been necessary for survival.' Subsequently, he further added that the 'Greatest threat to genetic diversity is posed by the emergence of commercial seed companies floated by the multinational corporations (MNCs). Mr. M.L. Oldfield, an expert on MNC's agribusiness says "Any person or group, who successfully achieved private control over a variety of genetic resources, would indeed possess almost infinite political and economic powers'.

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2 Conservation of Natural Resource

2.1 Fish Genetic Resources of North Eastern India and their Conservation Strategies

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The north-eastern region of India - comprising the states of Arunachal Pradesh, Assam, Manipur, Meghalaya, Mizoram, Nagaland, Sikkim and Tripura - encompasses a geographic area of 262,179 km^2. The region presents diverse topographical conditions ranging from the plains of Assam and Tripura, upland flat lands of the Imphal valley in Manipur to predominantly hilly/mountainous regions of Arunachal Pradesh, Mizoram and Sikkim. Hills and mountains comprise over two-third of the region's territory. (Bareh, 2001). These undulating topography and high rainfall has given rise to numerous rivers, floodplain wetlands (beels), lakes, ponds and low-lying areas, which form rich fisheries resources in the region. These vast and varied aquatic resources - including man-made reservoirs and mini-barrages - support a rich variety of freshwater fishes. The geological upheavals of the past have resulted in mixing up of drainages and consequent mixing up of their fish fauna; this admixture has rendered Assam Himalayas very important from the faunistic point of view (Menon, 1974). The eastern Himalayan region encompassing the Northeast is considered as one of the hot spots of freshwater fish biodiversity in the world (Kottelat and Whitten, 1996). However, there has been drastic reduction in the abundance and distribution range of fishes in this region due to habitat modification, overexploitation and other anthropogenic causes (Sinha, 1994; Bhattacharjya *et. al*., 1998; Ponniah and Sarkar, 2000). According to CAMP report (1998), as many as 83 fish species occurring in the region can be considered as threatened. This calls for carrying out extensive and systematic field surveys of the fish genetic resources of the region, which is a pre-requisite for their optimal and sustainable utilization as food (cultivable/wild), sport and ornamental fishes. Available information on the ichthyofauna of the Northeast is few and fragmented (e.g., Ghosh and Lipton, 1982; Sen, 1985; Sinha, 1994; Sen, 2000; Mahapatra *et. al*., 2004). CIFRI carried out extensive field studies on riverine fisheries of the region during 1998-2002 and on indigenous ornamental fishes during 2002-07, which forms the basis of the present communication.

Fishery resources of the region

Rivers: The north-eastern region is criss-crossed by as many as 58 notable rivers/tributaries besides numerous rivulets/hill streams; mighty Brahmaputra (the largest river of the region) and Barak along with their tributaries form more than half of these rivers (Bhattacharjya, 2007). Major rivers of Arunachal Pradesh like Kameng, Dikrong, Ranganadi, Subansiri, Siang, Dibang, Lohit, Noadihing and Tirap are steep and turbulent, often passing through deep gorges. They along with tributaries flow for 2,000 km in the state. In Assam, the Brahmaputra River flows for 730 km, receiving 47 important tributaries such as Dibang, Subansiri, Ranganadi, Jiabhoroli, Pagladiya, Beki, Manas, Saalbhanga and Sonkosh in the north bank and Lohit, Buhridihing, Disang, Dhansiri, Kopili, Kulsi and Jinjiram in the south. The Barak River drains the southern Assam districts of Cachar, Karimganj, Hailakandi and North Cachar Hills. The combined length of all rivers and their tributaries in Assam is 4,820 km. Manipur has two major rivers viz., Barak and Imphal. The Barak River with its tributaries like Irang, Leimatak, Nakaror, Makru and Tuivai mainly dissect the hills while the Imphal River (also known as Manipur River in the lower stretches) drains the valley districts. Iril, Thoubal, Chakpi and Khuga rivers directly join Manipur

River whereas Namol, Nambul and several rivulets draining the eastern slopes of Tamenglong hills are connected to the river through the Loktak Lake. Estimated length of rivers in Manipur is 2,000 km. Meghalaya's 5,600 km of rivers mainly comprise the north-flowing ones like Umiam, Digaru, Dudhnoi, Krishnai and Jinjiram (all southern tributaries of R. Brahmaputra). The main south-flowing rivers of the state are Balat, Kynchiang and Simsang. There are 21 rivers in Mizoram, of which Tuirial, Mat, Tlawng, Karnafuli and Tairei are the important ones. These rivers along with tributaries, streams and creeks run for 1,700 km forming an important fisheries resource of this hilly state. Jhanji, Dikhow, Diphu, Daiyung, Dhansiri (all tributaries of R. Brahmaputra), Barak and Tizu are the main rivers of Nagaland, which have a combined length of 1,600 km. Sikkim has two major rivers, Teesta and Rangeet, with a total length of 900 km. These rivers originate from the glaciers of north and west Sikkim. Important rivers of Tripura are Longai, Juri, Deo, Manu, Dhalai, (all in north Tripura), Khowai, Howrah (west Tripura), Gumti, Mahuri and Feni (south Tripura). These rivers - along with other small streams and rivulets - have a total length of 1,200 km. Thus, the combined length of rivers in the Northeast is 21,180 km (Table 1). Along with their tributaries, these rivers harbour a diverse and rich fish fauna.

Floodplain wetlands (beels), lakes and swamps: Floodplain wetlands (oxbow lakes, tectonic depressions and other wetland formations on the floodplains of rivers) and associated swamps constitute an important fisheries resource of the northeastern region, especially in the states of Assam and Manipur (Bhattacharjya, 2007). The region also has a number of upland lakes, the most important ones being Loktak Lake (Manipur) and Psango Lake (Sikkim) respectively. Assam has the largest area (100,815 ha) under floodplain wetlands (locally called *beel*s) in the country. However, a number of these beels have been converted to swamps as a result of continuous siltation and macrophyte infestation. The Imphal valley of Manipur has 21,000 ha of *pat*s (as the floodplain wetlands are known in the state), which along with the Loktak Lake (19,150 ha), make it the second most potential state in the region for fisheries development. Arunachal Pradesh Meghalaya, Tripura, and Nagaland have 2500 ha, 375 ha, 500 ha and 215 ha of *beel*s respectively. The total area of *beel*s, *pat*s, lakes and swamps in the region is 144,555 ha. Floodplain wetlands harbour rich fish fauna especially because these open water bodies present the conditions of both flowing and stagnant waters and therefore houses fish species present in both these habitats.

Ponds and 'mini barrages': Assam (31,232 ha water spread area) has the largest area of ponds among the northeastern states. Tripura has 13,342 ha aquaculture ponds, of which 4,270 ha are improvised impoundments created by blocking the streams. Locally called mini-barrages, this type of ponds are also popular in Mizoram where there is a dearth of plain land for digging ponds (Sugunan, 2003). Mizoram has 1,800 ha of ponds while Manipur, Meghalaya and Nagaland have 5,000 ha, 500 ha and 500 ha of ponds respectively. Arunachal Pradesh has 250 ha of ponds, some of which are suitable for coldwater fish culture. It is estimated that out of the 66,795 ha of potential pond area available in the region 52,119 ha are already available for aquaculture. The natural ponds still houses a considerable number of fish genetic resources even though natural fishes present in aquaculture ponds are by and large eliminated to give way to a few cultivable fish species (numbering 12 at present).

Reservoirs: Although the northeast has enormous potential for creating impoundments for generating hydroelectric power, only a few projects covering 17,435 ha water spread area have come up (Table 1). They include Umrang and Khandong reservoirs created under the Kopili

Hydroelectric Project in North Cachar Hills district of Assam (1,713 ha), Umiam, Kyrdemkulai and Nongmahir reservoirs in Meghalaya (8,430 ha), Gumti reservoir in Tripura (4,500 ha), Khopum dam of Manipur (100 ha) and the Palak lake of Mizoram (32 ha). In addition, Daiyang reservoir in Nagaland and Ranganadi reservoir in Arunachal Pradesh have recently being commissioned. A number of reservoirs are in the pipeline including the ones presently being constructed by NEEPCO, Shillong on Tenga and Bishom rivers (tributaries of R. Kameng/ Jiabhorali) in Arunachal Pradesh and the one on River Pagladiya in Lower Assam (by NHPC, New Delhi). It is estimated that the Brahmaputra and Barak river basins together constitute 50% of the total hydel power potential of the country (Sinha, 1990). Reservoirs also harbour rich fish fauna since (i) they create huge areas of comparatively stable environment, which is a continuum of the river, and (ii) they have both flowing and stagnant waters at the same time and therefore houses fish species present in both these habitats. Unfortunately, the exotic common carp has established itself in Umiam reservoir of Meghalaya (Bhattacharjya, 2005) at the cost of native fish species.

Low–lying paddy fields: The Northeast has 42,280 ha of low-lying areas of which only 2,670 ha is reportedly developed for undertaking paddy-cum fish culture in them (Bhattacharjya, 2005). At present, paddy-cum fish culture is practised in some appreciable extent only in Nagaland and the Apatani plateau of Arunachal Pradesh. There are some traditional practices of growing fish in the paddy fields in certain other areas like Juria block of Nagaon district (Assam) and the hill tracts of Ukhrul district (Manipur). But these culture practices are low yielding and mostly subsistence in nature. Natural low-lying areas of the region house a rich variety of fishes.

Ichthyo-faunistic resources

Sen (2000) reported 267 indigenous fish species belonging to 114 genera under 38 families and 10 orders occurring in the Northeast. Mahapatra *et. al.,* (2004) added seven exotic fish species recorded in the region to this list thereby taking the total to 274. Two endemic murrel species viz., *Channa bleheri* (Vierke, 1991) and *C. aurantimaculata* (Musikasinthorn, 2000) reported from the region (Goswami, *et. al*., 2006) were not included in the previous lists. In addition, 14 new species was reported by Viswanath under NATP (Germplasm Inventorization) sub-project led by NBFGR, Lucknow (Singh *et al*., 2006). Taking these new desciptions into account, the total number of fish species recorded and reported from the region now stands at 292. This is approximately 36.2% of total Indian freshwater fishes. The mixing of drainages and their fish fauna in the geological past has rendered the eastern Himalayas very important from faunistic point of view. The region shares its fish genetic resources with that of the Indo-Gangetic plains and to a lesser extent with the Myanmar and South Chinese fauna. The number of fish species recorded and reported from the region has gone up from 230 in 1994 (Sinha, 1994) to 266 in just six years (Sen, 2000) indicating that the region's fish genetic resources is yet to be fully explored. There has been little effort to identify fish genetic stocks possibly existing within a given species except for an ICAR Network Activity initiated in 2008 to study genetic stocks of the Indian major carps occurring in the Brahamaputra River for comparing them with those of R. Ganga and R. Narmada.

An overwhelming majority of the ichthyospecies occurring in the region (275 species) belonged to 3 orders, *viz*., Cypriniformes (159 species) followed by Siluriformes (78) and Perciformes (36). The remaining 7 orders, *viz*., Clupeiformes (7 species), Anguilliformes (3), Osteoglossiformes, Synbranchiformes (2 each), Cyprinodontiformes, Syngnathiformes and Tetraodontiformes (1 each) accounted for 17 species only.

Among the states Assam has the largest number of ichthyospecies numbering 216 (Bhattacharjya *et. al.,* 2003), followed by Arunachal Pradesh (167), Meghalaya (165), Tripura (134), Manipur (121), Nagaland (68) and Mizoram (48 species) (Sen, 2000). These include 31 species endemic to the region. The most important commercial fishes of Sikkim are the snow trout (*Schizothorax* spp.), mahaseer (*Tor putitora*), cat fishes (*Glyptothorax* spp., *Bagarius* spp., *Pseudechencies* sp.) and a number of Cyprinids (e.g., *Garra* spp., *Barilius* spp., etc.).

Ichthyofaunistic resources of the region present a combination of both torrential and plain water forms as well as cold and warm water species. The fauna include true hill stream forms like *Garra* spp*., Psilorhynchus* spp*., Glyptothorax* spp.; semi-torrential forms like *Crossocheilus* spp*., Nemacheilus* spp*., Acanthocobitis* spp*., Botia* spp*., Somileptes gongota, Lepidocephalus* spp*., Amblyceps mangois, Silurus berdmorei, Olyra* spp*., Aborichthys* spp.; migratory forms like *Anguilla bengalensis bengalensis, Schizothorax* spp*., Barilius* spp*., Cyprinion semiplotum, Labeo* spp*., Neolissochilus* spp*., Tor* spp*., Channa* spp*., Aorichthys* spp*., Mystus* spp*., Mastacembelus armatus, Badis badis, Anabas testudineus* as well as plain water forms.

Endemic species: A fish species endemic to a country or a drainage system where it is native and described. The issue of endemism has great relevance considering the current legislation regarding patenting of species (Ponniah and Sarkar, 2000). Preliminary evaluation by the National Bureau of Fish Genetic resources, Lucknow in 2000 revealed that out of 186 species assessed, 62 species appeared to be endemic to the Northeast (Ponniah and Sarkar, 2000), which needs further validation. Prominent endemic species of the region include *Channa bleheri, C. stewartii, C. aurantimaculata, Lepidocephalus goalparensis, Nangra assamensis, Barilius shacra, B. tileo, Conta conta, Crossocheilus latius, Danio aequipinnatus, D. naganensis, Garra manipurensis, G. naganensis, Puntius shalynius, Tor progeneius, Mystus menoda menoda, Colisa labiosus, Glyptothorax cavia, Aborichthys garoensis, Noemacheilus arunachalensis, Schistura manipurensis, Amblyceps apangi* and *Psilorhynchus homaloptera*.

Occurrence of exotics: As many as eight exotic species *viz*., common carp (*Cyprinus carpio* var. *communis*), grass carp (*Ctenopharyngodon idella*), silver carp (*Hypophthalmichthys molitrix*), bighead carp (*Aristichthys nobilis*), Tawes/China puthi *Puntius gonionotus,* tilapia (*Oreochromis mossambicus*) and African magur (*Clarias gariepinus*) have been observed in different parts of the region. In addition, Mahapatra *et. al.,* (2004) recorded established breeding population of *O. niloticus* from the region. The capture of the African **magur** (*C. gariepinus*) from the open waters of Assam indicates that this highly carnivorous species has already gained entry into the natural water bodies with potential adverse effects on the indigenous ichthyofauna (Bhattacharjya *et. al.*, 2000).

Utilization pattern

Food fishes: Almost all the fish species occurring in the state have food value except for a few species like *Chaca chaca, Badis badis*, *Conta conta*, *Aplocheilus panchax, Hara* spp. and *Tetraodon cutcutia.* Even these non-food fishes have potential ornamental value. Thus, none of the fish species occurring in the region can be termed as trash fish. *Xenentodon cancila* which was not consumed by most people until a decade ago is now consumed by some people mainly because of shortage of small economic fishes in recent years. However, out of the 274 fish species only 56 species were found to be commercially important. Among them, *Chitala chitala, Clarias batrachus, Ompok pabda, O. pabo, Tor putitora, T. tor, Labeo dyocheilus, Schizothorax richardsonii, Heteropneustes fossilis, Monopterus cuchia, Osteobrama belangeri*, *Aorichthys aor, A. seenghala* and *Setipinna phasa* are the most prized ones. The three species having red meat *viz.*, *C. batrachus*, *H. fossilis* and *M. cuchia* are believed to be helpful in recuperation (blood formation) and, therefore, command very high demand and price in the state.

Generally, fishes caught from open waters like rivers, reservoirs and beels fetch much higher prices than their counterparts from aquaculture ponds, since the wild fishes are considered to be more supple and tastier than farmed fishes. As a result, farmed Indian major carps imported from Andhra Pradesh are nearly as half as costly as those caught from open waters. Even smaller wild fishes like *Gudusia chapra*, *Notopterus notopterus, Cirrhinus reba* and *Labeo bata* fetch higher price than farmed major carps. According to a report (Bhattacharjya *et. al.,* 2000) **catla, rohu** and **mrigal** remained the mainstay of stocking in polyculture in lower Assam, followed by grass and silver carp; other species occasionally stocked include common carp, bighead carp (*Aristichthys nobilis), L. calbasu, L. gonius, L. bata, C. reba, Puntius gonionotus, Oreochromis mossambicus* and *Clarias gariepinus.* In recent years, there has been marked shift in consumers' preference from Indian major carps to minor carps like *Labeo gonius, Labeo bata and Cirrhinus reba*. Thus, there is need to develop culture techniques in respect of these more renumerative species. However, non-availability of fish seed is hampering their inclusion in aquaculture and culture-based fisheries at present. It may be noted that the prices of fresh fishes in the north-east is among the highest in the country because the demand for fresh fish far exceeds supply.

Sport fishes: Important coldwater sport fishes of the region are mahseers (*Tor putitora, T. tor, T. progenius, T. mosal*), *Bokar/katli* (*Neolissochilus hexagonolepis, N. hexastichus*), snow trouts (*Schizothoraichthys progastus, Schizothorax richardsonii*) and the Indian trout (*Raiamas bola*). At present, the upper stretches of R. Jiabharoli (North bank) and R. Kapili (south bank) in Central Assam are favourite angling spots; R. Jiabharoli has emerged as a favourite eco-tourism destination. The upper stretches of R. Manas located within the Manas sanctuary in lower Assam was also a good angling area, whose importance has waned temporarily in the past few years due to insurgency problem. The potential of R. Kulsi and R. Bargung in addition to R. Jiabharali and R. Manas as coldwater/ sport fisheries has already been documented (Kumar, 1986). Bhattacharjya *et. al*., (1999) reported that R. Lohit (up to Allubarighat in neighbouring Arunachal Pradesh) has the potential to be developed into sport fisheries/ eco-tourism centers.

Ornamental fishes: As many as 150 species occurring in the region were found to have potential ornamental value during field studies conducted by the Institute during 2002-07. Mahapatra *et. al*., (2004) stated that as many as 255 species out of 266 indigenous fish species of the region had potential ornamental value. According to MPEDA sources (Anil Kumar, *per. com*.), as many as 123 indigenous ornamental fish species occurring in the region (e.g., *Channa barca, C. bleheri, Sisor rabdophorus, Ctenops nobilis*, *Botia dario, B. rostrata, Puntius shalynius, Hara hara, Conta conta, Badis badis, Notopterus notopterus, Nandus nandus*) caught from the wild are exported from the region.

Conservation status

In recent years habitat modifications and over-exploitation have resulted in considerable depletion of fish stocks of the region. According to Yadava and Chandra (1994), six carps and five catfish species were threatened at various levels in the Brahmaputra River system. Similarly, Sinha (1994) listed eight threatened coldwater species occurring in the north-eastern region. Bhattacharjya *et. al.,* (2000) identified 25 fish species occurring in Assam as threatened ones. As per CAMP report (1998), out of 320 freshwater fish species including 105 from the NE region assessed in a CAMP workshop 83 fish species occurring in the region were threatened at various degrees (5 critically endangered, 1 extinct in the wild, 31 endangered and 46 vulnerable). Critically endangered species included *Garra litanensis, G. manipurensis* and *Osteobrama belangeri*. However, the assessment of the species for this purpose was based on their distribution in whole of India and not exclusively that in the north-eastern region (Sen, 2000).

Conservation of fish genetic resources of northeast: major issues

Macrophyte infestation: Most of the floodplain wetlands, unmanaged ponds and other low-lying areas of the region are infested with floating (especially water hyacinth) submerged (e.g., *Hydrilla* spp., *Vallisnaria* spp.), rooted emergent (e.g., water lily) and marginal macrophytes (e.g., *Typha* spp.). Excessive growth of macro-vegetation gradually converts the open water body into swamps; only a few air-breathing fish species like murrels, walking catch, stinging catfish, climbing perch, mud eel, etc. can survive in such water bodies at the cost of large number of non air-breathing fishes.

High rainfall and floods: The northeastern region receives very high rainfall during the southwest monsoon season (June to September), which coupled with its unique undulating topography and siltation of most of its rivers and associated wetlands, wrecks havocs on the floodplain areas every year. Floods are considered as one of the major constraints to aquaculture development on a commercial scale in the region especially in Assam and Tripura, because it submerges the aquaculture ponds and pens constructed in marginal areas of beels and reservoirs (Bhattacharjya, 2005). Such annual submergence of aquaculture systems results in escape of considerable numbers of farmed fish species (mainly Indian major and exotic carps) into the wild. The problems posed by the escape of exotic fish species into natural open water bodies including their possible establishment in them at the cost of native fish species is well documented (Walford & Wicklumd, 1973; FAO, 1980; IUCN, 2000; DIAS, 2003). Exotic fish introductions for aquaculture have already impacted the fish biodiversity and have provided significant warnings of the various effects in many countries world over (Lakra *et. al.,* 2006).

Fish disease: As aquaculture and fisheries enhancements have progressed in the region, fish disease in aquaculture systems have emerged as a notable problem; fortunately, the problem is not very acute except for the occasional outbreaks of the Epizootic Ulcerative Syndrome (Bhattacharjya, 2005). The diseases spread to open water bodies in due course and results in low abundance of the affected fish species as has happened during the early years of EUS attack in the region in late eighties.

Wind: Heavy winds (and associated waves) experienced in the region especially during the pre-monsoon season (March to May) can damage the pen and cage structures erected in beels and reservoirs. As a result, the fish farmers suffer losses by way of loss of stocked fishes and necessary repairs. Even though this problem can be pre-empted by erecting a stronger pen frame and putting some extra anchors and matching floats in the cage platform, such a step will increase the initial investment required to construct pens/cages. Therefore, construction of the pens/ cages in a sheltered area appears to be a cheaper option.

Aquatic pollution: Although the Northeast was known for its pristine aquatic environments, many of its rivers and floodplain lakes receives considerable quantities of effluents mainly sewage from the region's towns/ cities as well as industrial effluents from refineries, paper mills, etc. Aquatic pollution directly affects the abundance and survival of aquatic species present in them including fishes. Unfortunately, the status of aquatic pollution in the region and its impact on its fish genetic resources is yet to receive due attention from R&D departments.

Non-availability of funds for openwater fisheries development is a serious economic constraint for fisheries development in the region especially that in its large open water bodies. A substantial part of the resources in the northeast comprises capture fisheries, development and management of which requires higher initial costs, compared to pond aquaculture. Financial institutions are reluctant to advance loans to resource-poor fishers for capture fishery operations. Apart from the uncertainties of catch, they often cannot fulfil the criteria set by financial institutions regarding collaterals, sureties, *etc.* (Sugunan, 2003). Development of natural resources for fish production involves very high costs, which often has to be borne by the governments as part of its social welfare programmes for fishers (mostly SC). However, most of the north-eastern states are facing financial crunch, which has affected natural fisheries developments.

Shrinking area of open water bodies: Floodplain wetlands, reservoirs, mini-barrages and low-lying areas of the region receive a lot of silt from the rivers and/or surface run-off from their catchment areas especially during the rainy season. The region's hills and mountains are geologically unstable and therefore, soil erosion and landslides are common. The problem is aggravated by agricultural activities in the catchment areas, which loosens the top soil. Siltation is a serious problem faced by the beels/pats, swamps and low-lying areas. Infestation of aquatic macrophytes causes additional auto-siltation in these water bodies. Consequences of siltation include: shrinking water area, reduced water levels, reduced water renewal/ auto-stocking from rivers due to siltation of the connecting channels, faster ageing to swamps/paddy fields and diversion for agriculture/other uses (Bhattacharjya, 2005). Shrinking water area coupled with reduced water levels results in loss of crucial habitat for natural fishes and results in reduced abundance of their populations. In extreme cases certain fish genetic stocks may be lost for ever.

Siltation is a natural process and cannot be prevented. However, the rate of siltation can be reduced by enforcement of strict laws to prevent deforestation, planting trees around the water body to prevent soil erosion and controlling aquatic macrophytes. In case of beels/pats, eventhough constructing embankments will reduce the problem, this will disturb the natural ecological processes and therefore is not advisable (Bhattacharjya, 2004). Periodical desiltation of the water body is required for maintaining its productive area but is a costly proposition. Open water bodies like beels, lakes, swamps and reservoirs of the region face the threat of shrinkage in their water spread area over the years due to siltation and subsequent diversion to other uses. Random field surveys conducted by CIFRI in over 50 beels located in different parts of Assam indicated that up to 35-40% of the beel area shown in revenue records have been silted/ dried up (Bhattacharjya, 2004). The silted areas are gradually encroached by the local inhabitants and converted to private patta lands in due course with the connivance of revenue officials. A number of beels/pats have either dried up completely or are diverted to other uses like agriculture, pond construction, housing, etc. Encroachment/diversion of these water bodies is abetted by a number of factors like the absence of clear demarcation of boundaries, increased pressure on land resources for agriculture/housing, lack of effective government control, lack of awareness among the riparian communities about conservation of the wetlands for maintaining environmental balance, lack of participation of the local communities in the development/management process, economic benefits from the resource used by only a handful of individuals (lessees/fishers' cooperative society members), connivance of revenue officials, etc. (Bhattacharjya, 2005). Probable solutions to this burning issue include prevention and control of siltation, formulation and enforcement of strict laws to prevent reclamation/encroachment, creation of mass awareness about the need for conservation of wetlands/swamps and demarcation of boundaries.

River regulation: Construction of embankments along the banks of rivers for flood control has resulted in negligible auto-stocking of riverine fish species and annual flushing of water in many beels/pats, lakes and swamps. Further, since most riverine fish species use the open beels as spawning and nursery ground, such embankments also adversely affects the fish stocks of the parent rivers (Bhattacharjya, 2004). The harmful effects of dams on the ecology and fisheries of rivers have been well known (Jhingran, 1991) especially on the fisheries of migratory species. However, even though river regulation has harmful effects on the fish genetic resources of open water bodies, it is practically irreversible since flood control and electricity generation are given more importance than fisheries. Thus, construction and effective operation of sluice gates appears to be a practicable option.

Regulation of fishing: As a result of years of reckless over-exploitation, stocks of major fishes are depleted in most rivers and its associated water bodies of the region. This has resulted in reduced auto-stocking and fish abundance in these water bodies. In extreme cases, it may also result in threatening the existence of certain resident fish species like *Tor* spp., *Bengana elanga*, *Ompok* spp., *Mystus menoda, Labeo nandina, Pangasius pangasius*, *Puntius sarana sarana*, etc. Regulation of fishing is a difficult task because the fisheries departments of the region do not have enforcement machinery unlike that of forest and have to depend on the district administration and the local police stations. Providing alternative employment/financial support to affected fishers during closed season is another tricky issue. Regulation of fishing also requires formulation of practicable conservation technique suiting local conditions (e.g., minimum landing size is more practicable than mesh size regulation in case of multi-species fisheries), empowerment of fisheries officials for enforcement, strengthening fishers' cooperative societies and creation of mass awareness among the fishers and beel managers (Bhattacharjya, 2005).

Leasing policy: At present, most open water fisheries including river stretches are leased for short (one year) to medium-term periods (3-5 years). Only the registered **beels** under the administrative control of the Assam Fisheries Development Corporation are leased for a reasonably longer period of seven years (Bhattacharjya, 2004). However, such beels are only a handful in numbers. Short-term leasing of the open water fisheries is likely to result in depletion of fish stocks in them since the lessees usually have a tendency to catch as much fish as they can within their limited tenure and are unlikely to invest in management options like macrophyte control since they are unsure of securing lease for the next term. On the other hand, there is also an apprehension that if the fishery is leased for a long period (without a provision to cancel the lease midway, if needed) to a party interested only in maximizing its own profits it may cause irreparable damage to its fish genetic resources (Bhattacharjya, 2005).

Policy issues specific to the northeast such as those related to land holding system, access to water bodies, lack of alternative employment opportunities for fishers (resulting in increase in fishing pressure) etc. also come in the way of conservation of fish genetic resources in the region.

Natural phenomena having positive influence on fish genetic resources

Inclusion of certain rivers (e.g., R. Diphalu in Kaziranga National Park of Assam) and **beels** in wildlife sanctuaries and Ramsar sites (e.g., Dipor beel of Assam) is a blessing in disguise for conservation of fish genetic resources present in them.

Need for conservation of fish genetic resources

- Fish is a popular source of protein (over 95% of the region's populace are fish eaters)
- Fish is an integral part of rituals and traditions in the Northeast
- Fisheries support livelihood security of thousands of resource-poor fishers
- At present only 12 fish species are commercially bred and cultured in the Northeast; we need to conserve genetic resources for potential future use in aquaculture
- Intrinsic and Ethical value of our fish species

Strategies for conservation of fish genetic resources

The importance of genetic selection and hybridization in improving fish varieties was first stressed in 1966 at the FAO world symposium on warm water pond culture held in Rome. An *ad hoc* working party on genetic resources of fish was established by FAO in 1971 which reviewed information on genetic selection in fish farming, identified priority areas for research and made recommendations on conservation of fish genetic resources (Jhingran, 1984).

UNEP (1980) proposed the following two broad strategies for conservation of fish genetic resources, which are complimentary to each other.

I. *In situ* conservation: The conservation of genetic resources through their maintenance within natural or man-made eco-systems in which they occur. *In situ* conservation strategies or fishes include-

(i) Establishment of aquatic sanctuaries: At present there are separate aquatic sanctuaries in the Northeast. However, a river stretches and floodplain wetlands/ lakes situated within wild life sanctuaries of the region act as aquatic sanctuaries by default

(ii) Closed fishing seasons/ zones for ensuring natural spawning success

(iii) Banning/ phasing out of destructive fishing methods

(iv) Enforcement of minimum landing size/ mesh size of fishing nets

Although *in situ* conservation permits essential natural survival, it may interfere with immediate utilization of conserved species in induced breeding programmes. Further, religious beliefs/ taboos (e.g., non killing of all fishes in predominantly Buddhist Sikkim state, non killing of turtles present in the pond within Mata temple complex in Udaipur, Tripura as well as those within Kamakhya temple complex in Guwahati, Assam is often more effective than government enforced conservation efforts. Thus, spreading awareness about responsible fisheries and aquaculture among all stakeholders apparently holds the key to successful conservation efforts.

II. *Ex situ* conservation: Outside their habitats either by perpetuating sample population in genetic resources centres, culture operations or in the form of gene pools and gamete storage for fish, germplasm banks, etc. *Ex situ* conservation strategies for fishes include-

(i) Cryo-preservation of fish gametes (sperm and ova)

(ii) Establishment of fish gene banks (e.g., one set up by the Zoology Department of Gauhati University and sponsored by NBFGR, Lucknow).

Though convenient and relatively inexpensive, *ex situ* conservation could freeze natural evolution and interaction with the eco-system and cause genetic degradation at least in some cases. Therefore, a flexible mix of various methods is necessary (UNEP, 1980).

The UNEP further recommended the following possible approaches towards conservation of fish genetic resources:

(i) Consultation with experts particularly with respect to conservation techniques and the formulation of plan of action for fish genetic resource conservation

(ii) Promoting the establishment of a mechanism for monitoring changes in the genetic diversity of fish populations including the possibility of a registry of fish species introductions and encouraging guidelines for the exchange of exotic species, and a medium for dissemination of information on genetic impoverishment in fish-producing natural or man-made ecosystems

(iii) Encouraging the production of a catalogue of genetic material, especially including description of genetic qualities which would serve as a nucleus and as a basis for conservation efforts

(iv) Promoting of research directed at creation of knowledge on the genetics of fish which would assist in a more applicable definition of genetic impoverishment in fish species and appropriate mechanism to conserve and enhance genetic diversity

(v) Promotion of *in situ* conservation through appropriate management of certain ecosystems with rich genetic diversity, especially those relating to fish species having or known to have the potential for a major socio-economical role.

Conclusion

Natural open water bodies of the Northeast are being subjected to considerable natural (e.g., siltation) and anthropogenic stresses (e.g., pollution and reclammation). In addition, many natural lentic water bodies like ponds, closed **beels**, swamps and low-lying paddy fields are being converted to aquaculture ponds, wherein the native fish fauna are eliminated for culturing a few fast growing species like Indian major and exotic carps. This is bound to result in considerable loss of rich fish genetic resources of the region. Thus, a thorough evaluation of the region's fish genetic resources along with their current conservation status is urgently required for their conservation and sustainable utilization. More so, because unspecified quantities of indigenous ornamental fish species are being exported out of the region through traders based at Kolkata. Conservation of the region's fish biodiversity is a major challenge, since it is difficult to make legislators and public realize the importance of protecting the fishes live because unlike land animals or trees fishes are not easily visible in their natural habitats. Fisheries development often comes into conflict with environmental conservation norms and, therefore, careful planning is required in achieving fish yield enhancement while accommodating the concern for conservation of its rich fish genetic resources. This is particularly important in the Northeast, which has so much at stake in the form of pristine aquatic environments and precious endemic fish species to be preserved for posterity. Towards this end concerted efforts are needed on the part of all concerned. Creation of public awareness should form an integral part of conservation of fish biodiversity for their possible future use in addition to relevant technical innovations.

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Table 1. Fisheries resources of the north-eastern states.

States	**Rivers** (km)	**Reservoirs** (ha)	**Beels, lakes and swamps** (ha)	**Ponds/mini-barrages** (ha)	**Low-lying fields** (ha)
Arunachal Pradesh	2,000	160	2,500	250 (1,250)	575 (2,925)
Assam	4,820	1,713	1,00,815	31,232 (3,768)	- (20,000)
Manipur	3,360	100 (40,000)	40,150	5,000 (4,500)	- (10,000)
Meghalaya	5,600	8,430	375	500 (1,900)	85 (4,915)
Mizoram	1,700	32	-	1,795	120 (1,440)
Nagaland	1,600	2,500 (24,600)	215	500 (1,500)	2,000 (3,000)
Sikkim	900*	-	-	-	-
Tripura	1,200	4,500 (1,500)	500	13,342 (3000)	-
Northeast	**21,180**	**17,435 (66,100)**	**144,555**	**52,619 (14,576)**	**2,680 (42,280)**

Source: State governments; *Handbook of Fisheries Statistics, MoA, DAHDF, Govt. of India (Figures in parenthesis indicate resources, which are yet to be created/developed).

Varied fish genetic resources of the northeastern region

2.2 Molecular and Biotechnological Tools for Characterization, Conservation and Utilization of Plant Genetic Resources

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Plant genetic resources (PGR) refer to the variability existing among plant populations for traits of actual or potential value. They play a pivotal role in the long term sustainability of diverse agricultural ecosystems as they act as buffers in the event of any imbalance that may be caused due to climate change or any other serious biotic or abiotic challenge to the cropping system. PGR, if effectively characterized and conserved can be utilized as a repository of favourable genes, traits and phenotypes whose incorporation in the cropping system would not only increase its productivity, but also enhance its sustainability. PGR has been the basis of genetic improvement of crop species to overcome the productivity constraints and to increase productivity *per se*. Despite their importance, they are facing imminent threats of erosion at a rapid rate primarily due to the development of modern agriculture unidirectionally concentrating on increasing yield at the cost of diverse resources. Therefore, proper management of PGR has become key to sustainable agricultural development in the country.

In the recent years, biotechnological and molecular tools have played an increasingly important role in conserving and precisely characterizing PGR. The diversity of PGR originates from the diversity of the genetic material which is common to all organisms, ie. the DNA (Deoxyribonucleic acid). The heritable change in the DNA molecule is termed as mutation, which together with several factors like recombination, repetitive sequences, mating system, selection pressure, genetic bottlenecks etc. lead to the creation of phenotypic variation in the germplasm. Therefore, for precise characterization of PGR, it is important to study them at the molecular level together with the phenotypic and morphophological characterization and evaluation.

Molecular markers for characterization of PGR

Markers are characters whose inheritance pattern can be followed at morphological, biochemical, or DNA level. Markers are so called because we use them to obtain information about genetics of traits of interest. Morphological markers like flower colour, plant height etc. are inexpensive and easy to score but are limited in number. Also, their expression can be differentially affected by the environment. Biochemical markers like isozymes or allozymes are most cost effective tools for data point generation. However, their number is a limiting factor and their expression may also vary in different parts of the plant and may also be affected by the environment. On the other hand, DNA based markers produce a large number of data points, they are not influenced by environment, and they are present in all tissues and can be scored at all stages of plant growth. DNA markers can be broadly classified as follows:

Hybridization based markers:

Restriction Fragment Length Polymorphism (RFLP)

Description: RFLPs are bands that correspond to DNA fragments, usually within the range of 2–10 kb, that have resulted from the digestion of genomic DNA with restriction enzymes. DNA fragments are separated by agarose gel electrophoresis and are detected by subsequent Southern blot hybridization to a labeled DNA probe (Fig. 1a). Labeling of the probe may be performed with a radioactive isotope or with alternative non-radioactive stains, such as digoxigenin or fluorescein. DNA sequence variation affecting the absence or presence of recognition sites of restriction enzymes, and insertions and deletions within two adjacent restriction sites, form the basis of length polymorphisms.

Strengths: RFLPs are generally found to be moderately polymorphic. In addition to their high genomic abundance and their random distribution, RFLPs have the advantages of showing codominant alleles and having high reproducibility.

Weaknesses: The main drawbacks of RFLPs are the requirement of laborious and technically demanding methodological procedures, and high expense. Moreover, large quantities (1–10 µg) of purified, high molecular weight DNA are required for each DNA digestion. Larger quantities are needed for species with larger genomes, and for the greater number of times needed to probe each blot. RFLPs are not amenable to automation and collaboration among research teams requires distribution of probes.

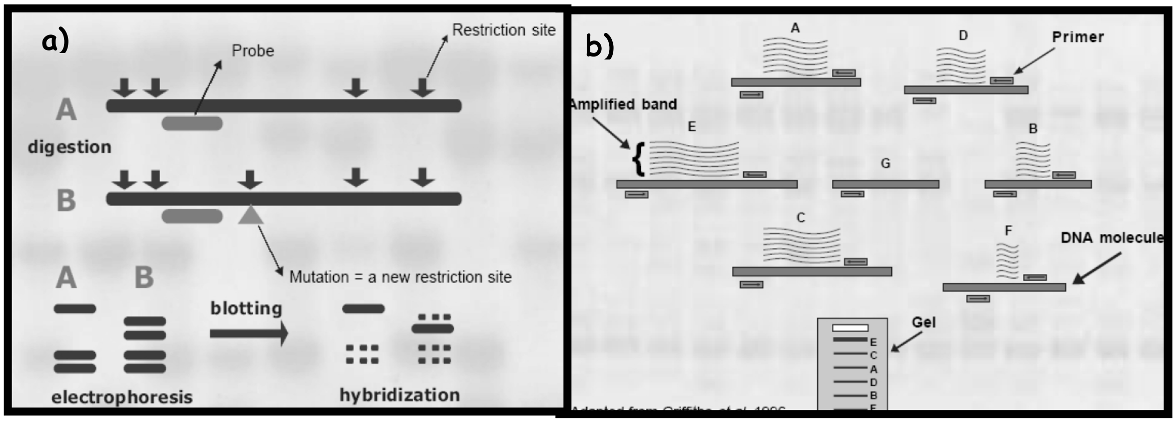

Figure 1. Illustration of basic techniques of restriction digestion and PCR followed by electrophoresis to detect polymorphism. a) Due to the creation of an extra restriction site in individual B (due to mutation), it gives an extra band (polymorphism) upon electrophoresis. b) Fragments of genomic DNA are amplified by PCR and separated electrophoretically. Variation in DNA sequence different individuals may give different band sizes.

Polymerase Chain Reaction (PCR) based markers:

The **polymerase chain reaction** (**PCR**) is a technique to amplify a single or few copies of a piece of DNA across several orders of magnitude. The method relies on thermal cycling, consisting of cycles of repeated heating and cooling of the reaction for DNA melting and enzymatic replication of the DNA. Primers (short DNA fragments) containing sequences complementary to the target region along with a DNA polymerase (after which the method is named) are key components to enable selective and repeated amplification. As PCR progresses, the DNA generated is itself used as a template for replication, setting in motion a chain reaction in which the DNA template is exponentially amplified using dNTPs (building blocks of DNA) and primers. This process is repeated several times (usually 30-40) and consequently, the DNA fragments are amplified exponentially. The amplified fragments are then separated on a gel and scored for polymorphism (Fig. 1b)

Random Amplified Polymorphic DNA (RAPD)

Description: RAPDs are DNA fragments amplified by PCR using short synthetic primers (generally 10 bp) of random sequence. These oligonucleotides serve as both forward and reverse primer, and are usually able to amplify fragments from 1–10 genomic sites simultaneously. Amplified fragments, usually within the 0.5–5 kb size range, are separated by agarose gel electrophoresis, and polymorphisms are detected, after ethidium bromide staining, as the presence or absence of bands of particular sizes. **Strengths**: The main advantage of RAPDs is that they are quick and easy to assay. Because PCR is involved, only low quantities of template DNA are required, usually 5–50 ng per reaction. Since random primers are commercially available, no sequence data for primer construction are needed. Moreover, RAPDs have a very high genomic abundance and are randomly distributed throughout the genome. **Weaknesses**: The main drawback of RAPDs is their low reproducibility, and hence highly standardized experimental procedures are needed because of their sensitivity to the reaction conditions. As for most other multilocus techniques, RAPD markers are not locus-specific, band profiles cannot be interpreted in terms of loci and alleles (dominance of markers), and similar sized fragments may not be homologous.

Applications: RAPDs have been used for many purposes, ranging from studies at the individual level (e.g. genetic identity) to studies involving closely related species. RAPDs have also been applied in gene mapping studies to fill gaps not covered by other markers. Variants of the RAPD technique include Arbitrarily Primed Polymerase Chain Reaction (AP-PCR) which uses longer arbitrary primers than RAPDs, and DNA Amplification Fingerprinting (DAF) that uses shorter, 5–8 bp primers to generate a larger number of fragments. Multiple Arbitrary Amplicon Profiling (MAAP) is the collective term for techniques using single arbitrary primers.

Microsatellites

Description: Microsatellites represent short tandem repeats on DNA nucleotides (1–6 base pairs). If nucleotide sequences in the flanking regions of the microsatellite are known, specific primers (generally 20–25 bp) can be designed to amplify the microsatellite by PCR. Polymerase slippage during DNA replication, or slipped strand mispairing, is considered to be the main cause of variation in the number of repeat units of a microsatellite, resulting in length polymorphisms that can be detected by gel electrophoresis.

Strengths: The strengths of microsatellites include the codominance of alleles, their high genomic abundance in eukaryotes and their random distribution throughout the genome, with preferential association in low-copy regions. Because the technique is PCR-based, only low quantities of template DNA (10–100 ng per reaction) are required. Due to the use of long PCR primers, the reproducibility of microsatellites is high and analyses do not require high quality DNA.

Weaknesses: One of the main drawbacks of microsatellites is that high development costs are involved if adequate primer sequences for the species of interest are unavailable, making them difficult to apply to unstudied groups. Although microsatellites are in principle codominant markers, mutations in the primer annealing sites may result in the occurrence of null alleles (no amplification of the intended PCR product), which may lead to errors in genotype scoring.

There are several other types of markers that have been developed in recent years and have been used for analyzing diversity of PGR. These are generally variations, modifications or combinations of the above mentioned basic techniques and are based on the similar principles of PCR or/and restriction digestion followed by detection of fragment length polymorphism. Some of these markers are Inter Simple Sequence Repeats (ISSR), Single-Strand Conformation Polymorphism (SSCP), Cleaved Amplified Polymorphic Sequence (CAPS), Sequence Characterized Amplified Region (SCAR) and Amplified Fragment Length Polymorphism (AFLP). Detailed review about molecular markers is provided by Spooner *et al*. (2005) and Joshi *et al.* (1999).

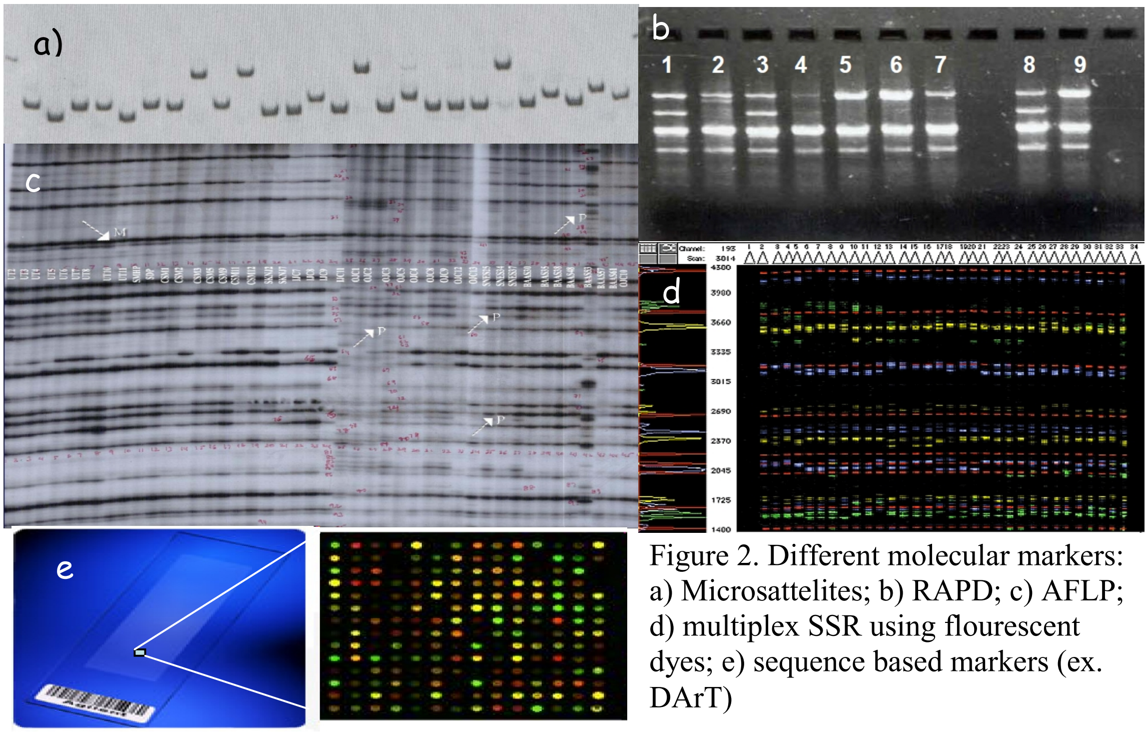

Figure 2. Different molecular markers: a) Microsattelites; b) RAPD; c) AFLP; d) multiplex SSR using flourescent dyes; e) sequence based markers (ex. DArT)

Sequence based markers:

With the advent of modern sequencing technology, complete genomes of several organisms have been sequenced. *Arabidopsis* and rice genomes have been completely sequenced. Genomes of other important crops like maize, tomato, potato, sorghum have been partially sequenced. The availability of sequence information, together with the use of different fluorescent dyes, automation and robotics has given rise to new generation of molecular markers which are high throughput and detect polymorphisms that usually go undetected by traditional markers. Some examples of sequence based markers are Expressed Sequence Tags (ESTs), Single Nucleotide Polymorphism (SNPs), Diversity Array Technologies. Moreover, with increasing cost-effectiveness of new age sequencing platforms like Illumina, Solexa, ABI etc., it is becoming increasingly feasible to directly go for large scale sequencing followed by *in silico* comparison of the sequence information to detect polymorphism. The suitability of different categories of molecular markers in addressing various biosystematics questions is outlined in Table 1.

Table 1. Comparison of different marker technologies (Hillis *et al.* 1996).

Problem	**Allo zymes**	**RE**	**RAPD**	**SFP & Micro**	**Multi FP**	**Seque Ncing**
Gene evolution	M	M	-	M	-	+
Population subdivision	+	+	M	+	-	+
Mating systems	+	M	M	+	-	$
Clonal detection	+	+	+	+	+	$
Heterozygosity	+	+	-	+	M	M

Paternal testing	M	M	M	+	+	$
Individual relatedness	M	M	M	+	M	$
Geographic variation	+	+	M	+	M	+
Hybridization	+	+	+	M	-	$
Species boundary	+	+	+	M	-	+
phylogeny	M	M	-	-	-	+

+ = appropriate and effective method; - = inappropriate; M = marginally appropriate; $ = appropriate but not cost effective

Using the above mentioned molecular tools, efforts are on in India and internationally to characterize PGR so that they can be protected. Realizing the importance of molecular markers in establishing the uniqueness of genotypes, ICAR established the National Research Center for DNA Fingerprinting (NRCDF) at National Bureau of Plant Genetic Resources for developing DNA profiles of important crop varieties/ genotypes that would help in safeguarding the national wealth in terms of PGR. 2146 varieties had been fingerprinted by NRCDF by the end of 2005. For details, please see Randhawa *et. al*., (2006).

Molecular markers are also helping in precisely answering long standing evolutionary questions about origin, domestification and diversification of important crop species (Garris *et. al*., 2005, Rebourg *et. al.,* 2003, Rakshit *et. al.,* 2007). The use of molecular markers has also led to the mapping, cloning and characterization of several genes that are responsible for agronomically important traits in several major crops, which can be used in crop improvement as discussed in the later section.

Biotechnological tools for conservation of PGR

Biotechnological approach to PGR conservation, especially utilizing in vitro conservation and cryopreservation techniques have gained in importance. These techniques are especially important for plant species that cannot be conserved by conventional seed storage methods.

***In Vitro* Conservation**:

Use of *in vitro* techniques for conservation of PGR is a popular and viable alternative to conventional methods like *in situ* conservation and seed storage. *In vitro* culture technique in plants exploits the phenomenon of totipotency, whereby each cell has the potential to develop into a complete plant. The advantages of *in vitro* conservation are the ease of rapid multiplication, reduced requirement of land and labor, freedom from insect pests and diseases, low risk of genetic instability to various stresses and ease in exchange and shipment. *In vitro* cultures can be conserved under either normal growth conditions or slow growth conditions. Normal conditions are more suitable for naturally slow growing species like *Coffea arabica* and *Morus alba* (Mandal, 1997).

Slow growth involves reduction in the growth rate of cultures with the aim of increasing the subculture interval. Several methods can be used to achieve slow growing cultures. The most effective and commonly used method is reduction of temperature with decreased light intensity. Culture at 15-22^{0}C is generally suitable for tropical plant species, whereas 0-5^{0}C is suited to temperate species. By this method, subculturing period can be generally increased to 6-12 months. Other approaches that have been used to achieve slow growth are inclusion of osmotica or growth retardants in the medium, modification of gaseous environment, minimal growth media, volume and type of culture container, culture tube closure, induction of storage organs, dessication and encapsulation. The success of these techniques may vary from specie to specie.

The culture media and conditions are standardized on different accessions before they can be used at a large scale.

Fig. 3: *In vitro* culture of pigeonpea.

Cryopreservation

Storage of viable biological material below -100^{0}C conventionally using liquid nitrogen is termed as cryopreservation. For storage of seeds, this technique is generally suitable for orthodox, ie. Dissication tolerant seeds because it is a prerequisite for cryopreservation that the moisture content of the seeds be about 5 percent. However, recalcitrant (dissication intolerant seeds may also be stored after treating with cryoprotectants. A better alternative for crops producing recalcitrant seeds is to use embryos or embryogenic axis for cryopreservation. Pollen is also cryopreserved in some cases as it has certain advantages such as facilitating wide hybridization between species separated by physiological, geographical and seasonal limitations. For long term storage of *in vitro* cultures, they can also be cryopreserved in the form of buds, shoot tips, meristems, embryos and cells in liquid nitrogen after treatment with cryoprotectants.

As an alternative to preservation of tissues and organs, with the cloning and characterization of several agronomically important genes in major crop species, the genes themselves can be stored in a gene bank (literally) and introduced into a plant through transgenesis if and when required. For a detailed review of biotechnological approaches to conserve PGR, please refer to Chaudhury *et. al*., (2006).

Biotechnological tools for utilization of PGR

The availability of wealth of molecular data about the germplasm helps the plant breeders to choose precisely what genes and genotypes they would like to use in their crop improvement programme. For example, if a breeder wants to exploit heterosis for crop improvement, he/she would be looking for diverse parents. By looking at the molecular data, the breeder can make an informed decision and choose parents with optimum diversity from a pool of germplasm. The use of molecular markers has led to the mapping, cloning and characterization of several genes that are responsible for agronomically important traits in several major crops. These genes are being transferred to modern cultivars, either through marker assisted breeding or through transgenesis (genetic engineering). Some examples in case of rice are submergence tolerance gene (sub1A, which codes for an ethylene response factor) and cytokynin oxydase gene (OsCKX2), which regulates the number of grains per panicle (Ashikari *et. al*., 2005).

Biotechnology is also adding to the existing diversity of PGR. A well known example is that of *Bt* cotton, where a bacterial gene has been introduced into cotton, and is now a part of cotton germplasm. Another example is that of *golden rice*, where two genes have been introduced from different species into rice to enable rice seeds to produce beta-carotene (Rai *et a*l. 2007).

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2.3 Plant Germplasm Registration

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National Bureau of plant Genetic Resources (NBPGR) is a nodal agency having responsibility to assign the registration number through Plant Germplasm Registration committee (PGRC). Germplasm or genetic stock of agri-horticultural and other economic crops, including agro-forestry species, spices, M. & AP., ornamental plants contains unique, uniform, stable and potential attributes of academic, scientific or commercial value registered.

Types of germplasm

Introduced germplasm: Tomato, peas, French bean, scarlet bean, Lima bean, winged bean, Faba bean, Brassicae (cauliflower, cabbage, knol-khol, turnip, leafy mustard etc.), radish, carrot, *Beta*, capsicum, Chayote, potato, *Cyclanthera pedata*, *Allium* spp. (onion, leek, shallot, garlic), asparagus, artichoke and parsley.

Indigenous germplasm: Eggplant, sponge gourd, ridge gourd, snake gourd, round gourd, *Cucumis melo*, phunt, kakri, cucumber, leafy vegetables viz., Basella, Chenopodium, Amaranthus, Brassica, spinach, Rumex/Sorrel; taro, yam, elephant foot yam, ginger, *Allium* spp. and bitter gourd.etc.

Germplasm of exotic origin for which India is a centre of diversity: Okra, pumpkin, chilli, cowpea, *Brassicae*, Chyote and coriander.

Under utilized / under exploited vegetables: In tribal areas of India many minor vegetables are grown in their field as well as in kitchen garden. Such crops are consumed locally. The genetic resources of such minor vegetable crops include over 50 species (Arora, 1995). Some important ones are: *Allium rubellum*, *Amaranthus* spp., *Apium graveolens*, *Asparagus officinalis*, *Basella alba*/ *rubra*, *Bamboo* spp., *Fagopyrum cymosum*, *Hibiscus sabdariffa*, *Ipomoea aquatica*, *Lactuca sativa*, *L. indica*, *Malva* spp., *Moringa oleifera*, *Ocimum* spp., *Parkia roxburghii*, *Polygonum* spp., *Pilea* spp., *Portulaca oleracea*, *Sesbania grandiflora*, *Solanum torvum*, *Trichosanthes* spp., *Trigonella* spp., *Vigna* spp., *Zizania latifilia*, several aroids and yams.

Wild relatives and related species of vegetable crops: The wild relatives and related species of vegetable crops belongs to the categories, legumes – 31 spp., vegetables – 54 spp., spices and condiments – 27 spp. (Arora and Nayar, 1984) and these are distributed in the Western and Eastern Himalayas, Northeastern region, Gangetic plains, Indus plains and in the Western and Eastern peninsular regions. Botanically these can be classified as follows (Arora, 1995).

Identification of genetic stock/ germplasm for registration: The distribution of a germplasm for a particular geographical area with ecological conditions, agricultural systems and cultural patterns that make possible the survibility and use of the biodiversity in that area in relation to specific genetic stock. Though the concentration of variability could have ethnical and cultural origin besides biological evolution. It is an assert that the farmers family / concerned personnels / scientist is able to identify genetic variations (specific genetic stock/varieties) based on phenotypic elements, growing period, soil adaptation, colour and shaped, flavour and quality and time is a variable factor to define.

Gene pool classification: It is a proposition of some guidelines for classification or grouping of genetic diversity based on cross-compatibility relationships that can simplify use of genetic diversity. Harlen (1992) developed '*gene pool*' concept by assigning the constituent taxa to primary, secondary and tertiary gene pools. At the intra-specific level, cultivars are grouped into races and sub-races.

Primary gene pool: Here those species / germplasm fall which are easily crossable; hybrids are fertile with good chromosome pairing; normal gene segregation and gene transfer is generally easy. Includes spontaneous races (wild and/or weedy) as well as cultivated races. It can be divided into two subspecies: subspecies A to include the cultivated races and subspecies B to include the spontaneous races.

Secondary gene pool: Includes species which are crossable within the crop species. Gene transfer is possible, but with barriers (poorly or not at all). This gene pool is available for use; however, the plant breeder or geneticist will have to put an extra effort to overcome the cross-ability barriers with application of various possible cyto-genetic manipulations to establish a fertile hybrid.

Tertiary gene pool: Refers to wild species that produce hybrids with crop species which are lethal or completely sterile. Gene transfer is either not possible with known techniques, requires embryo culture or grafting to obtain hybrids, doubling chromosome number or using bridging species or biotechnological techniques. It is the outer limit of potential genetic reach. It is rather ill defined.

Survey and characterization: We have to make the survey and could be identified previously, therefore, we have to array the data and then analyze it under historical, geographical, agro-ecological, cultural, social and economic points of view. Variables habitat, number and cultivated area in each zone, zone importance, crop and wild species concentration, uses, customs, accessibility and relation between hot spot are the prime factors (Verma et.al. 2008a, 2008b). In case of a perennial fruit plants the growers constitute the primary source of information data. It is important to strengthen the relation with the growers to get first hand information. The base of this relation is mutual respect and the responsibility to assume commitments is based on friendship.

Plant Genetic Resources (PGR): It refers to genetic material of plant origin of actual or potential value in the form of seed, vegetative propagule, tissue, cell, pollen, DNA molecule etc. containing the functional unit of heredity that can be utilized in crop improvement. This is generally referred to as a germplasm and includes varieties, landraces and wilds / weedy relatives of economically important plant species available in India. This large group of texa needs to be collected, studied, documented and conserved for posterity.

Indian Gene Centre: The Indian gene center is one of the 12 mega-biodiversity centre of crop plant diversity with two major hot spots (Western Ghats & North-Eastern Hill Region) which holds rich floristic wealth of over 17,500 species of higher plants and about one-third of endemic flora. High priority accorded to nearly 500 species of cultivated plants where 166 crop plants have originated in Indian Sub-Continent and over 320 species of wild relatives of crop plants are reported.

Crop Diversity in Indian Gene Centre

- Cereals - rice (*Oryza sativa* and wild species), wheat and barley
- Minor millets - (*Panicum, Paspalum* and *Brachiaria*) and forage grasses (*Iseilema*, *Cenchrus, Cynodon, Heteropogon*, etc.)
- Legumes - Vigna spp., chickpea, pigeon pea, lablab bean, horse gram, sword bean, velvet bean and cluster bean

- Oilseeds – rapeseed-mustered and sesame
- Vegetables okra , egg plant, cucumber, melons, ridge gourd, bottle gourd and sponge gourds
- Fruits- Citrus spp., banana and plantain, jackfruit, mango, Indian gooseberry, karonda & jamun
- Fiber – Jute, Asiatic cotton, mesta and sunhemp.
- Spices - pepper, ginger and turmeric

Stepwise plant registration process

	Plant Germplasm Registration Committee (PGRC)
(i)	Chairman – DDG (CS) for maximum of 03 years.
(ii)	Permanent member – Director, NBPGR; Member Secretary Senior Level Scientist, NBPGR identified by the Chairman, PGRC Other Members – Co-opted as per the advice of the Chairman.
(iii)	Need a based crop specialist with reference to the material.
	Nodal agency
(i)	NBPGR, New Delhi. Application is to be addressed to the Director along with seed samples or a certificate of submission of propagules with respective crop / plant based NAGS for establishment/conservation.
(ii)	Member Secretary, PGRC duly acknowledge with date, the receipt of the application and of the seed material, communicating application No. and the National identity.
(iii)	NBPGR maintains permanent register and data base listing the germplasm materials approved by PGRC with details on unique and other related information.
	Application form
(i)	Application on the prescribed proforma (Form A, Annexure II). The PGRC meet at least twice a year with the concurrence of the Chairman for consideration of application and related matters.
	Eligibility criteria for registration
Germplasm or genetic stock of agri-horticultural and other economic crops, including agro-forestry species, spices, M. & AP., ornamental plants contains unique, uniform, stable and potential attributes of academic, scientific or commercial value registered. All claims concerning the material submitted for registration should accompany scientific evidence for uniqueness, reproducibility and value in the form of :	
(i)	Publication in standard peer reviewed journal (reprint copy). AND OR
(ii)	Evaluation data for at least three years under AICRP trial / nursery test or verification by concerned PD/PC or 03 location / year data under any other relevant system. AND OR

(iii)	Publication of information on potential value of proposed germplasm (Annual report or any other such reports). AND OR
(iv)	Certificate of the validation test of the claimed attribute by any institution as per the advice of Member Secretary. AND OR
(v)	Recommendation of institute's germplasm identification committee regarding the novelty and uniqueness of germplasm for trait(s) claimed.
	Germplasm ineligible for registration
(i)	Without accompanying documentary evidence.
(ii)	Does not contain complete passport data (Annexure VI), correct / authentic identification, parentage, institutional or National identity, geographical location of origin and uniqueness.
(iii)	Exotic material Per se, with no evidence of human intervention in its improvement.
(iv)	Varieties of common knowledge or selection from traditional or farmer's varieties without prior approval from the concerned personnel.
(v)	Variety Prior art, with no evidence of human intervention.
(vi)	Varieties and hybrids (including parents) released in the country, zone or state. However, parental lines of non released hybrids may be submitted for consideration.
(vii)	Germplasm of any genera or species, which involves any technology, which is injurious to the life or health of human being, animals or plants.
(viii)	Material for which any form of protection has been sought elsewhere.
	Screening of application (s) and their consideration by the PGRC
(i)	The Member Secretary, PGRC screen the proposal(s) on prescribed proforma, as per the guidelines of the checklist (Annexure II).
(ii)	Proposal forwarded to the relevant Director, PD or PC for validation of information, particularly on uniqueness and novelty of the proposed germplasm.
(iii)	After initial screening, the incomplete applications may be advised for appropriate revision.
(iv)	Validation of the data is necessary, the applicant should be asked to produce a validation report from an appropriate institute, advised by the Member Secretary. Revised application must accompany such report duly endorsed by the CA of the Institute, advised for the validation.
(v)	Proposals complete in all respect along with the comments of relevant Director, PD or PC will be put up to the PGRC for consideration.
(vi)	The PGRC consider the proposal as early as possible as and not later than one year.
(vii)	The decision of the PGRC final.

	Validity of registration
	Period for validity of registration is 18 years for trees and vines; 15 years for other plant species, after which the registered germplasm will be national sovereign property.
	Publication of registered germplasm
Germplasm material approved for registration will be officially communicated to the applicants along with registration number (IN GER). Certificate will be issued to the applicant. Brief description not more than one page (Annexure III) is to be published in the appropriate periodicals, i.e.,	
(i)	Indian J. Pl. Genet. Res. Published by the ISPGR, NBPGR, New Delhi-12.
(ii)	Indian J. Genet. & Pl. Breed. – published by the ISG&PB, New Delhi.
(iii)	NBPGR, New Letter, NBPGR, New Delhi-12.
(iv)	ICAR, News-published by the PID, KAB, ICAR, New Delhi.
(v)	NBPGR, Internet website http.//nbpgr.delhi.in.
(vi)	In addition (a) Concerned crop news letter (b) ICAR Annual Report(s)
9.	**Conservation, maintenance and sustainable utilization of registered germplasm**
(i)	Registered germplasm conserved either in NGB or at designated crop / plant based NAGS.
(ii)	All material registered with PGRC should be sent to the relevant Director, PD / PC or NAGS with request for sowing / planting in demonstration plots for field days , multiplication and distribution to the bonafide users.
(iii)	Institution associated with the development of the germplasm is to be mandated with the maintenance of working stock of germplasm for supply to bonafide users.
10.	**De-registration**
(i)	Registration repealed by the PGRC in case of false claim(s). Appeal for counter claim, if any, should reach the PGRC within a period of three months of the publication of brief note in the Indian J. Pl. Genet. Res.

Procedure for submission of proposal / germplasm material

	Submission of application and material
(i)	Plant germplasm proposed to be registered should be submitted to following address: The Director, National Bureau of Plant Genetic Resources, Pusa Campus, New Delhi-110 012 - Phone: 011-2584 3697; EPABX: 2584 9208, 2584 9211 Extn. 209 210

	FAX: 011-2584 2495 Email: director@nbpgr.ernet.in
(ii)	Material is to be accompanied with properly filled Form –A (Annexure I) duly signed by the applicant and Head of the institution with official rubber seal (15 copies, each attached documentary evidences submitted).
(iii)	Form A accompanied complete description of the germplasm material using standard descriptors (as per concerned crop AICRP or NBPGR descriptors). Include photograph(s) of plant/plant parts/crop and /or fingerprints (DNA or biochemical profile), if available.
(iv)	Declaration to the effect that working –stock for supply to users maintained by the institution associated with the development of material.
(v)	Another declaration is that such germplasm does contain any gene or gene sequence involving terminator technology mandatory.
	Guidelines for submitting the orthodox seed material
	Seed material dried to low moisture level without loss of seed viability.
(i)	Minimum number of 5000 seeds in case of cross-pollinated crop species, 3000 in self – pollinated and 500-1000 in difficult species, such as some vegetables, M. & AP., wild relatives etc. submitted.
(ii)	Seed supplied from a fresh harvest and not more than 90 days old.
(iii)	Seeds supplied sound, healthy, physiologically mature and collected from healthy plants.
(iv)	Providing good quality healthy seeds. it is advised to dry the seed material in shade immediately after the harvest.
(v)	Potential viability of seeds more than 85% in most crop species except in special cases, such as cotton, some vegetable crops etc.
(vi)	Seeds not treated with chemicals.
(vii)	Seeds packed in good quality paper, muslin cloth or plastic packet(s) with proper identity. If required, the packets should be packed in card-board boxes to minimize damage and moisture absorption.
	Guidelines for Submission of Recalcitrant / Intermediate Seed Material
Generally characterized by large sized and high moisture contents (20-80%) at the time of shedding. These can be supplied to NBPGR, only in case, where established protocols are available for conservation using cryogenic technology. The guidelines to be follows are given below:	

(i)	Preferably, more than 1000 seeds supplied. However, recognizing the importance of material, even small quantity may be acceptable. Supply of additional seeds may help develop DNA profiles.
(ii)	Sent complete fruit. To avoid any injury to the fruit surface, it should be sent in aerated polythene bags/cardboard boxes.
(iii)	If fruits are bulky and difficult to transport, the seeds should be extracted without causing any injury and should be transported within 48 hrs, packed in saw dust/charcoal /peat moss etc.
(iv)	Avoid transporting at high temperature (above 30^0 C). Store and transport should be preferably in moist conditions between 15-200C temperature conditions.
(v)	Extracted seeds should be treated with suitable fungicide (0.1 % Captan or Thiram powder).
(vi)	Avoid air drying and washing of seeds.
In remaining cases the genetic material should be supplied to relevant NAGS in the form of propagules establishment in the field gene bank following the guidelines given below. Acknowledgement deposition and establishment of genetic material has to be obtained from the concerned NAGS and submitted along with application.	
	Guidelines for Submission of Propagules
For vegetatively propagated crop species, the germplasm material / propagules (tuber, bulbs, rhizomes, cuttings etc) supplied to concerned crop based designated NAGS after initial establishment and conservation. Acknowledgement obtained from concerned NAGS has to accompany the proposal. Additionally, following guidelines need to be followed for safe supply and conservation of germplasm	
(i)	10-25 propagules (depending on crop) supplied to the concerned NAGS for their maintenance in field repository or in-vitro repository (if available) with a request for an acknowledgement.
(ii)	Concerned NAGS should be informed in advance about the supply of material to facilitate processing and establishment of germplasm.
(iii)	Genetic material, stocks, propagules of non-orthodox seed producing crops are generally being maintained in the form of grafts, slips, propagules, seedlings and plants. While supplying genetic material following steps and precautions are to be followed depending on the crop:
(a)	Slips, grafts, propagules or plants supplied to the NAGS should be free from insects, weeds and diseases as far as possible. Material should be well labeled and packed properly in aerated polythene bags. During the dry summer grafts or crafts are to be wrapped in

	moist moss grass to retain the moisture.
(b)	In case of crops like coconut, the material should be sent either embryos or seedlings. If the embryos need to be transferred from the field, the embryos need to be embedded in the endosperm and packed in the sterile plastic bag with sterile moist cotton. These are to be kept in the refrigerator over night and transferred in the same box with proper labels on it.
(c)	In case of seedlings, the embryos are to be grown using the river sand in plastic bags/boxes. Established seedlings are to be transferred to bigger pots. The healthy, vigorous seedlings can be supplied.
(iv)	Material should be packed in small wooden/card-board boxes with proper aeration. Also these boxes should be well marked with labels at 3 or 4 places "To be handled carefully: seedlings" in order to avoid any damage during transit.
(v)	Material should be sent to the NAGS immediately after harvest. To avoid any delay in transaction, use speed post or courier services or airfreight.

Check List for Screening of Applications

(i) Whether this is a new application or a registered one? (Yes/No)

(ii) Whether same or similar material has been registered earlier? (Yes/No)

(iii) Whether unique or distinguishing evidence or data is provided in support of the claim on potential value of germplasm? (Yes/No)

(iv) Whether documentary evidence or data are provided in support of the claim on potential value of germplasm? (Yes/No)

(v) State any other economic potential value of germplasm, if possible.

(vi) NBPGR viewpoint about the candidate germplasm.

(vii) Whether applicant, institution, university, or centre has given a commitment for maintenance and supply of germplasm for use? (Yes/No)

(viii) Whether appropriate size of germplasm sample for long – term storage at National Gene Bank or for conservation and maintenance of active collections at the concerned NAGS has been sent? (Yes/No)

(ix) Whether the applicant has sent maintainer line of the National Gene Bank, (Yes/No)

(x) Whether acknowledgement receipt of germplasm from concerned NAGS for deposition and establishment is attached, whether required? (Yes/No)

(xi) Whether detailed address of the corresponding person is given? (Yes/No)

(xii) Whether appropriate institutional authority has duly endorsed the application? (Yes/No)

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2.4 Unconventional Methods of Crop Improvement

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The understanding of plant growth, development and differentiation remains one of the most basic and challenging problems in plant biology. Plant tissue culture techniques, among many other methodologies, provide a powerful and unique tool for the study of many of the problems. Plant tissue culture methods offer a rich scope for the creation, conservation and utilization of genetic variability for the improvement in the field, vegetable and horticultural crops. "Plant tissue culture" is used as a blanket term for protoplast, cell, tissue and organ culture under aseptic conditions. This technique has great potential for rapid, large scale and true-to-type multiplication. For instance, in strawberry, millions of plants can be produced from 1mm explant in a year. It is estimated that more than 500 million plants belonging to different plant species are being produced through micropropagation, annually in different parts of the world. There is ample evidence in all the contributions here that plant tissue culture technique is not an end in itself, but it is a vigorous and living science, which has greatly improved, and will continue to improve our understanding in plant biology. During the last few decades, even for development of new crops or for improvement in the characteristics of existing crops the techniques of tissue culture in combination with genetic manipulation have been widely used. Developing a resistant variety for both biotic and abiotic stresses is possible through genetic transformation techniques.

Somaclonal variation

It is the variation among the callus derived plants and is a potent emerging aspect for broadening the genetic base and thus obtaining incremental improvement in the commercial cultivars, especially in the vegetatively propagated species. Using the technique of *in vitro* selection many millions of cells/protoplasts can be screened against various biotic and abiotic stress factors in a single petridish which is more efficient as compared to the screening of similar number of plants in the field which requires more time and space.

Molecular markers

Molecular markers have provided useful information in understanding the genomic architecture of plant species, their evolutionary relationships and in manipulation of genomes to increase efficiency of various conventional crop improvement programmes. Three kinds of markers, morphological (plant traits), biochemical (storage proteins and isozymes), and molecular markers (DNA) have been used in construction of genetic maps. Morphological markers are limited in number, and are influenced by the environment, development stage and pleiotropic effect. Isozymes markers are also limited and thus cannot saturate the genetic maps. Molecular markers or the DNA markers are numerous in number and represent a milestone in genetics by providing the capacity for complete coverage of nuclear, mitochondrial and chloroplast genomes. These markers are unaffected by the environment or the developmental stages.

Types of molecular markers

DNA markers can be classified by whether they are visualized by hybridization of cloned probes to gel blots of restriction digested genomic DNA, or by electrophoresis of DNA samples that have been amplified from genomic DNA by the polymerase chain reaction (PCR). The former markers are commonly referred to as restriction fragment length polymorphism (RFLPs) and latter as PCR based markers.

Restriction fragment length polymorphism (RFLP)

When a cloned DNA fragment is hybridized with the restricted DNA from two different individuals and their hybridized bands appear at two different places on the filter paper, then the two individuals are said to be polymorphic. This type of polymorphism is known as RFLP. The RFLP markers show codominance and are highly reliable in linkage analysis and breeding. However, their utility has been hampered due to the large amount of DNA required for restriction digestion and southern blotting.

PCR based markers

Different types of PCR-based markers have been developed such as sequence tagged sites (STS), expressed sequence tags (ESTs), simple sequence repeats (SSRs) or microsatellites, randomly amplified length polymorphism DNA (RAPDs), sequence characterized amplified regions (SCARs) and amplified fragment length polymorphic (AFLP) markers. In addition several other variations of these markers have been developed.

Molecular markers provide an excellent opportunity to develop saturated genetic maps and to integrate genetic, cytological and molecular maps. Molecular markers are also capable of producing patterns that are unique for each individual genotype. These patterns, whether they are generated by PCR or by hybridization with single copy, multicopy or repeated sequences, are referred to as genetic ‘fingerprints’. DNA fingerprinting is used for characterization of genetic diversity and relatedness among the crop germplasm. Microsatellite markers have been used in pedigree analysis as they represent single locus. The multi-allelism of these markers facilitates comparative allelic variability detection reliably across a wide range of germplasm and allows individuals to be ubiquitously genotyped, so that gene flow and paternity can be established. Evolutionary relationships and probable causes of differentiation among different species have been well elucidated in several plant species using RFLP analysis. The taxonomic classification is most essential to determine whether any germplasm is a part of the primary, secondary or tertiary genepool. This can be clearly revealed by analysis through RAPD markers. ESTs markers are used to look at the evolution of functional genes. Molecular markers have given new dimension to concerted efforts of breeding and marker assisted selection that can reduce the time span of developing new and better varieties and will make the dream of super varieties come true.

Plant transformation

With the availability of cloned genes in efficient vector constructs along with screenable and selectable marker genes, have resulted in the production of transgenic plants in different crop plants. The examples include rice, maize, rye, cotton, sorghum, wheat arabidopsis tobacco, tomato etc. Transgenic plants expressing genes of economic importance eg. insect-pest and disease resistance, herbicide resistance, abiotic stress tolerant, seed storage proteins, antibodies, therapeutic proteins, pharmaceutical compounds, biodegradable plastics etc. have been produced. Plant genetic transformation is an important tool for the crop improvement and also for the basic molecular genetic studies. As various crops are transformed with new resistance traits, these traits will become part of the gene pool of that species and will be available for wider use in a number of varieties created through traditional breeding.

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2.5 Wide-Hybridization in Relation to Crop Improvement with Special Reference to Wheat-Rye Crossability

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Wide-hybridization is an important tool in the hands of the plant breeder and a cytogeneticist. It is the first step to transfer genes of the wild species into the cultivated ones. It provides a means to study genome structure and phylogeny, and sometimes may result in a new crop, for example triticale, which is a cross between wheat and rye.

Successful sexual hybridization involves a series of events including pollen germination, pollen tube growth, fertilization, embryo and endosperm development and seed maturation. Stebbins (1950) divided crossability barriers into two broad groups, namely pre-fertilization and post-fertilization barriers. The pre-fertilization category includes those mechanisms which prevent fertilization and includes geographical isolation, apomixes, and pollen-pistil incompatibilities. Post-fertilization barriers are a greater hindrance to hybridization and can be a result of ploidy differences, chromosome elimination, seed dormancy and hybrid breakdown. Of particular importance is the need to get hybrids that are fertile.

Cross incompatibility which prevents fertilization arises when pollen grain does not germinate or there is abnormal development of the pollen tube (i.e. pollen tube growing in the wrong direction, swelling of the tip of the pollen tube, two pollen tubes coming out of the pollen grain, bursting of the tip of the pollen tube or coiling of the pollen tube, or pollen tube does not reach the ovary or male gamete does not fuse with the female gamete). The weakness of the F_1 hybrid can be due to lack of harmony between genomes of the parental species, between genome(s) of one species and cytoplasm of the other, or between genotypes of F_1 zygote and the genotype of the endosperm. When the hybrid chromosomes do not pair, gametes receive different number of chromosomes leading, in general, to sterility.

To bypass pre-zygotic barriers, the following can be done. Where premature flower abscission takes place, hormone application may prolong the life of the flower. To increase pollen germination, one can apply boric acid, sucrose or extract of the compatible anthers. We can amputate the stigma and apply sucrose-gelatin paste. One can apply self and other species pollen. One can try bud pollination. To speed up pollen tube growth, application of growth regulators e.g., IAA, 2,4-D or GA_3 or use of radiation or an immunosuppressant like alpha-amino caproic acid as in *Vigna radiata* x *Vigna umbellate* can help. If there is stylar incompatibility, then one can shorten the style as in maize into *Tripsacum* cross or we can manipulate the ploidy levels of the parents. The use of intra-ovarian pollination has also been used to effect pollination by bypassing the style. This technique which involves injecting a suspension of pollen grains directly into the ovary, was used with *Papaver somniferum* to produce normal fruits *in vivo* which contained viable seeds.

To bypass post-fertilization barriers, embryo-rescue, ovule culture and manipulations with protoplasts have been successfully used.

The intergeneric hybrids between wheat (*Triticum aestivum* L. em. Thell) and rye (*Secale cereale* L.) are difficult to obtain and this is attributed to two loci, Kr_1 and Kr_2 carried on chromosomes 5B and 5A of wheat, respectively (Riley and Chapman, 1967). The dominant alleles of the crossability genes caused retardation and eventually inhibition of pollen tube growth at the base of the style and in the ovary wall (Lange and Wojciechowska, 1976). However, the crossing barrier is not complete, because seed set can occur. But the chemical and/or physical nature of the mechanism remains unknown. The present study reports the role of secretions produced after pollination in the obturator and the role of Kr genes in the production of these secretions, pollen tube growth and seed set in wheat-rye crosses.

Materials and Methods

The experimental material consisted of four genotypes of hexaploid wheat, viz. Chinese Spring (CS) (kr_1 kr_1 kr_2 kr_2), Hope (Kr_1 Kr_1 Kr_2 Kr_2), Highbury (Kr_1 Kr_1 Kr_2 Kr_2) and a substitution line, CS/Hope 5B (Kr_1 Kr_1 kr_2 kr_2) and a diploid rye genotype, viz. Rye 8461. The seeds were sown in December for two years. Emasculation was done in March during the morning and the evening hours on randomly selected plants when anthers were still pale green and two days later, when the stigmas were feathery and receptive, the pollinations were performed.

To study the process of fertilization and early development of the seed, pistils were collected at 2, 8, 24, 48 and 72 hours after pollination and fixed immediately for 2 hours and then preserved in 70% ethanol. Dehydration, infiltration and embedding were performed according to the ethanol-tertiary-butanol-paraffin schedule of Sass (1958). For microtomy, a Spencer rotary microtome was used. The material embedded in wax was cut to 8 µm thickness. The paraffin ribbons affixed with Haupt's adhesive were stained with periodic acid Schiff's reagent (Feder and O'Brien, 1968) for insoluble carbohydrates, with Commassie brilliant blue (Fisher, 1968) for proteins, with aniline blue for callose and with safranin, crystal violet and light green (Gerlach, 1969) for embryo-sac development. The permanent slides were prepared with DPX mountant and the photomicrographs were taken with the help of an automatic camera.

Results and discussion

Crossability studies

The seed set in wheat-rye crosses was clearly related to crossability genes (Pawar and Khanna, 2004). When CS (with homozygous recessive Kr_1 and Kr_2 genes) was crossed with Rye 8461, the seed set was highest (50.0 %), but in the crosses of the substitution line CS/Hope 5B (Kr_1 Kr_1 kr_2 kr_2) with Rye 8461, the seed set was up to 13.3%. However, in the crosses of Highbury and Hope (having homozygous dominant Kr_1 and Kr_2 genes) with rye 8461, seed set was nil or very less (upto 5.4%).

The light microscopic studies were performed in the highly crossable wheat cultivar Chinese Spring and in the very little or non-crossable cultivar Hope to study the role of obturator tissues in wheat-rye crossability. After pollination in wheat and wheat-rye crosses, the secretions produced in the cells of the style, obturator and the ovule were studied at 2, 8, 24, 48 and 72 hours after pollination in longitudinal sections of the ovary.

Periodic acid-Schiff's reagent staining for insoluble carbohydrates

In the case of selfings of CS and Hope, immediately after pollination, insoluble carbohydrates were produced in the extra-ovarian region and in the obturator through which the pollen tube had to pass (Plate 1). This showed that the pistil and the ovule were immediately prepared for pollen tube growth and the fertilization process.

In CS x Rye 8461 cross, from 24-72 hours after pollination, there was a uniform staining on the extra-ovarian portion and the obturator, suggesting that the homozygous recessive kr genes of CS let the pollen tubes to cross the barrier in the base of the style by its secretions and permitted fertilization resulting in a high seed set. However, at the end of 72 hours of pollination, a degenerated and shrunken embryo was seen, as a result of which the seeds formed were shriveled and did not germinate.

When Hope was crossed with Rye 8461, in the initial hours after pollination, there was no staining for insoluble carbohydrates in the obturator region, but the extra-ovarian tissues were lightly stained. At 24 hours after pollination, the extra-ovarian portion was lightly stained and the obturator did not take the stain (Plate 2). At 48-72 hours of pollination, there was a complete absence of insoluble carbohydrates on the entire extra-ovarian portion including the obturator and in the ovule there was a complete degeneration of endosperm and embryo; as a consequence, it prevented the pollen tube growth and fertilization, resulting in no seed formation.

Coomassie brilliant blue staining for proteins

In case of selfings in CS and Hope, from 2 to 24 hours after pollination, there was a uniform presence of protein in the extra-ovarian tissues, obturator and ovule (Plate 3). At 48-72 hours of pollination, the obturator and the ovule took a darker stain. This suggested that after selfing in wheat, the flower was immediately prepared to permit pollen tube growth and fertilization.

In the case of CS x Rye 8461 cross, the sequence of staining was almost like the selfing indicating a constant and uniform presence of protein in the obturator and the ovule, but after 24 hours of pollination, the endosperm started to degenerate and there was an increase of the empty space in the ovule with the passage of time (Plate 4) due to which the grains formed were shriveled.

When Hope was crossed with Rye 8461, the results were different. There was no protein during the initial hours of pollination in the extra-ovarian portion, obturator and in the ovule and after 24-48 hours of pollination, there was protein in the obturator cells. These results were similar to the delayed presence of insoluble carbohydrates in the obturator region for this cross. This might have delayed the growth of the pollen tubes towards the egg, resulting in less or no seed set as compared to the CS x Rye 8461 cross.

Aniline blue staining for callose

Aniline blue staining is commonly considered to indicate the presence of callose, a cell wall polysaccharide consisting mainly of β-1, 4-glucoside linkage (Vithanage *et al*., 1980). In the case of selfings of CS and Hope, there was no staining in the extra- ovarian tissues, but the ovule took the stain and a light stain was observed in the adjoining obturator region from 2-72 hours post-pollination (Plate 5) indicating the presence of the least amount of callose. So, pollen tubes might be entering the ovule for fertilization up to 72 hours without much hindrance.

In CS x Rye 8461 cross, callose was mostly localized in the ovule portion from 2-72 hours of pollination, hence, the entry of pollen tubes into the ovule might not be hindered as the extra-ovarian tissues including the obturator were not stained and the staining in the ovule also became light with the passage of time. An increase in empty spaces outside the central cells of the ovule indicated that the cell cytoplasm was going to degenerate and would eventually shrink, resulting in shriveled seeds. In the case of Hope x rye 8461 cross, the extra- ovarian portion including the obturator and the ovule took the stain from 2-48 hours after pollination (Plate 6). At 72 hours of pollination, the entire ovary along with the obturator was darkly stained and there was complete degeneration of cell cytoplasm in the ovule. The presence of callose in the obturator prevented the entry of pollen tubes into the ovule from 2-48 hours of pollination and at the end of 72 hours, and there was shrinking of the ovule and very less or no seed was formed.

Safranin-crystal violet-light green staining for embryo-sac development

In CS selfing, by 72 hours post-pollination, a well developed embryo could be seen (Plate 7). On selfing Hope also, the process of embryo development seemed to be normal (Plate 8), though delayed, as the post-fertilization stages for embryo formation were still underway at 72 hours (Jagadev and Khanna, 2002).

In CS x Rye 8461 cross, with the progress of time, there was a continuous increase in the formation of empty spaces and finally at 72 hours post-pollination, a degenerating and shrunken embryo was seen. This might be responsible for the formation of wrinkled seeds, which did not germinate.

In Hope x Rye 8461 cross, though the process of fertilization was normal in the initial hours, but after 8 hours of pollination, a lot of abnormalities like increase in empty spaces and degeneration of cell cytoplasm were seen at 72 hours, there was a complete degeneration of endosperm and no embryo was seen resulting in very poor or no seed set (Jagadev and Khanna, 2003).

The regulation of fertilization has proved to be remarkably complex involving various kinds of controls imposed at different interactions between the male and the female gametophytes that determine whether fertilization will or will not be affected. The evidence presented here provides a mechanism operating in the obturator that controls the entrance of pollen tubes into the ovary, which might play a significant part in the regulation of fertilization in wheat-rye crosses. There is clear evidence that Kr genes are responsible for the release of insoluble carbohydrates, proteins and callose after pollination in wheat x rye crosses. The timing of their secretion at different places of the transmitting tissue has a role to play in pollen tube movement towards the egg and seed formation.

Interspecific and intergeneric crosses have been by far the most important in ornamental plants. Rhododendrons, iris, orchids, cannas, dahlias, gladioli, roses, poppies, and violets have resulted from wide crosses. In tree crops, apples, plums, cherries, grapes and berries have resulted from wide crosses. Crops such as wheat, tobacco, oat, cotton and sugarcane are allopolyploids that were derived originally from hybrids among different species. Among the vegetables, only potato and sweet potato have benefitted from interspecific hybridization.

Wide hybridization may be more valuable in vegetatively propagated species then in those reproduced by seed. They are of less value when quality aspects are more important than quantity of yield.

There has been considerable progress in the field of wide crosses. In recent years several new hybrids have been produced and several useful genes have been transferred from wild relatives into the cultivated ones. To declare two species as non-crossable is a personal conclusion. Incompatibility is not a condition which cannot be reversed. Seed set does not seem to be a problem, at least in one direction. The use of embryo-rescue and ovule-culture has increased the number of successful crosses. Considerable progress has been made in somatic hybridization of higher plants.

The transfer of specific genes is frequently associated with transfer of whole chromosome segments having undesirable traits. Alien chromosome segments can be broken down by refined cytogenetic techniques and undesirable characters which got transferred along with the desirable ones can be eliminated by direct selection. Transfer of genes from diploid to tetraploid species carrying homologous genomes is associated with the reduction or total loss of a character due to inhibition or other types of epistasis. The resistance carried by more distant relatives (homoeologous genomes) therefore, appears to be stabler, though more difficult to transfer. The problem of replacing hybrid seed every season can be overcome by fixing the hybrid vigour through the use of apomixes. Once apomixes is transferred to a hybrid variety, it would breed true to type. Obligate apomixes can also provide a means of seed production of aneuploids, polyploids, structural hybrids and other chromosomal aberration that might otherwise be sterile.

The above difficulties, however, should not in any way discourage research on wide-hybridization because of its great potential.

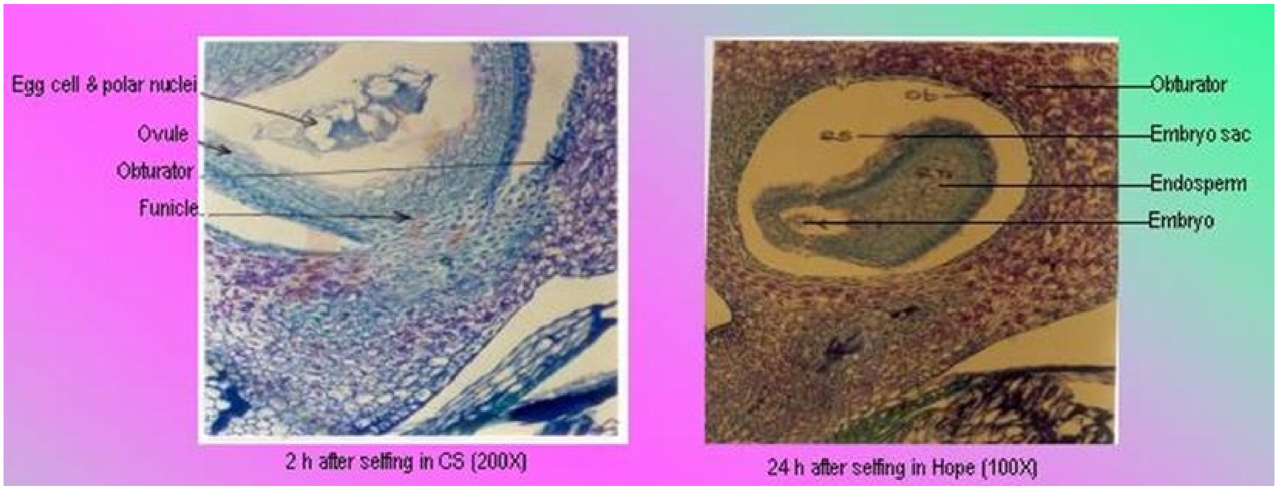


Plate 1 **Plate 2**

L.S. of a portion of the ovule and the obturator (Periodic acid Schiff's reagent)

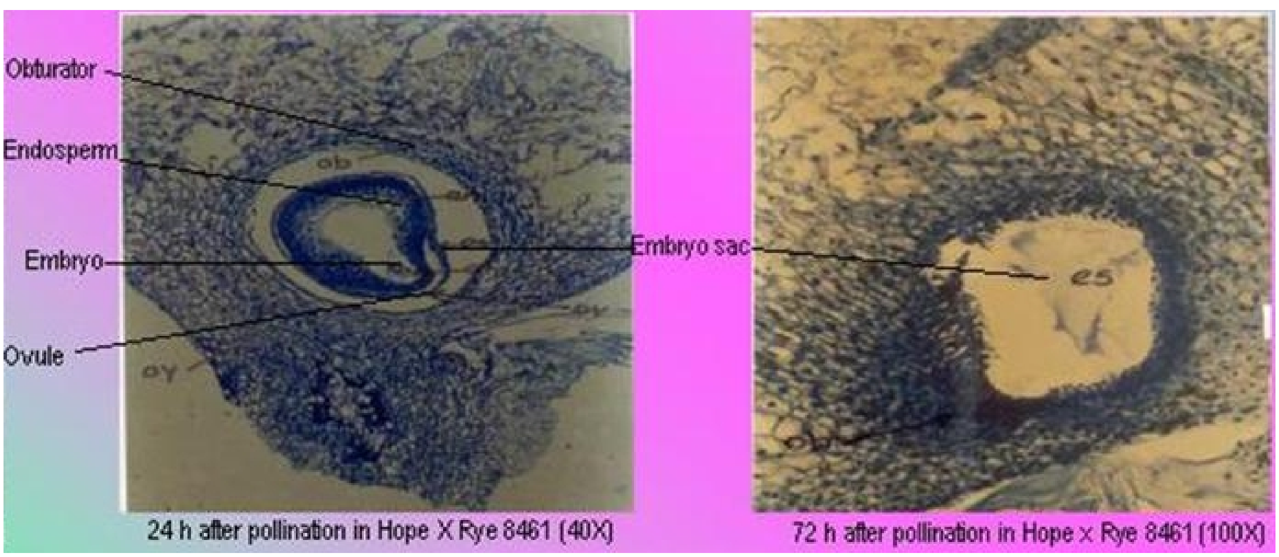
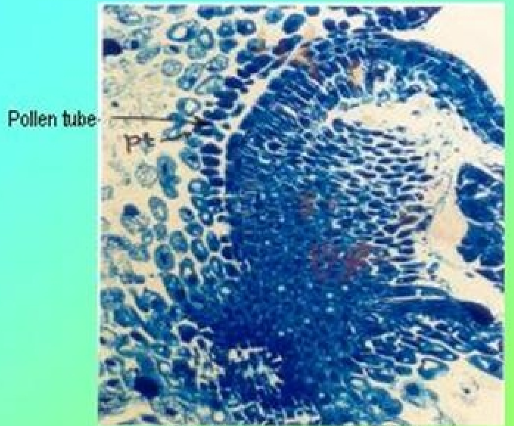


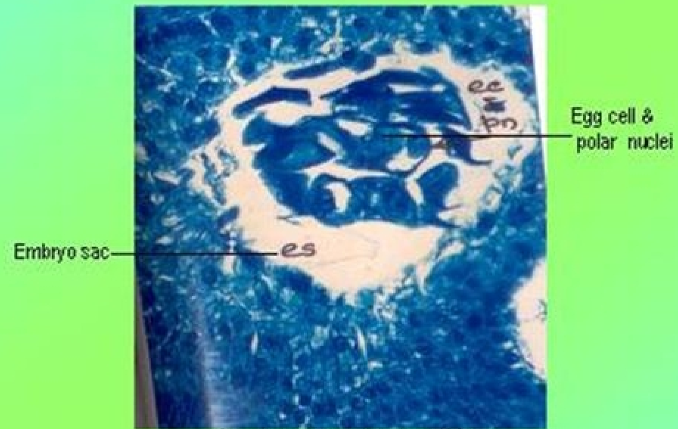
Plate 3 **Plate 4**

L.S. of a portion of the ovule and the obturator (Periodic acid Schiff's reagent)



8 h after selfing in CS (200 X)

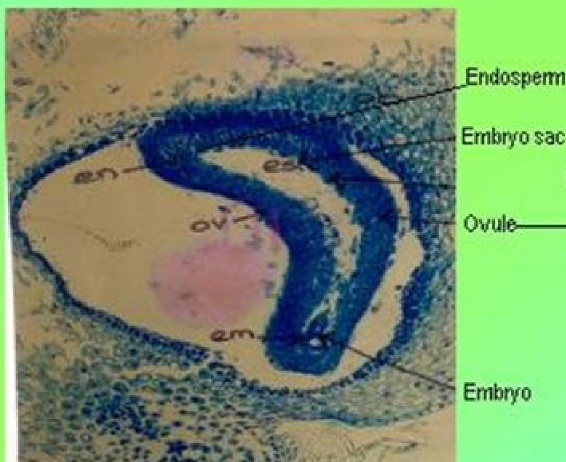
Plate 5



2 h after selfing in Hope (400 X)

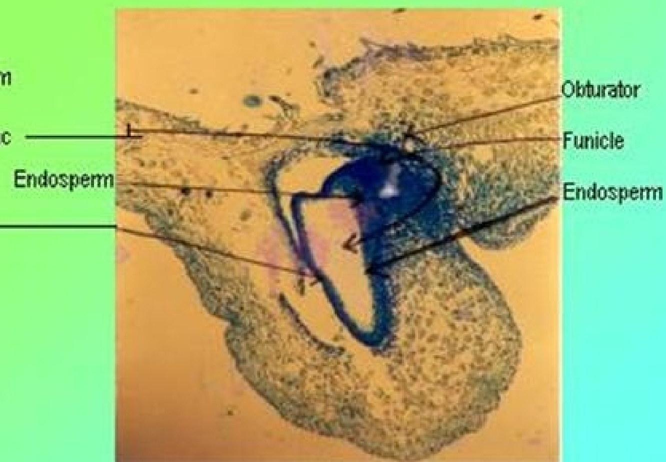
Plate 6

A portion of the ovule & the obturator (Coomassie brilliant blue stain)



72 h after pollination in CS X Rye 8461 (100 X)

Plate 7



72 h after pollination in Hope X Rye 8461 (40 X)

Plate 8

A portion of the ovule & the obturator (Coomassie brilliant blue stain)

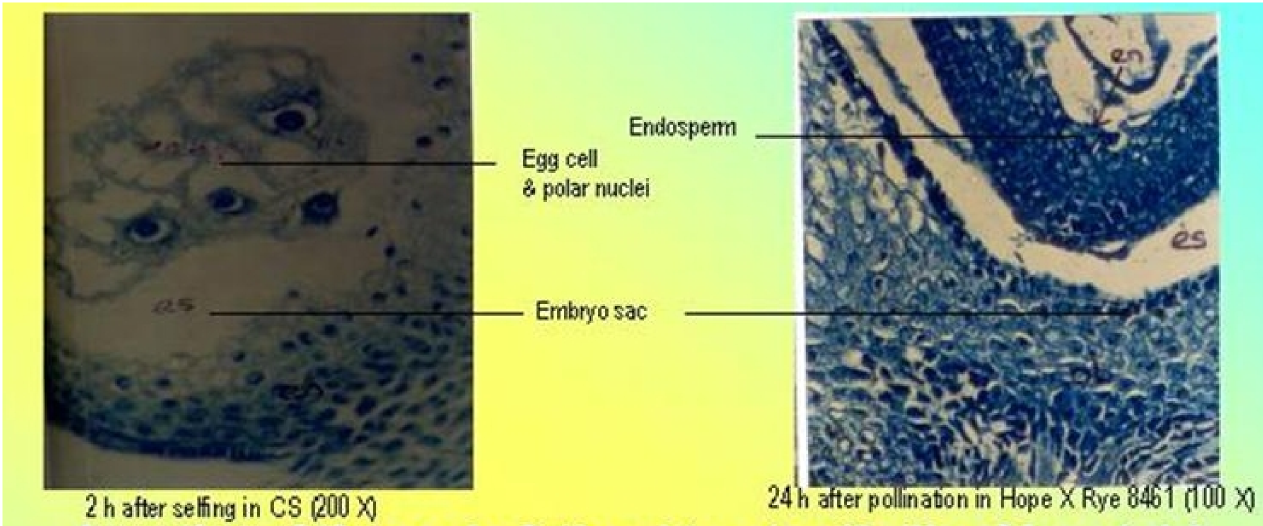


Plate 9 **Plate 10**

A portion of the ovule & the obturator (Aniline blue stain)

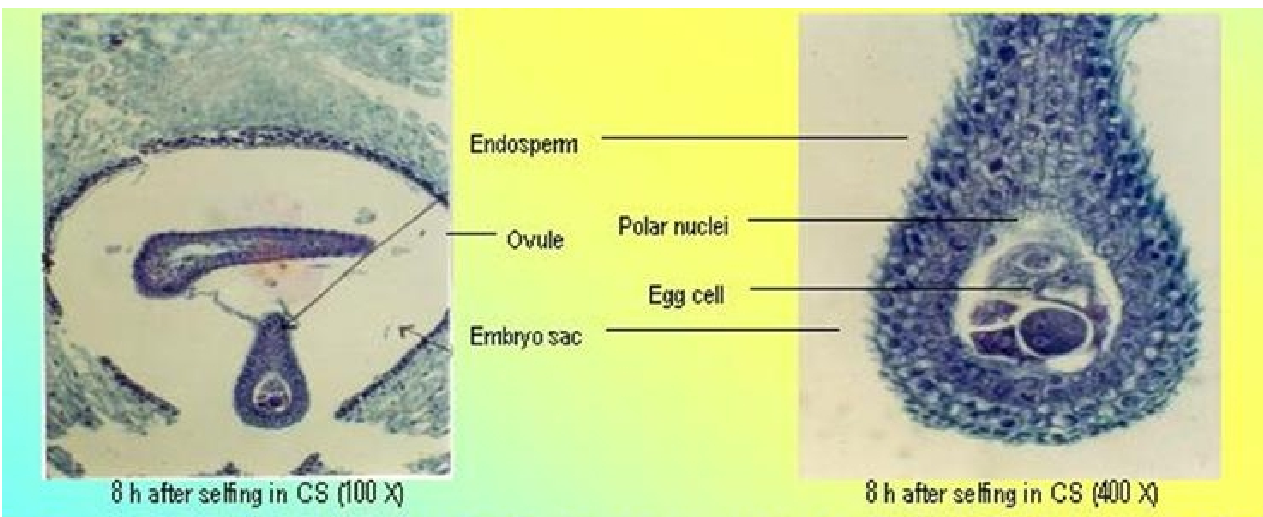


Plate 11 **Plate 12**

Embryo-sac development (Safranin-crystal violet-light green stain)

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2.6 Conventional and Biotechnological Tools for Conservation of Local and endangered Animal Species

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The northeastern hill region has been in focus for its high biodiversity and this region has been a priority for conservation agricultural. The northeastern hill region rich in biodiversity not only in the plant but also in animal species and birds. The reasons for conservation of animal genetic resource are economic potential, scientific use and cultural interest of particular animal population/species. The aim of animal conservation is to maintain biodiversity because removal of single species can affect the functioning of global ecosystems. Habitat preservation is one of the best ways to conserve biodiversity. In situ conservation strategies enable live populations of animals to be maintained in their adaptive environments. However, these efforts are sometimes insufficient for the propagation of small populations and maintaining adequate genetic diversity.

Economic potential

Endangered populations should be conserved for their potential economic use in the future. Their economic potential may be the production of meat, milk, fiber, skin or draught power and it may be in diverse climatic and environmental conditions. Endangered populations with economic potential may have regional adaptation developed for the country of origin, or adaptations which may be beneficial in other areas of the world where similar or complementary conditions exist. Animals with distinct characteristics may be beneficially incorporated into the breeding programmes of other countries, for example, the prolific characteristics of the once rare Finnsheep (Maijala *et. al,* 1990), Twinning and triplet kidding in Assam hill goat and specific milk composition of yak and mithun in the NEH region. Economic potential cannot be measured by looking simply at performance. Rare or endangered breeds are often highly adapted and their performance should be measured comparatively, within their own environmental conditions. They should not be compared with other breeds in improved or modified conditions or under intensive management. Furthermore, they should be examined with respect to the products for which they were selected and valued in the conditions under which they evolved. There are many examples where growth rate, prolificacy, or milk production have been measured and used to illustrate the inferiority of purebred indigenous stock over that of exotic imported breeds or their crosses (Hodges, 1986).

Scientific use

Endangered populations should be conserved for their possible scientific use. This may include the use of conservation stocks as control populations, in order to monitor and identify advances and changes in the genetic makeup and production characteristics of selected stocks. They may include basic biological research into physiology, diet, reproduction or climatic tolerance at the physiological and genetic level. Genetically distinct breeds are needed for research into disease resistance and susceptibility, which could help in the development of better medication or management of disease. It could also help with the identification of specific genes involved in natural disease or parasite control. Some populations may also be used as research models in other species, including man. Example, isolation and identification of gene responsible for diseases resistant in Indian cattle.

Cultural interest

Many populations have played an important role in specific periods of national or regional history. There are also breeds which have been associated with social and cultural development; the Navajo-Churro sheep whose wool is essential in the production of the native rugs of the Navajo. Yak and mithun is essential for social and cultural identity of tribes in the NEH region. There are also many breeds which may be conserved for their aesthetic value. Cattle breeds in India and many of the ornamental and fighting/games for poultry breeds in India

Principles of conservation

The idea of conserving animal genetic resources focuses on two separate; the first is the conservation of 'genes' and the second, the conservation of 'breeds' or populations. But both are interlinked concepts. The conservation of 'genes' refers to action to ensure the survival of individual genetically controlled characteristics inherent within a population or group of populations. However, it does not require that the genetic function at the chromosome or DNA level be understood. Such a characteristic may in fact be a complicated biochemical function controlled by several sections of DNA on more than one chromosome, but provided the characteristic can be identified in the appearance or function of the animals that exhibit.

The conservation of populations or breeds refers to action to ensure the survival of a population of animals as defined by the range of genetically controlled characteristics that it exhibits. This form of conservation is applied to endangered species as well as to breeds and it ensure the conservation of all the characteristics inherent with a given population, including many which may not have been recognized, defined, identified or monitored. The differences between breeds may often be due to differences in the frequency of quantitative genes rather than the presence or absence of unique genes.

Candidates for conservation

Opinions may vary over the years to which animal genetic resources are candidates for conservation. Estimates have been influenced by the relative cost/benefit of conserving all genetic variation as compared to those that can be demonstrated to have predictable economic, scientific or cultural value.

Unique population: Uniqueness is difficult to define with respect to livestock populations. There are populations with obviously unique and clear characteristics or traits. But for the vast majority of populations their uniqueness is subjective. It refers to the fact that no other population has the same ancestry, environmental adaptation, human selection, appearance or production characteristics. In effect, the difference between two populations may only be a function of the relative frequencies of the same genes. From the point of view of conservation any population which is historically or geographically isolated or which has had little genetic influence from other breeds over a long period of time, or which exhibits unusual characteristics or traits should be considered to be a unique population.

Endangered species: In wildlife conservation, a population said to be endangered when the chance of the survival in the wild is unlikely unless action is taken to conserve that population. There is no simple numerical level at which a population is defined as being endangered or eligible for consideration as a candidate for conservation. Rather it is dependent upon a number of factors: the actual numbers of animals; the rate of decline in the population size; the closeness of relationship between individuals within the population; the geographical range and the rate of reduction of that range; special threats from introduced species; rapid changes in the environmental conditions including climate, predators and parasites.

In common domestic species for which varieties, strains or breeds are in danger of extinction, the population levels at which action needs to be taken can be much lower. In these cases the common strains or breeds can be used for cross breeding, grading up or as surrogate mothers in an embryo transfer programme.

The International Union for the Conservation of Nature (IUCN) provides clear definitions for the variety of species in its international Red Data Books. These definitions relate to the survival chances of the populations and take all the variables of population structure and environmental factors into account. Wildlife conservation, based upon these categories is most commonly centered on the in situ conservation of populations in their natural environments. The population size must be sufficient to enable the necessary genetic diversity to survive within the population, so that it has a good chance of continuing to adapt and evolve over time. This reserve size can be calculated for target species by examining the population density in naturally occurring situations. The reserves must then be protected from intrusion or destruction by man, and against other catastrophes.

Rapid change in population: Rapid genetic changes in intensively selected breeds, often involving the use of high levels of advanced technology including artificial insemination (AI) and embryo transfer. These breeds are producing at a very high level under intensive management, veterinary care and feeding regimes. They include breeds likely to be affected by the introduction of transgenic technology. They are the intensively selected dairy cattle breeds of the temperate regions and the industrialized pig and poultry stocks. Conservation may be needed of samples of these populations as they change to ensure that alternative selection options exist. Collection of cryogenic samples would be a useful precaution enabling future changes in direction within these breeds and the establishment and maintenance of live control populations as in situ conservation.

Characterization of germplasm

Characterization of the breed which includes the measurement and description of external appearance, production characteristics, climatic adaptation, disease resistance, parasite tolerance, management and any other special feature. It may also involve the collection of biochemical information from blood types, milk proteins and the comparative analysis of DNA fragments.

Use of molecular markers

Molecular markers are a tool to study diversity on the genetic level. The most widespread use of molecular markers in this context is the assessment of diversity within and between breeds.

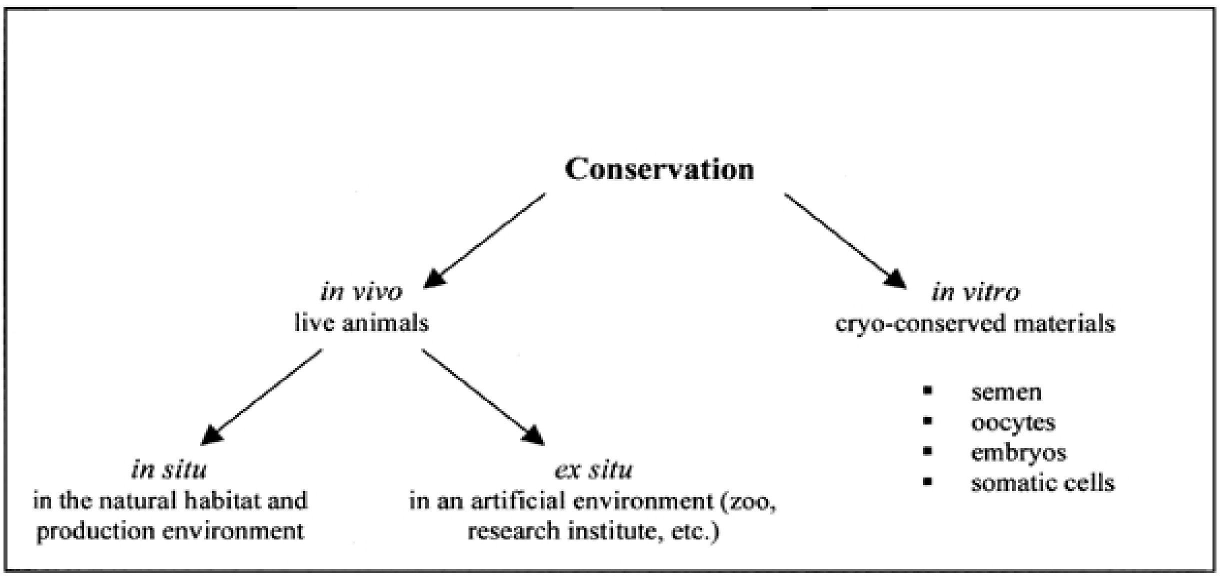
In addition, one might also consider markers associated with so-called quantitative trait loci (QTL), i.e. markers that reflect the genetic potential of an animal for a given quantitative or qualitative trait. Farm animal research focuses very strongly on mapping QTLs and single genes so that such markers will be increasingly available in the future. Of special interest will be markers linked to disease-resistance QTL, such as trypanotolerance in cattle (Hanotte *et. al.,* 2003), nematode resistance in sheep (Coltman *et. al*., 2001), and E.coli-resistance in pigs

(Meijerink *et. al.,* 2000).Molecular markers are an indispensable tool to understand the genetic structures of populations.

Conservation methods

The terms conservation, preservation, ex situ and in situ are used here according to the definition given by FAO (1992). There are several ways, differing in efficiency, technical feasibility and costs, to conserve animal genetic resources. Developing and utilising a genetic resource is considered the most rational conservation strategy. However, there are cases where ex-situ approaches are the only alternatives. Ex-situ approaches include: maintenance of small populations in domestic animal zoos; cryopreservation of semen (and ova); cryopreservation of embryos; and some combinations of these. Cryopreservation of gametes, embryos or DNA segments can be quite an effective and safe approach for breeds or strains whose populations are too small to be conserved by any other means.

Systematic overview of basic conservation schemes for farm animals



Regeneration of offspring following transfer of frozen-thawed embryos has been successful for all major domestic species, Respective pregnancy rates of 58 and 50% for fresh and frozen-thawed in vitro produced embryos have been reported (Lu *et. al* 1990). Also, calves have been produced from transfer of both split and frozen-thawed in vitro produced embryos.

Development in genetic engineering, cryobiology, cell biology and embryology will provide techniques that may enhance our ability to preserve germplasm in vitro. Techniques such as transfer of DNA within and between species and the production of viable transgenic animals are far from practical application. However, biotechnology will certainly contribute newer and cheaper methods for preservation such as storage of catalogued DNA. At present, other than live animal and embryo preservation, the other techniques do not allow preservation of genomes in a form which can be reactivated in toto at a later stage, but they permit the preservation of individual genes or gene combinations for possible future regeneration.

Conservation of indigenous animal genetic resources should be one of the priority livestock development activities for developing countries. The critical importance of these resources to their owners in developing countries need not be emphasised. Their importance to developed countries is also becoming evident as indicated by the increasing importation of tropical germplasm by these countries. It is highly likely that these resources will become of increasing importance to the industrialised countries either as sources of unique genes or when environmental concerns necessitate change in production systems. Developed countries should, thus, assist in the conservation and development of these resources. Technology for cryopreservation of semen and embryo is sufficiently developed and to be applied in developing countries.

Ex situ **versus** ***in situ*** **conservation methods**

Ex situ preservation involves the conservation of plants or animals in a situation removed from their normal habitat. It is used to refer to the collection and freezing in liquid nitrogen of animal genetic resources in the form of living semen, ova or embryos. It may also be the preservation of DNA segments in frozen blood or other tissues. In situ conservation is the maintenance of live populations of animals in their adaptive environment or as close to it as is practically possible. For domestic species the conservation of live animals is normally taken to be synonymous with in situ conservation.

Ex situ and in situ conservation are not mutually exclusive. Frozen animal genetic resources or captive live zoo populations can play an important role in the support of in situ programmes.

1. *Ex situ* conservation /Cryogenic Preservation

a. Advantages

- Relatively low cost for collection, freezing and storing frozen material, as compared to maintaining large scale live populations.
- The cost of maintaining a cryogenic store is minimal. Such banks require little space and few trained technicians.
- A very large number of frozen animals from a large number of populations can be stored in a single facility.
- Cryogenically preserved populations suffer no genetic loss due to selection or drift.
- A sample in suspended animation and that sample remain genetically identical from the time of collection to the time of use.
- The effects of long term radiation are considered to be negligible.

b. Disadvantages

- The principal disadvantages of *ex situ*, or cryogenic preservation is the availability of the necessary technology and access to the frozen populations.
- It requires a guaranteed supply of liquid nitrogen which may be costly.
- Cryogenic stores have no intrinsic value with respect to financial income unless material can be sold for research and development.
- It does not produce food or other agricultural commodities and might therefore be deemed to be expensive luxuries in periods of financial austerity.
- If sampling method and collection of genetic material from a limited number, cryogenic storage can result in an initial genetic drift.

- Shift in gene frequencies between the original population and the cryogenically conserved sample population.
- There is a potential danger in cryogenic storage, from large scale loss of material due to serious accidents due to human error, power failure, loss of liquid nitrogen, fire, flood, storm, earthquake or war.
- Cryogenically preserved populations are not able to adapt through gradual selection, to changes in the climate or disease background of the local or global environment.

2. *In situ* Conservation

a. Advantages

- *In situ* conservation relate to the availability of technologies and the utilization of the breeds.
- The in situ conservation of live populations requires no advanced technology.
- The farmers of every region and nation know how to manage and maintain their local strains.
- It can ensure that financial commitment to the conservation of animal genetic resources involves helping to improve the livelihood of farming communities associated with the breeds targeted for conservation.
- Live conservation projects involve animal utilization and are net producers of food, fibre and draught power.
- It does not require the importation of expensive materials, skills or equipment.
- Live conservation programmes may survive major political or environmental upheaval, wars, or climatic disasters.
- Sufficient numbers of breeding units must be established and maintained, however, for each conserved population.
- It enable breeds to be properly characterized and evaluated in their own and related localities.
- It allow for comparative trials, research and crossing experiments.
- This method of conservation also allows populations to adapt to changing environmental conditions and endemic diseases.

b. Disadvantages

- Lack of complete control over the many factors which influence the survival of individuals and therefore the genetic makeup of the conserved population.
- In situ conservation requires land and people which are limited resources in some regions.
- It dependent upon unpredictable financial and political change particularly and capacity to produce agricultural commodities and sell livestock to supplement their budgets.
- Genetic drift is an inevitable feature of all live animal conservation projects, even when steps are taken to minimize the problem.
- Selection and the resultant shift in the gene frequencies within a population are a real possibility.
- Selection is a particular concern when it is applied to populations being maintained under modified environmental conditions

- *In situ* conservation incurs the possible threat of disease eliminating whole or substantial parts, of a conserved population, particularly if the conserved herd is in a single or only a few linked locations.
- Diseases may also act as a major selection pressure within a population, and may substantially change its characteristics. Finally, live animal conservation programmes do not assist in the easy international transfer of animal genetic resources as compared to the movement of frozen material and it is relatively more expensive and there are international restrictions on the movement of animals to control disease.

3. Co-ordination between *in situ* conservation and *ex situ* conservation

Cryogenic methods allow for animal genetic resource material to be suspended, unchanged, for long periods of time. Live conservation efforts enable breeds to be properly evaluated, monitored and used in the present changing agro-economic climate as well as being available for future farmers and livestock breeders. The two strategies are not mutually exclusive and should be considered as complimentary strategies which may be easily and beneficially linked. Collecting and freezing of semen is far simpler in most species than collecting and freezing of embryos. Recent development in the technology to mature ova from the ovaries of slaughtered females has produced a relatively cheap and easy method for the collection of haploid cells from females to parallel the collection of sperm. It is likely that this technique will become increasingly useful as the methods become more widely available.

Conventional techniques /steps to be taken

- To undertake systematic cataloguing of animal germplasm and to establish a data bank and information service on animal genetic resources.
- Identification, evaluation, cataloguing and conservation of herds or flocks identified as valuable for purposes of conservation consisting of important indigenous breeds of livestock and poultry in the country.
- To undertake survey for the evaluation of merits or attributes of breeds discovered recently or threatened with extinction.
- Formulation of criteria and parameters to enable identification of animals and flocks of superior genetic merit or worthiness for conservation. To take steps for the preservation of germplasm both as live animals or by setting up frozen semen and embryo banks.
- Documentation of pertinent information in regard to identity of herds and flocks on a computer readable format.
- Processing of information collected under surveys carried out for the identification of valuable animal resources material.
- Dissemination of information in a cogent manner to enable individuals and agencies to use information in regard to the available animal genetic resources,
- Maintenance of national/international liaison with institutions concerned with similar work.
- Rendering financial assistance to universities, IGAR institutes and government and private bodies, where maintenance of such valuable germplasm is considered desirable.
- Monitoring of the entire improvement programme and maintenance of rare breeds/herds/ flocks in the country.
- Monitoring of new introduction of animal germplasm and new synthetics.

- To stimulate programmes for improvement in the various breeds and to give adequate financial and technical support to these.

Application of biotechnological tools for conservation of endangered species

Biotechnological methods offer many advantages to conventional captive breeding procedures currently in use today. For one, the animals do not have to be moved around, procedures that often cause severe stress and affect fecundity of the individuals. Samples can be taken from animals in the wild without removing them from their environment. Space is also a limiting factor in most zoos around the world and taking only samples from the animals would help that situation. The procedures that are in current use in animal farming have been shown to be relatively harmless to the animals. Storage of the genetic information will help to preserve biodiversity and counter the effect of genetic drift on small populations. The genetic material is available to many generations not just one. Even if the animal dies its genes are still available. Even animals that have been dead for 24 hours are still useful because their gametes can be extracted. Successful protocols could possibly be used to re-inject diversity back into wild populations that have become very small.

The main disadvantage is that research on these techniques for endangered animals is still at a very early stage and is very costly. The amount of resources available for conservation of species is very limited and the main argument is whether or not to invest in such research. The resources are needed for habitat preservation. Some argue that the best way to help endangered animals is to protect their environment not freeze them. Entire ecosystems cannot be frozen because of our limited knowledge of the role of the different organisms. If the habitat is destroyed it can never be recreated in exactly the same way so it is useless to bring some of the species back. It is also very arguable whether just preserving the genes will be enough to conserve the entire animal. Many animals need to learn behaviour in order to survive. This technique does not allow that. It is also believed that public perception will be to accept these techniques as complete solutions thereby giving people further excuses to destroy habitats.

In situ and *ex situ* conservation programs for some endangered mammalian species can benefit from modern reproductive biotechnologies or assisted reproductive techniques (ART) including artificial insemination (AI), embryo transfer (ET), in vitro fertilization (IVF), gamete/embryo micromanipulation, semen/embryo sexing and genome resource banking (GRB). With more knowledge emerging on the basic biology of reproduction, cloning or somatic cell nuclear transfer (SCNT) have been suggested as a potentially integral part of wildlife conservation programs. To date, however, natural breeding coupled with traditional ART has been the preferred method for increasing endangered animal populations, due to the poor efficiency of SCNT. With future progress in the field of cloning, this technology will also become helpful for saving species at risk of extinction. It is believed that modern biotechnologies or ART for mammalian species threatened with extinction will allow more offspring to be obtained from selected parents to ensure genetic diversity and may reduce the interval between generations.

Strategies for application of reproductive biotechnologies in endangered species

Within the past few decades, a powerful new approach has emerged for conservation of threatened wildlife species, through in situ and ex situ conservation programs. Hanks (2001) in his review on conservation strategies suggested that zoo-based captive breeding programs should also be regarded as a supplement rather than an alternative to in situ conservation activities. Also captive breeding programs should essentially be guided by rational priorities for ex situ conservation, ideally focusing on threatened species or groups with which zoos already have husbandry experience. One of the major problems with the implementation of in situ and ex situ conservation programs is the lack of availability of the biological material which is required for a better understanding of reproductive patterns as well to maximize reproductive efficiency. This constraint arises from the strict procedures adopted for restraining or anaesthetizing free-living animals for collection of biological/reproductive samples. However, this has been partially resolved by the development of viable methods for assessment of hormonal profiles from voided urine and faeces, also termed as non-invasive hormonal monitoring.

Many studies have highlighted the possibilities for non-invasive, remote monitoring of reproductive status in a number of endangered mammalian species (Broen, 2000). Further development of techniques that allows the instantaneous assessment of the endocrine status of animals living in nature would offer exciting opportunities to interrelate their physiology, especially that of reproduction, with their natural environment. This information would also help to apply available ART like AI and ET more efficiently for in situ or zoo-based conservation of endangered species. Other developments have taken place on the collection of biological material, like semen from aggressive males, by the use of internal artificial vaginas or vaginal condoms, collection from the epididymes following the death of an animal post-coital sperm recovery. For embryo recovery, non-surgical or less invasive methods like transcervical embryo collection have been applied in the recent past. Ultrasonography is another non-invasive technology that can be helpful for monitoring female ovarian function, reproductive tract morphology, pregnancy, foetal growth and assessing the male reproductive tract in many non-domestic species.

Reproductive biotechnological tools

A number of reproductive biotechnologies are available that are being widely applied for in situ and ex situ conservation of endangered species. The main technologies that have been used or considered are artificial insemination, embryo transfer (and its combination with in vitro fertilization) and sexing, gamete and embryo micromanipulation, sperm sexing, genome resource banking, and cloning.

1. Artificial insemination

One of the major applications of AI in conservation is to avoid genetic depression caused by fragmentation of groups in free-living species. Therefore, for some species living in small populations, it may be feasible to capture females for short periods for AI with sperm collected from zoo-maintained healthy males. Alternatively, for some species it would be more appropriate to capture free-ranging males for short time for semen collection, and AI captive females. Another possible application of AI, for in situ or zoo-based conservation, is to circumvent the poor natural mating behaviour in some species like giant pandas (Wildt *et. al*., 2003). Additionally, AI can be applied in captive non-domestic species to avoid the challenges of translocation of the animals for breeding purposes (Pukazhenthi and Wildt, 2004).

Besides the vast potential of AI in conservation programs there are also significant boundaries for AI technology in wildlife. Although it is generally possible to collect semen from most nondomestic mammals by artificial vagina, vaginal condoms, digital masturbation of penile bulb or electroejaculation (under anaesthesia), these processes remain difficult for some species, including the rhinoceros, non-domestic equids, certain great apes, canids and marsupials (Pukazhenthi and Wildt, 2004). Another challenge is the poor knowledge on female reproductive physiology and anatomy in many non-domestic species, particularly a comprehensive understanding of female reproductive cycles and determination of the most suitable site for semen deposit in female tract, which are very necessary for successful AI.

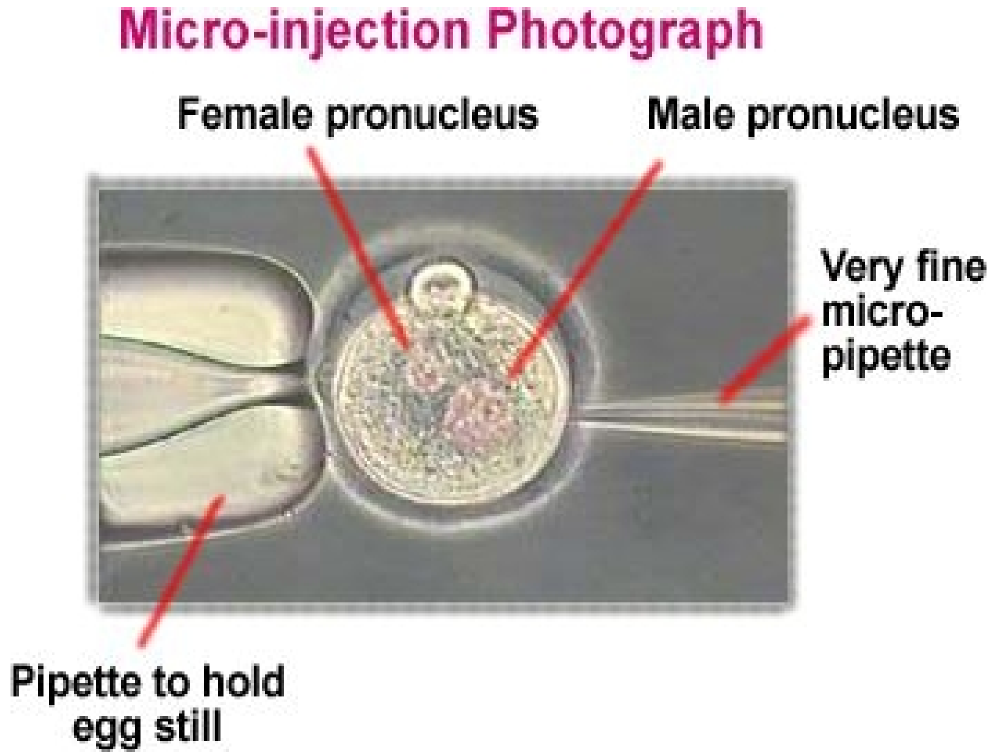
2. Embryo transfer and in vitro fertilization

Despite some early successes ET like AI has not been fully applied to the genetic management of wildlife populations. The key conservation strategy in this regard has been to pave the way for interspecies ET. In this case, embryos from an endangered species are cryopreserved and/or transferred to a more common surrogate of a different species. In wildlife ET, sexing pre-implantation embryos could be a useful conservation tool. Currently there are no references on endangered species, but techniques for sexing bovine and ovine embryos in breeding programs to manipulate the sex ratios of offspring could be modified for application in wildlife species of the same families. A recent study on sexing of in vitro produced sheep embryos describes the advancements and advantages with embryo sexing by duplex PCR (Mara *et. al*., 2004). This, demonstrated the possibility of transferring fresh sexed embryos on the same day of biopsy, a feature extremely important when the animals are in synchronized oestrus and recipient dams are available for immediate ET. This could eliminate the tedious step of embryo cryopreservation. In cases where recipients are not available, sexed embryos could be frozen after selective retention of the most likely the female embryos and discarding the unwanted males (Mara *et. al*., 2004). In vitro fertilization has been also tried in various wildlife species but with sporadic success.

Another potential application of IVF in endangered wildlife species is the use of in vitro oocyte maturation (IVM) to save the germplasm from females that die unexpectedly or accidentally (Pukazhenthi and Wildt, 2004). In a recent review by Galli *et. al*. (2003) this strategy is termed “genetic recovery”. The oocytes recovered from the ovaries of a dying individual would be matured *in vitro* and subsequently utilized for *in vitro* production of embryos.

Gamete and embryo micro-manipulation

The importance of intra-cytoplasmic sperm injection (ICSI) to wildlife or rare animal preservation appears limitless, as even non-viable sperm in cattle has resulted in the birth of live calves (Goto *et. al*., 1991). The development of ICSI in humans has lead to its application in non-human primate species, a number of which are endangered. Similarly, improvements in ICSI techniques in some domesticated animals could be useful for conservation programs of endangered species belonging to the same families. It should be noted that for the fertilization of feline and murine oocytes, ICSI has been less effective than sub-zonal insemination (SUZI; Pope *et. al*., 1995; Yanagimachi, 1998), raising the possibility that ICSI, like most of the other reproductive biotechnologies, is also species-specific. Despite this, there is a preference for applying ICSI to wildlife conservation.



The different procedures used for sperm insertion (ICSI and SUZI) will have an important role to play in future conservation efforts, particularly for endangered species in which males might develop a higher proportion of abnormal sperm and no other method except ICSI or SUZI would be available for successful IVF. This is particularly important for some feline species, such as the clouded leopard and cheetah, where a high level of abnormalities have been detected in the spermatozoa of animals in captive populations (Wildt *et. al*., 1986; Roth *et. al*., 1994, 1995). Drilling holes on the zona pellucida aims to facilitate earlier hatching of embryos from the zona pellucida when it has been hardened by ovarian stimulation and/or embryo culture. Results obtained by Loskutoff *et. al*. (1999) indicates that partial zona dissection improves the hatching frequencies of bovine blastocysts produced in vitro and co-culture conditions can affect survival after thawing. Hence, it is probable that the embryos of endangered wildlife species will also benefit from micro-manipulated hatching techniques.

3. Sperm sexing

Sex pre-selection of offspring through the use of sexed spermatozoa has great potential as a captive population management strategy for endangered wildlife, particularly those species with single-sex dominated social structures. Moreover, unbalanced sex ratios, especially excessive male births, can play havoc with small population management of wildlife (Pukazhenthi and Wildt, 2004). Producing predominantly female offspring is advantageous in accelerating the re-population rate, especially in species that are notorious for slow reproduction (Maxwell *et. al*., 2004). Thus, recent advances in sexing mammalian sperm on the basis of the differences in DNA content in X-compared with Y-chromosome bearing sperm deserves consideration for wildlife conservation (Pukazhenthi and Wildt, 2004). Recently, an AI study of sexed and thawed elk sperm has been conducted that produced 11 offspring, nine of which were of the predicted sex based on the use of predominantly X- or Y- bearing sperm in the inseminates (Schenk and De Grofft, 2003).

A significant challenge in using the sperm sexing technique for controlling gender in wildlife breeding programs will be the often low sperm densities encountered and/or the tendency for males to produce pleiomorphic spermatozoa (Pukazhenthi and Wildt, 2004). Also for use of sex-sorted semen in AI, insemination close to the site of fertilization and time of ovulation is critical for successful fertilization and ongoing pregnancy (Maxwell *et. al*., 2004).

4. Genome resource banking

There have been a number of approaches proposed to slow or halt the rate of species decline. One suggestion is to undertake a program aimed at preserving genetic material or ex situ cryoconservation of germplasm, specifically spermatozoa, oocytes or embryos, and other cells/tissues or DNA from endangered species. Often termed as genetic resource banking (GRB), the aim is to create depositories of germplasm as an interface between in situ and ex situ conservation programs (Holt and Pickard, 1999). Therefore, GRB can be tool for managing the exchange of genetic diversity among endangered species by facilitating the creation of a global gene pool (Hanks, 2001).

a. Semen banks: Systematic cryopreservation and storage of semen from endangered species can facilitate maintenance of genetic heterozygosity, while minimizing movement of living animals between captive areas/zoos/research centers or countries (Johnston and Lacy, 1995). Using frozen-thawed spermatozoa would facilitate the infusion of new genetic material across populations by AI. The use of frozen sperm from semen banks increases the generation interval indefinitely and allows fewer males to be held in captivity because some of the genetic diversity is maintained strictly as frozen spermatozoa. Having sperm samples preserved from representative free-living males protects the existing diversity from unforeseen danger and eliminates the need to remove males from their natural habitats to support in situ or zoo-based breeding programs.

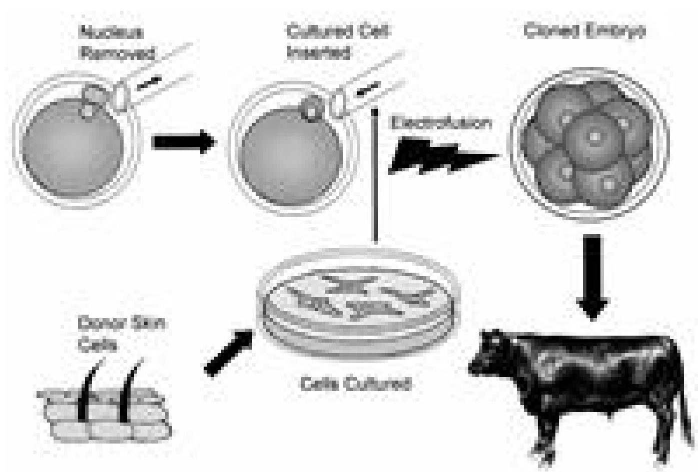
b. Embryo or oocyte banks: Embryo cryopreservation and storage allows conservation of the full genetic complement of the sire and dam and thus has enormous potential for protecting and managing species and population integrity and heterozygosity. However, the success of applying this technology to wildlife will be dictated by the uniqueness of the embryo of each species (Pukazhenthi and Wildt, 2004). Furthermore, the differences among embryos in cryosensitivity are substantial, as demonstrated by the variance between the freezable bovine compared with the difficult to freeze swine embryos (Nieman and Rath, 2001). In the case of carnivores, there has been some progress in that a baseline protocol for embryo freezing and thawing has been established for the domestic cat (Pope, 2000). Conventional freezing and thawing procedures for embryos are time-consuming and require the use of biological freezers and a microscope. Complicated embryos freezing procedures may soon be replaced by a relatively simple procedure called vitrification. However, its greatest advantage is its simplicity, because to date vitrification is only used experimentally in embryos from domestic animal breeds like cattle et cetera (reviewed by Vajta, 2000). Therefore, the biggest challenge is to establish a standardized vitrification method, which can be successfully applied for cryopreservation of embryos at different developmental stages of endangered mammalian species.

c. Tissue graft banks: Although little research has been directed towards wildlife species, the cryopreservation and subsequent use of gonadal tissue offers fascinating opportunities. This has particularly been the case since the news of a live birth following orthotopic transplantation of cryopreserved ovarian tissue in humans. Recent developments in the auto-grafting and xeno-grafting of ovaries and testes clearly demonstrate the potential value of cryopreserving gonadal tissue (Oktay and Yih, 2002; Tibary *et. al.,* 2005). The aim of ovarian and testicular tissue cryo-preservation is to store primordial follicles and spermatogonial cells, respectively (Pukazhenthi andWildt, 2004). A similar phenomenon has occurred in immunodeficient (nude) rats receiving transplants of thawed wombat ovarian tissue (Wolvekamp *et. al*., 2001). This could have a huge impact in wildlife conservation, as ovarian tissues could even be collected and preserved from young females who had died due to unknown etiology. The stage has probably not been reached where cloning technology is ready for application to maintain population viability or conserve species but in the future tissue samples (somatic cells) collected and stored from endangered species could be exploited by nuclear transfer. Research is required now to identify suitable sources of cells which could be exploited for banking and future cloning-based conservation programs. Therefore, the establishment of worldwide tissue graft banks, to store reproductive/somatic tissue and cells collected opportunistically from threatened wildlife species, could be a milestone in conservation planning. This is particularly the case in situations where population numbers are critically low, other options have failed and conservationists are faced with the need to rescue all extant genetic diversity, including from dying neonates.

5. Cloning

Somatic cell nuclear transfer (SCNT) is a process by which the nucleus (DNA) is moved from a donor cell to an enucleated recipient cell to create an exact genetic match of the donor. If this happens to be a viable embryo that proceeds to term, the resulting offspring has the same genetic complement as the original donor, except for the mitochondrial DNA, which is derived from the recipient (Wolf *et. al*., 2001; Yang *et. al*., 2004). Conservation has been highlighted recently as an area where SCNT may be useful.

Transfer of a somatic cell nucleus into the enucleated egg of a genetic stock, a closely related species or another subspecies can potentially allow the recovery of the entire nuclear genetic complement of the donor without the genetic dilution that would occur in producing biparental hybrids (Corley-Smith and Brandhorst, 1999). Moreover, SCNT may preserve and propagate endangered species that reproduce poorly in captivity until natural habitats can be restored and populations reintroduced to their ecological units



(Tong *et. al*., 2002), and may even allow the resurrection of extinct species from appropriately preserved tissue.

A major practical objection to using cloning technology in wildlife conservation is the fundamental lack of information about the basic physiology of endangered species. While it is obvious that the species requiring most urgent protection and conservation are those that are considered endangered, it may be less obvious to some that these are the very same species for which the least background biological information exists (Holt *et. al*., 2004). For the present, it has been suggested that SCNT should be only considered as a useful tool for basic research for the investigation of cell biology and reprogramming (Van Heyman, 2005). In present circumstances, where rapid advances in cloning technology are being made, perhaps it is more appropriate to focus on developing realistic strategies for using these methods in wildlife conservation and ensuring that scarce resources are deployed where they will be most effective (Holt *et. al*., 2004).

Conclusion

- Precise and reliable estimates of different genetic components of variability of important economic traits of indigenous breeds of livestock and wild animals should be obtained.
- Properly designed selection experiments should be carried out for important indigenous breeds which are not involved in genetic improvement experiments through crossbreeding.
- The present evaluation of different breeds and breed crosses is being done only under intensive management system. Such evaluation should be done under intensive, medium and low input (as close to the existing practices in the farmers fields as possible) so that the most efficient genotypes for each of these management levels could be identified.
- A number of native breeds, strains or varieties are, or may be, in danger of genetic dilution through indiscriminate crossbreeding with exotic breeds. Such native breeds should be identified, so that they can be evaluated before this process leads to their essential loss.
- Some native breeds are in danger of losing genes for high production because high-performing animals are withdrawn from breeding populations for use in units of high production and/or subsequent slaughter (e.g. city milk production in India or slaughter animals closed because of large size). Such breeds should be identified and breeding units kept intact.
- Application of conventional and biotechnological tool for endangered free-living animals is rarer than for endangered domestic breeds. Progress in ART for non-domestic species will continue at a slow pace due to limited resources, but also because the management and conservation of endangered species is biologically quite complex. In practice, biotechnologies are species-specific or inefficient for many endangered animals.

2.7 Advanced Techniques in Diagnosis of Livestock Diseases and Zoonotic Pathogens I. Shakuntala, ICAR Research Complex for NEH Region, Umroi Road, Umiam, Meghalaya – 793103

Infectious diseases of livestock can cause major economic losses, both to the livestock owners and the country as a whole. Besides, some diseases are often credited to have been associated with public health significance and zoonoses. Zoonoses poses serious burdens of diseases on vast number of people particularly those who are in close contact with domestic as well as wild animals. Establishment of a good diagnostic laboratory for rapid and reliable diagnosis to ensure proper preventive and control measures of infectious diseases in livestock is a necessary step. The most authentic diagnosis of diseases is made by isolation and identification of the pathogen. However, it is time consuming, tedious and sometimes requires living medium. The development of various immunological and molecular techniques has revolutionized diagnostic procedures by providing specific diagnosis or detailed characterization of any pathogen or host pathogen interactions. Some of the recent immunological and molecular techniques employed in addition to the conventional ones for the diagnosis of diseases are discussed in brief.

Immunological techniques

Conventional immunoassays for the diagnosis of diseases have been based on the detection of antibody to the pathogen of interest, using techniques such as virus neutralization, enzyme-linked immunosorbant assay (ELISA), complement fixation and agar gel immunodiffusion. These assays generally rely on the interaction of serum polyclonal antibodies against the agent of interest, followed by the use of a detection system such as the cytopathic effect, haemolysis or colour change of a reaction medium. New biotechnological methods such as cloning of genes, over expression of immunogens, use of expression vectors and peptide synthesis have made possible the production of specific proteins or peptides. The use of these improved antigens can increase the specificity or sensitivity of immunoassays.

The immunological techniques like western blotting, immunofluorescence, immunoperoxidase/enzyme immunohistochemistry, flowcytometry, confocal laser microscopic techniques etc. are routinely used for diagnosis of various diseases or to study the expression profile of various genes.

Fluorescent antibody technique (FAT)

Fluorescent antibody techniques are based on the principle of antigen and antibody interaction. It involves the detection of antigen/protein using the specific antibodies conjugated with fluorescent dye such as fluorescein isothiocyanate (FITC), phycoerythrin (PE) etc. by direct or indirect methods. In the direct method of FAT, primary antibody is labeled with a fluorescent dye whereas in the indirect method (IFAT); secondary antibody raised against the species of origin of primary antibody is labeled with fluorescent dye. In indirect method, primary antibody is specific for antigen while the secondary antibody is specific for the primary antibody. Immunofluorescence techniques can be used for the detection of expressed protein following transfection and microbial antigen in infected cell culture, tissue sections, clinical samples etc., thus aid in the identification of the protein/pathogen of interest.

Immuno-Peroxidase technique (IPT)

IPT is similar in principle to FAT except that antibody is conjugated to an enzyme e.g. Horse Radish Peroxidase (HRPO). Upon addition to substrate solution that contains diaminobenzidine hydrochloride (DAB) and H_2O_2, first H_2O_2 is catalyzed by the HRPO to yield nascent oxygen and a molecule of water. Nascent oxygen thus formed oxidizes DAB which forms the brown colour. Thus IPT also offer the detection of expressed antigen in the cultured mammalian cells/tissue sections/impression smears. It has advantages over FAT in the sense that there is no need of fluorescent microscope and slides can be stored for long period without affecting the results. Similar to FAT, IPT is also performed in both direct method and indirect method.

Flow cytometry

Flow cytometry has emerged as a major new technology in veterinary clinical laboratories. Flow cytometers offer rapid and quantitative analysis of a variety of cell types based on cell size, molecular complexity, and antigenic composition. Therefore, flow cytometry complements and extends knowledge that can be obtained by light microscopy. The most prominent uses of flow cytometers are for immunological characterization of lymphomas and leukemias, crossmatching tissues for organ transplants, and counting lymphocyte subpopulations in the peripheral blood infected individuals. Flow cytometric evaluation of cellular proteomics has become an integral part of the laboratory diagnosis and classification of haematopoietic neoplasms. Recent technical advances in lasers, monoclonal antibodies, fluorochromes, and computer-based color compensation algorithms have expanded the usefulness of flow cytometry. Detection of minimal residual disease by flow cytometry in leukaemias and lymphomas is incorporated in many treatment protocols (Dalal, 2007). Flow cytometry analysis is carried out using the instrument known as flow cytometry/fluorescence activated cell sorter (FACS).

Western blotting

In western blotting, electrophoretically separated proteins are transferred from a gel to a solid support and probed with reagents that are specific for particular sequences of amino acids (peptide). In case of proteins, they usually are antibodies that react specifically with an antigenic epitopes displayed by the target protein which is attached to the solid support. Western blotting is therefore extremely useful for the identification and quantification of specific proteins in a mixture of protein that are not labeled.

Enzyme-linked immunosorbent Assay (ELISA)

ELISA is a highly sensitive and accurate immunodiagnostic technique in which antibody is conjugated to an enzyme and utilized to detect the presence of an antibody or an antigen in a sample. It can also be used as a tool for quality control checking in various industries. In ELISA, an unknown amount of antigen is affixed to a surface (micro-titer plates or Nitrocellulose paper/Nitrocellulose membrane strips), and then a specific antibody is washed over the surface so that it can bind to the antigen. This antibody is linked to an enzyme, and in the final step a substance is added that the enzyme can convert to some detectable signal. Indirect ELISA, Sandwich ELISA, Competitive ELISA are the different types of ELISA technique.

Immunochromatography

Immunochromatography provides a conventional method for detection of antigens in several minutes without special apparatus.The sample is applied on one end of the filter and the microbeads (such as colloidal gold) conjugated with antibody is applied. The anibody binds to microbeads-antigen complex, is trapped on the second antibody that is on the filter, and is easily visualized at the site where the second antibody was fixed.

Newer immunological techniques

Peptide synthesis

Synthetic peptides or recombinant antigens produced by recombinant DNA technology offer many advantages over natural antigens isolated from other biological sources. These advantages include a high purity, high specific activity and consistency. The use of synthetic peptides or recombinant antigens in detection of animals infected with diseases such as classical swine fever, foot -and -mouth disease or with a zoonotic or endemic disease (Langedijk *et al*., 2001; Davis *et al*., 2001; Soutullo *et al*., 2001), reduces the risk involved in the production of the assay and the risk of producing kits with antigen that has not been completely inactivated and, therefore, remains potentially infectious.

Cloning and expressin of specific protiens

The cloning and expression of specific proteins produced by a pathogen have enabled the development of assays that can differentiate vaccinated from non-vaccinated (infected) animals. The genes encoding the specific protein are identified and cloned in appropriate vectors, and these genes/proteins are expressed in bacteria, yeast or eukaryotic systems. The expressed proteins can be easily extracted or secreted and the purified if necessary. These proteins can be used as antigen for more specific diagnosis of diseases.

Detection of gamma-interferons

Recently, commercial assays to detect cell-mediated responses have become available e.g., gamma-interferon assays use for detection of tuberculosis. Presence of gamma-interferon in animals may be an indication of infections by microorganisms such as tuberculosis. The assay rely on detection of gamma-interferon, a cytokine expressed when sensitised immune cells in the blood are exposed to the target agent. These assays rely on the use of host-species specific monoclonal antibodies and require a fresh blood samples with viable white cells.

Biosensors

A new approach to the detection of either the agent or antibodies is the development of biosensors. This type of assay involves the use of a receptor (usually an antibody) for the target pathogen or a disease-specific antibody and a transducer which converts a biological interaction into a measureable signal (Cruz *et al.,* 2002). Some of the transducer technologies under development include electrochemistry, reflectometry, interferometry, resonance and fluorimetry (Barker, 1987). Biosensors are frequently coupled to sophisticated instrumentation to produce highly-specific analytical tools, most of which are still in use only for research and development due to the high cost of the instrumentation, the high cost of individual samples analysis, and the need for highly trained personnel to oversee the testing. An example of a commercial application of fluorimetry is the particle concentration fluorescence immunoassay for brucellosis and Aujeszky's disease antibody screening. Fluorescence polarization technology has recently become available for the detection of bovine brucellosis (Nielsen *et al*., 1996).

Proteomics

Proteomics is the study of proteins, including their expression level, post-translational modification and interaction with other proteins, on a large scale. The use of proteomics for the diagnosis of infectious disease is in the infancy but may prove to be of considerable importance.

An extremely useful application of proteomics to the diagnosis of infectious disease is the indentification of novel diagnostic antigens by screening serum from infected and uninfected individuals against immunoblotted, 2DGE mapped proteomes of infectious agents. Within the veterinary field, proteomics-based research projects are now underway and these will undoubtly yeild novel diagnostic tools for the future. Proteome maps are being derived for a range of veterinary pathogens such as *Brucella melitensis* (Mujer *et al.*, 2002), *Toxoplasma gondii* (Cohen *et al*., 2002), *Eimeria tenella* (Bromley *et al*., 2003), *Trypanasoma brucei* (Rout and Field, 2001) and nematodes such as *Haemonchus contortus* (Yatsuda *et al*.,2003).

Detection of Nucleic Acids

Polymerase chain reaction (PCR)

Polymerase chain reaction (PCR) is a highly sensitive and reliable molecular technique to amplify a single or few copies of a piece of DNA under *in- vitro* condition. Million copies of DNA segment can be obtained from a single copy of DNA template within 2-3 hours. Most PCR methods can amplify DNA fragments between 10 - 40 kb in size. This method involves denaturing (94-95ºC) of double stranded DNA to be investigated followed by hybridization (50-65ºC) of specific short oligo-nucleotides (primers) to a specific segment (complimentary sequences) of the targeted genome which get extended (72ºC) with the help of Taq polymerase. This process is repeated for 25- 40 cycles to obtain the amplified genes. The amplified DNA segment is electrophorized in 0.8- 2% agarose gel; stained with ethidium bromide and visualized under UV light (Sambrook and Russell, 2001). Serotypes, genotypes and pathotypes of a particular organism can be identified by using specific primer pairs. Multiplex PCR is used to detect more than one target genes. Reverse Transcription-PCR (RT-PCR) is used for detection of RNA or a cDNA copy of the RNA of microorganisms (e.g. RNA viruses).

Real time PCR

Real time PCR is the latest improvement in the standard PCR technique that enables rapid and specific diagnosis of disease outbreaks. Real time PCR require less manipulation, is more rapid and specific than conventional PCR technologies, has a closed-tube format therefore decreasing risk of cross-contamination, is highly sensitive and specific, thus retaining qualitaive efficiency, and provides quantitative information. Detection of positive samples is dependent on the amount of fluorescence released during amplification. It can be used to quantify DNA or RNA content in a given sample. The PCR is also used extensively for the genotyping and phylogenetic analysis of veterinary pathogens. In many cases, the real-time PCR assays have proved to be more sensitive than existing reference methods (Heim *et al*., 2003; Weidmann *et al*., 2003)

Diagnosis by DNA probes

In DNA probe hybridization the DNA, derived from sample suspected of containing a pathogen (the 'unknown'), bind with highly characterized DNA derived in advance from a pathogen of interest (the 'known' DNA). In conventional DNA probing the unknown DNA (or RNA), the target, is immobilsed on a solid surface e.g. a filter; and the known DNA (labelled/stagged probe) which is applied to the target, is in the liquid phase. The bound probe can be detected by addition of specific molecules/substances linked to an enzyme that generate colour or light (chemiluminescence). Detection of pathogen by this method is limited by the number of probes used.

DNA micrarray technology

A microarray comprises 20,000 or more different known DNAs, each being spotted onto glass slides, to form the array. In microarray diagnosis the known DNA that is the target, immobilsed on a glass slide, and the unknown DNA, in the liquid phase, which is labelled to make a probe. In microarray analysis, the detection of pathogen is limited only by the number of target DNAs on the array. Microarray analysis has great potential when one is investigating diseases of unknown aetiology, diseases where more than one pathogen might be present and when subtyping is required. The great advantage of microarray analysis in searching of pathogens is that hundreds of pathogens can be looked simultaneously when probing a single microarray slide. To enhance sensitivity in pathogen detection, microarrays can be coupled with PCR amplifications.

Newer Techniques

Fluorescent in situ hybridization (FISH)

FISH is a technique that can localize nucleic acid sequences within cellular material. Peptide nucleic acids, molecules in which the sugar backbone has been replaced by a peptide backbone, are perfect mimics of DNA with high affinity for hybridization that can be used to improve FISH techniques (Stender, 2003).

Nucleic acid sequence-based amplification (NASBA)

NASBA is a promising gene amplification method. This isothermal technique is comprised of a two-step process whereby there is an initial enzymatic amplification of the nucleic acid targets followed by detection of the generated amplicons. The entire NASBA process is conducted at a single temperature, thereby eliminating the need for a thermocycler. The use of this technique has been shown to detect avian and human influenza viruses (Collins e*t al*., 2003; Moore *et al*., 2004).

Nanotechnology

Nanotechnology is broadly defined as systems or devices related to the features of nanometer scale (one billionth of a metre). The small dimensions of this technology have led to the use of nanoarrays and nanochips as test platforms (Jain, 2003). One advantage of this technology is the potential to analyze a sample for an array of infectious agents on a single chip. Applications include the identification of specific strains or serotypes of disease agents or the differentiation of diseases caused by different viruses but with similar clinical signs. Another facet of nanotechnology is the use of nanoparticles to label antibodies. The labeled antibodies can then be used in various assays to identify specific pathogens, molecules or structures. Example of nanoparticle technology includes the use of gold nanoparticles, nanobarcodes, quantum dots and nanoparticle probes (Santra *et al*., 2004; Zhao *et al*., 2004). Additional nanotechnologies include nanopores, cantilever arrays, nanosensors and resonance light scattering. Nanopores can be used to sequence strands of DNA as they pass through an electrically- charged membrane (Emerich *et al*., 2003). Nanotechnology is still in the research stage but it is anticipated that nanotechnologies will eventually be applied to the diagnosis of endemic veterinary diseases in the future.

DNA Based Typing of Microorganisms

Random Amplification of Polymorphic DNA (RAPD)

In RAPD analysis, unknown target sequences in a genomic DNA are amplified by PCR employing primers with arbitrary sequences (10 bp primers). Many fragments with varying size may be amplified that can be observed in agarose gel and dendogram analysis is done with the help of computer softwares. These results can be used for study of genetic variability among closely related genotypes.

Restriction fragment length polymorphisms (RFLP)

This DNA- based method is used to distinguish between isolates of closely related pathogens, whether they are viruses, bacteria, fungi or parasites. The RFLP approach is based on the fact that the genomes of even closely related pathogens are defined by variation in sequence. The RFLP procedure consists of isolating the target pathogen, extracting DNA or RNA (with subsequent reverse transcription to DNA) and then digesting the nucleic acid with one of a panel of restriction enzymes. The individual fragments within the digested DNA are then separated within a gel by electrophoresis and visualized by staining with ethidium bromide. Ideally each strain will reveal a unique pattern, or fingerprint. The results can be further analysed with the help of computer softwares.

PCR-RFLP

PCR-RFLP is a modification of the basic RFLP technique whereby the polymerase chain reaction (PCR) is incorporated as a preliminary step. The PCR method is used to amplify a specific region of the genome (known variable sequence between pathogens), which then serves as the template DNA for the RFLP technique. This new combination (PCR-RFLP) offers a much greater sensitivity for the identification of pathogens and is especially useful when the pathogen occurs in small numbers or is difficult to culture.

Pulsed field gel electrophoresis (PFGE)

The limitation to separate very large DNA molecules by standard gel electrophoresis techniques can be overcome with this new technique, called pulsed field gel electrophoresis (PFGE). In PFGE an alternating voltage gradient is applied which facilitates the differential migration of large DNA fragments through agarose gels by constantly changing the direction of the electrical field during electrophoresis. The development of PFGE expanded the range of resolution for DNA fragments by as much as 2 orders of magnitude. PFGE has been successfully applied in subtyping of many pathogenic bacteria among other applications such as cloning of large plant DNA, construction of physical maps, genetic fingerprintings, etc. This technique is time consuming and require high-level of skill.

Conclusion

Diagnosis of infectious diseases of livestock and zoonotic pathogens primarily comprised of traditional diagnostic techniques. However, in the recent years a profound change has occurred with the introduction of new biotechnological assays. These new assays include the production of more specific antigens by the use of recombination, expression vectors and synthetic peptides. Application of these assays coupled with the use of monoclonal antibodies, the sensitivity and specificity of a number of traditional diagnostic assays have been significantly improved. Various forms of PCR have become routine diagnostic tools in veterinary laboratories for specific typing as well as rapid screening of large numbers of samples during disease outbreaks. Proteomics has the potential to look at the broader picture of protein expression by a pathogen of interest or by infected animals and may lead to a special niche of veterinary diagnostics. Though it is not yet implemented in veterinary laboratories, nanotechnologies hold the promise of screening for numerous pathogens in a single assay. Nanotechnology may be the choice for mobile or pen side testing for disease diagnosis in future. Biotechnology and its applications hold great promise for improving the speed and accuracy of diagnostics for veterinary pathogens and much developmental work will be required to provide improved diagnostic capabilities to safeguard animal health.

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3 Resource Productivity and Efficiency

3.1 Present Status and Prospects of Ginger and Turmeric in NE States

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The North Eastern Region produces a variety of spices including chillies, ginger, turmeric, large cardamoms, black pepper, tejpatta etc. Ginger and turmeric are prominent among them and their cultivation is undertaken as a cash crop mostly in **jhum** fields spread over the hills and tribal areas of the entire region. Ginger is grown in almost all the states of the region but the leading states are Meghalaya, Mizoram, Arunachal Pradesh and Sikkim (Govind *et al.,* 1998). Apart from improved varieties like Nadia, China, Varada, etc., a number of local cultivars exist in northeastern region. These varieties are high yielder of rhizomes as compared to standard cultivars like Nadia and Rio-De-Janeiro but have more fibre content. The ginger produced in higher altitude contains high oleoresin and gives higher oil recovery.

The region as a whole produces over 207 thousand tonnes of raw ginger every year. The product is mostly marketed in the fresh form. The local demand being very limited, roughly 70-80per cent of the total production is reportedly available as marketable surplus from the region. A sizeable quantity of ginger is wasted in transit because of the perishable nature of the commodity. The post harvest loss is estimated to be about 10.5 per cent during handling and transportation (Deka *et. al*., 2004). As it is abundantly available in the region, different products like ginger oil, ginger oleoresin can be prepared for export, which are very common in developed countries. Dried ginger can also be prepared and it may be either sold as such or in the form of an off white to very light brown powder. The dried ginger or ginger powder is generally used in manufacturing of ginger brandy, wine and beer in many western countries. Ginger oil is primarily used as a flavouring agent in confectionary and for soft drinks.

Similarly, in turmeric, apart from improved varieties like Lakadong and Megha Turmeric-1, a number of local cultivars exist in northeastern region. The turmeric produced in this region contains high oleoresin and curcumin content. The product is mostly marketed in the fresh form. The local demand being very limited, roughly 70-80per cent of the total production is reportedly available as marketable surplus from the region. As it is abundantly available in the region, different products like turmerones (turmeric oil), oleoresin, and powder can be prepared for export, which are very common in developed countries.

Present status of ginger and turmeric production in NE region

The area under ginger in NE region is 30.84 thousands ha which gives total production of 209.15 thousand tonnes at an average yield of 6.78 t/ha against the national productivity of 3.56 t/ha. The production of ginger is highest in Meghalaya followed by Mizoram and Arunachal Pradesh. However, the productivity is highest in Manipur (9.86 t/ ha) followed by Nagaland (9.05 t/ ha) and Arunachal Pradesh (Table 1). The most popular cultivated variety in the region is Nadia that possess low fibre (4.10 per cent) and has maximum demand for culinary purposes. Although it is said that Nadia is popular among the farmers on productivity aspect, the local medium sized varieties are still grown in larger area in the region.

The area under turmeric in the region is 17.27 thousands ha with a total production of 32.36 thousand tones. The productivity of the crop is much lower (1.87t/ha) compared to the national productivity of 3.47 t/ha (Spices Statistics, Spices Board, 2004). The production of turmeric is highest in Meghalaya followed by Assam, Tripura and Nagaland. However, the productivity is highest in Mizoram (Table 1). The most popular cultivated variety in the region is Lakadong (7.5 per cent) and Megha Turmeric-1 (6.8per cent) that possesses higher curcumin content and has maximum demand

Table 1. State-wise area, production and productivity of ginger and turmeric in northeastern region (2004-05)

State	**Area ('000 ha)**		**Production ('000 t)**		**Productivity (t/ha)**	
	Ginger	**Turmeric**	**Ginger**	**Turmeric**	**Ginger**	**Turmeric**
Arunachal Pradesh	4.61	0.40	38.02	1.50	8.25	3.75
Assam	4.20	12.00	32.10	8.00	7.64	0.67
Manipur	1.27	0.37	12.52	2.09	9.86	5.69
Meghalaya	8.40	1.60	46.59	8.70	5.55	5.44
Mizoram	4.53	0.30	38.07	2.97	8.40	9.9
Nagaland	1.37	0.60	12.40	3.10	9.05	5.17

Sikkim	5.10	0.50	24.00	1.70	4.71	3.40
Tripura	1.36	1.50	5.45	4.30	4.01	2.87
N.E. Region	**30.84**	**17.27**	**209.15**	**32.36**	**6.78**	**1.87**
India	**86.32**	**150.5**	**307.09**	**521.9**	**3.56**	**3.47**

Table 2: Promising varieties of ginger grown commercially in northeastern region

Sl.No.	Adapted Varieties	Crude fibre (per cent)	Dry matter (per cent)	Gingerol (per cent)	Oil (per cent)	Yield (t/ha)
1	Nadia	4.56	22.25	0.64	1.45	30.00
2	Poona	6.24	19.76	0.93	1.17	25.10
3	Varada	5.93	21.38	0.96	1.75	22.00
4	Thingpui (local)	5.74	22.47	1.25	1.80	19.30

Diversity of ginger and turmeric in the region

In ginger, the region can be considered as treasure house of germplasm. There are several cultivated types of ginger available in the region, which are generally named after the localities they are being grown. Certain indigenous types namely Maran, Bhola and Jorhat Local of Assam have been reported to be equally good in rhizome yield as well as in size. Dry ginger recovery of these varieties has been found to be even better than exotic type Rio-de-Janeiro. The pungency in ginger is due to gingerol, which is found highest in Meghalaya Local genotype (medium size) and very suitable for export purposes. In Mizoram, local types **Thingpui**, **Thingaria** and **Thinglaidum** are grown at large scale. Black ginger having rhizomes with bluish black tinge inside is reported to have medicinal properties and is grown by the inhabitants of Mizoram for commercial as well as their own use. In Sikkim, local types **Bhainse** and **Gorubathan** are grown commercially due to their high yield potential and big size rhizomes. In Meghalaya, in addition to local types namely **Meghalaya Local** and **Tura Local**, considerable area has been brought under selected type Nadia (Table 3).

Similarly, there are several cultivated types of turmeric available in the region, which are generally named after the localities they are being grown. Certain indigenous types namely Manipur Local, Nagaland Local, Sikkim Local and Jorhat Local of Assam have been reported to be equally good in rhizome yield. Dry matter recovery of these varieties has been found to be even equal or better than certain improved types. In Meghalaya, Lakadong is the main variety and more than 50per cent area is under this variety.

Table 3. Promising local genotypes of ginger of North East Region

Genotype	Crude fibre content	Dry matter content (per	Gingerol (per cent)	Oil (per cent)	Yield (t/ha)

	(per cent)	cent)			
Manipuri No. 1	6.77	21.18	1.14	1.45	17.126
Basar	7.02	22.54	1.12	1.30	20.940
Tura Local	5.50	21.9	1.32	1.55	17.826
Thingpui	5.74	22.47	1.25	1.80	19.341
Maran	6.25	24.02	1.10	1.75	19.815
Meghalaya Local	6.02	20.12	1.71	2.10	14.765
Thinglaidum	5.86	22.38	1.23	1.45	15.425
Kachai Ginger	5.72	24.87	1.20	1.70	20.097
Nagaland Local	6.93	19.8	1.18	1.85	19.18
Nadia	4.56	22.25	0.64	1.45	30.00

Source: Sanwal *et al*, 2007

Commercial qualities

Ginger is generally sold as raw ginger in local markets but there are several other products of ginger like dry ginger, ginger powder, ginger oil, and oleoresin. The oleoresin and oil are known as high value and low volume products, which have great demand in western countries. The varieties with less fibre, high dry matter recovery, and high oil and oleoresin contents are having great export potential in international markets. Therefore, more emphasis may be given to develop those varieties, which are having the above qualities. The Indian Institute of Spices Research, Calicut has evolved Varada, a new variety of ginger, which is being multiplied at Ginger Development Station, Umsning, Meghalaya and the performance of the variety is quite encouraging. The local varieties of ginger contain higher quantity of gingerol compared to the variety like Nadia and Varada.

Production and marketing constraints

1. Abiotic factors: Ginger and turmeric are mostly grown in sub-tropical hill zones where soil is acidic in nature. Cultivation is being practised on steep slopes under **jhum/ bun** (raised beds) system in rainfed conditions without adoption of soil and water conservation. Deep virgin soils of forest brought under **jhum** system are giving higher yields in first and second year of cultivation even under zero nutrient management conditions. But heavy rains and earthing works associated with the cultural operations and harvesting accelerate the erosion reducing the fertile soils into abandoned wasteland. In second cycle of cultivation on such fields after a gap of 3-5 years very low yields (5-8 t/ha) are obtained. Farmers apply only FYM at planting and no other nutrient application strategies are followed. These factors lead to low productivity. Research on soil water conservation technologies, sustainable production system etc is being carried out by the Institute.

2. Biotic factors: Non-availability of quality planting material is another important factor attributing to low productivity. The serious diseases of ginger are seed rhizome borne, viz. soft rot (*Pythium sp, Rhizoctonia sp and Sclerotium rolfsii*), dry rot (*Fusarium oxysporum*) and bacterial wilt (*Ralstonia solanacearum*). Some of these, particularly bacterial wilt once introduced into cultivated fields it is very difficult to eradicate. The supply of quality planting material free from diseases can contribute enormously to enhance the productivity. Ginger stem borer (*Dichochrosis punctiferalis*), Shoot borer weevil (*Prodiotes halmaticus*) causes crop damage between 30-40 per cent during July-September.

There is a need for the establishment of seed agencies to supply certified seed rhizome in north-eastern region. Farmers / Farmers' clubs / NGOs could be trained to develop technical skill to produce home grown quality seed to meet their own seed requirements. Further, bio-organic/ botanical extracts developed by the Institute controls serious diseases and increases ginger yield. Such materials at low cost are technically feasible in slope areas and are eco friendly substances.

3. Socio-economic factors: Cultivators in northeastern regions are resource poor and have low produce holding capacity. Lack of storage facilities at farm, non-existence of organised marketing system/ growers association etc force the growers to sell their produce just after harvesting through commission agents. Sale in village markets (weekly markets), city markets are very limited.

Absence of adequate number of post harvest processing units to absorb marketable surplus (which is nearly 70per cent) forces the cultivators to sell the produce as fresh only. Unorganised marketing system is another constraint determining the low adoption of improved production packages and enhancing the productivity system. Establishment of processing units in the region is needed to absorb the market surplus and produce value added products that have longer shelf life.

Future thrust

The followings are the areas where more intensive research is needed so that overall scenario of the ginger production can be changed by increasing production and productivity of ginger in the northeastern region.

Post- harvest management: There is need to develop quality control measures, adequate packaging, transportation and storage techniques. Intensive research for protocol development of different value added products may be taken up. Low cost storage structure for long-term storage is the need of the hour. Sprouting inhibition after harvesting for a minimum period of 2-3 months using organic sources will increase the volume of export.

Introduction, evaluation and improvement: Introduction of indigenous and exotic high yielding strains suitable for the state may help in increasing the total production of the region. Breeding with local germplasms should be done for high yielding and better quality varieties with resistance to biotic and abiotic stress. DNA finger printing of the local germplasm should be done immediately to safe guard the interest of the farmers.

Quality planting materials: Since there is inadequate supply of quality planting materials and true to the type varieties are not maintained properly, a mechanism may be devised for regulating the production and supply of disease free planting materials to the growers. Micro propagation techniques may help in rapid multiplication of quality planting material.

Emphasis on organic farming: The production sytem in the northeastern region is organic by default. Bio-organics, bio-pesticides, integrated approach for pest and disease control and strategies for each farming systems has to be worked out. The need of the hour is to have a simplified and affordable organic certification system.

Economics and technology transfer: The cost benefit analysis of different farming systems is required. There is immense need to strengthen the extension system for transfer of technologies and to provide training to the farmers.

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3.2 Importance and Management of Soil Biology for Sustainable Agriculture

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Soils form on surface of the earth. Soils provide the base for cycling of matters and transfer of energy and hence, consider as nature's integrator. They interact reciprocally with the biosphere, hydrosphere, lithosphere and atmosphere (McGill, 2007). The interactions among these four spheres involve biological, chemical, biochemical, and physical transformations and biological and physical translocations. Soil organisms especially microorganisms are intimately involved in biological and biochemical transformations. Soil organisms are both sinks for elements and catalysts to speed transformations of elements. Hence, physiology and biochemistry of soil organisms is fundamentally important to understanding earth systems. Before understanding eco-physiology and biochemistry of soil organisms (What are they doing at ecosystem level?); it is essential to identify "Who are they and what are their biogeographic distributions at spatial- and temporal scales?"

The governments of various countries including India are becoming increasingly concerned about sustaining biodiversity and maintaining life support functions. Emphasis has been given by implementing several regional or national programmes to monitor soil quality and /or the state of biodiversity. Most monitoring programmes include microbiological indicators, because soil microorganisms have key functions in decomposition and nutrient cycling, respond promptly to changes in the environment and reflect the sum of all factors regulating nutrient cycling. Policy makers, as well as land users, need indicators and monitoring systems to enable them to report on trends for the future and to evaluate the effects of soil management.

Soil fauna

Members of the soil fauna are numerous and diverse and include representatives of all terrestrial phyla (Wolters, 2001; Coleman and Wall, 2007). Many groups of species are not described taxonomically and details of their natural history and biology are unknown (Fig. 1). For example, among the microarthropods only 10per cent of populations have been explored and perhaps 10per cent of species described (André *et al.*, 2002). So, soil biologists feel protection of biodiversity in ecosystems clearly must include the rich pool of soil species including micro-organisms, mesofauna, macro- and megafauna. Recent advance research on roles of soil biota and ecosystem processes generated data for some of these soil species individually or collectively and these findings indicated tight connections to biodiversity aboveground, major roles in ecosystem processes, and provision of ecosystem benefits for human well-being (Wall, 2004; Wall *et al.,* 2005).

In general, soil fauna are separated into four size classes: microfauna, mesofauna, macrofauna and megafauna. Swift *et al.* (1979) proposed the size classification of organisms in decomposer food webs by body width. This classification encompasses the range of body width for microfauna and mesofauna are less than 100-μm and between 100-μm to 2-mm, respectively. The range of body width for macro- and megafauna is from 2-mm upto 20-mm. However, there is considerable gradation in the classification based on body width. For example, the smaller mesofauna exhibit characteristics of the microfauna, and so forth. The members of Nematode, Protozoa and Rotifera are microfauna; the members of Acari, Collembola, Protura, Diplura, Symphyla, Enchytraeidae, Chelonethi, and Isoptera are mesofauna; the members of Opiliones, Isopoda, Amphipoda, Chilopoda, Diplopoda, Megadrili (earthworms), Coleptera, Araneida and Mollusca are within macro- and megafauna. There is considerable overlapping in body width ranges of the members of the macro- and megafauna. The vast range of body sizes among the soil fauna emphasizes their effects on soil processes at a range of spatial scales. Three levels of participation have been suggested (Lavelle *et al.*, 1995; Wardle, 2002). The fauna, those alter the physical structure of soil and influence the rates of nutrient and energy flow are considered as "Ecosystem engineers"; for example: earthworms, termites, or ants. The microarthropods fragment decomposing litters and improve its availability to microbes and are considered as "Litter transformers". And the third level of participation "Micro-food webs" includes the microbial groups and their direct micro faunal predators (nematodes and protozoans). The feeding habits of different groups of soil fauna and their possible role in soil processes are presented in the Table 1.

Soil fauna plays important role in assisting microbes in colonizing and extending their reach into the horizons of soils worldwide. Being soil faunas' roles as colonizers, comminutors and engineers within soils, it is important to establish how soil fauna contribute to long-term soil sustainability with respect to global environmental issues.

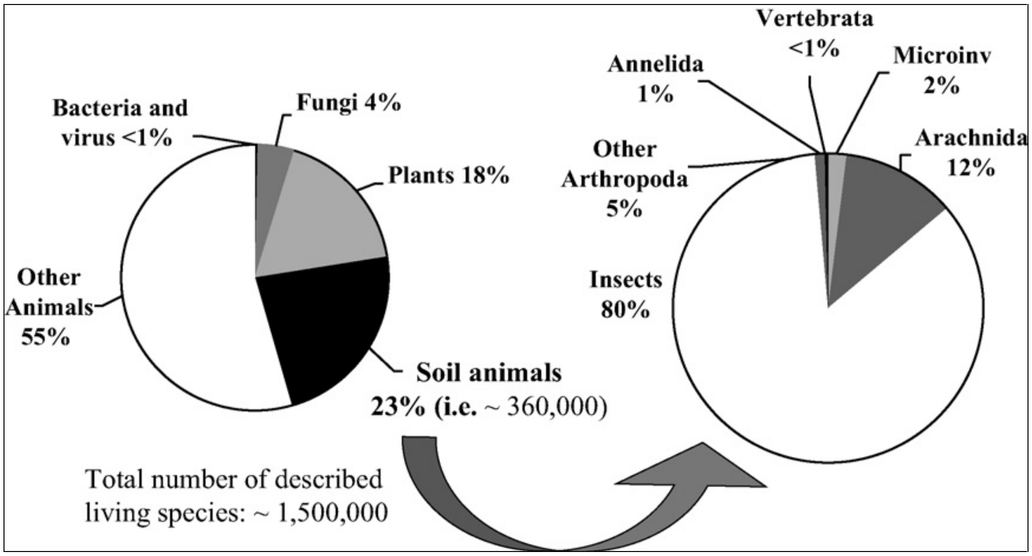

Fig.1. Importance of soil animals for (a) the global biodiversity and (b) relative importance of major taxa within soil communities worldwide (data adapted from Decaëns *et al.*, 2006).

Table 1: Population and feeding habits of soil fauna and their roles in soil processes

Soil faunal group	**Population (numbers)**	**Feeding habit**	**Possible role in soil process**
Protozoans (flagellates-, naked-, testate-, and ciliate amoebae)	10^2 g^{-1} in desert soil to 10^5 g^{-1} in forest soils.	Bacteria principal prey items. Phagotrophic with bacteria, fungi, algae and other fine particulate organic matter.	Nutrient turnover in the rhizosphere and production of plant-growth promoting substances.
Rotifera	Some cases numbers may exceed 10^5 m^{-2} in moist organic soils.	Vortex feeders, creating currents of water that conduct food particles, such as unicellular algae and bacteria.	Role of rotifers in soil processes is largely unknown.
Soil faunal group	**Population (numbers)**	**Feeding habit**	**Possible role in soil process**
Nematoda	330-4650 individuals per 250ml soil (Yeates *et al.,* 1999)	Bacteria feeders, fungal feeders, plant root feeders, top predators, omnivores and plant associates.	Nutrient turnover and soil organic matter decomposition dynamics.
Microarthropods (mainly mites and collembolans)	33-88 x 10^3 individuals m^{-2} in temperate forest floor; 130 x 10^3 individuals	Feeds on bacteria, fungi, mineral soil particles, organic matter, protozoa,	In soil food web chain, microarthropods link the microfauna and microbes with mesofauna and in turn

	m^{-2} in conifer forest floor and less density in tropical forest floor.	and nematodes	microarthropods are prey for macroarthopods, such as spiders, beetles, ants and centipeds. Thereby, microarthropods have significant impact on litter decomposition processes.
Enchytraeids (Known as potworms and classified as “microdrili” oligochaetes)	4,000-14,000 individuals m^{-2} in agricultural plots and >140,000 individuals m^{-2} in peat moor	Feeds on finely fragmented plant residues often enriches with fungal hyphae and bacteria (approx. 80per cent of the population is microbivorous and 20per cent of the population is saprovorous).	Significant effects on soil organic matter dynamics and on soil structure formation through fecal pellets. For example: enchytraeid fecal pellets constritutes nearly 30per cent of the volume of A_h horizon in Scottish grassland soils.
Macrofauna **Oligochaeta** (Earthworms) **Formicidae** (Ants) **Termitidae** (Termites)	Typical densities of earthworms in tropical forest and certain arable lands range from <100 to over 400 individuals m^{-2}. Ants’ population is generally large in tropical areas. In Amazonian rainforest ants population in excess of 8 million per hectare. Similarly, termite may constitute up to 75per cent of insect biomass and 10per cent of all terrestrial animal biomass in the tropics.	Feeding groups of earthworms: Epigeic, endogeic and anecic; Ants are major predator of small invertebrates and their activities also reduce the abundance of other predators such as spiders and carabid beetles; termites have three nutritional categories viz. wood-feeders, soil humus feeders and fungus growers.	Consider as “ecosystem engineers”. Effect on soil structure through formation of biogenic structure and burrowing activities. For example: earthworm casts above- and belowground; termite nets. Plays significant roles on soil food web and ecosystem processes, such as nutrient cycling, SOM decomposition dynamics and effects on microbial and other microfaunal community structure etc. Ants move large volumes of soil, as much as earthworms do.

(Population density data adapted from Coleman and Wall, 2007).

Soil micro organism

Ecosystem functioning is governed directly by soil microbiota, although they are affected by the activities of soil animals living alongside (Schimel, 2007). The functional processes such as nutrient cycling, residue decomposition, soil structure formation, and plant interactions, both positive and negative are regulated by soil microbiota communities and thereby, they regulate the productivity and health of agricultural systems (Kennedy and Papendick, 1995; Pankhurst *et al.,* 1996; Harris, 2009). Recent advance findings on soil biochemistry, microbial eco-physiology and biogeochemical cycles have strongly indicated that soil organisms especially microbiota perform the biogeochemical transformations that determine ecosystem C and N cycling rates (Paul, 2007). For example, dynamics of C and N are known to interact closely during decomposition due to simultaneous assimilation of C and N by the heterotrophic soil microbiota (Sall *et al.*, 2007). Therefore, it is necessary to determine microbiota diversity and quantification of variability in the microbiota community composition to better understand their functional role on regional and landscape level differences in biogeochemical cycling.

Exciting achievements on molecular microbial ecology during the past two decades made it clear that the most important gene for prokaryote phylogeny is the 16S ribosomal RNA (rRNA) gene (length of the gene approximate 1500 bases), which is present in all cells. This gene possesses regions in which sequences are conserved, facilitating sequence alignment for homology between organisms, and the variable and hypervariable regions, which enable discrimination between organisms. Woese *et al.* (1990) divided prokaryotes into two major domains, the Archaea and the Bacteria using the 16S rRNA gene analysis approach. This discovery is regarded as one of the most important events in the history of microbial ecology. Analysis of 16S rRNA sequences those retrieved from various natural habitats led to identification of several phylogentic groups within the domain bacteria (Table 2).

Table 2: 16S rRNA based phylogenetic groups of bacteria, their habitat and metabolism

Bacterial group	**Environmental origin**	**Metabolism**
Aquificales	Extreme environments (hot, sulphur pools, thermal vents)	Microaerophilic, chemolithotrophic, can oxidise hydrogen and reduced sulfur
Thermodesulfobacterium	Thermal vents	Sulfate reducers, autotrophic or organotrophic, anaerobic
Thermotogales	Hot vents and springs (moderate pH and salinity)	Sulfur reducers, organotrophic, some produce hydrogen
Coprothermobacter	Anaerobic digesters, cattle manure	Heterotrophic, methanogenic, sulfate reduction
Dictyoglomus	Hot environments	Chemoorganotrophic
Green non-sulfur bacteria and relatives	Wide range but few cultured	Anoxygenic photosynthesis, organotrophic
Actinobacteria (high G+C gram-positives, including actinomycetes)	Soil, some are pathogens	Aerobic, heterotrophic-major role in decomposition
Planctomycetes	Soil and water	Obligate aerobes
Chlamydia	Intracellular parasites	Heterotrophic
Verrucomicrobia	Freshwater and soil; few cultured	Heterotrophic
Nitrospira	Soil and aquatic environments	Autotrophic nitrite oxidizers, facultative heterotrophs
Acidobacterium	Wide range of environments, including soil	Acidophilic or anaerobic (very few cultured)
Synergistes	Anaerobic environments	Anaerobic

	(termite guts, soil, anaerobic digesters)	
Flexistipes	Animals	
Cyanobacteria	Aquatic but found in soil	Oxygenic, photosynthetic, some fix N_2
Firmicutes (Low G+C gram-positive)	Soil, water, some are pathogens	Aerobic or anaerobic (rarely photosynthetic)
Fibrobacter		
Green sulphur bacteria	Anaerobic and sulphur containing muds, fresh water and marine	Photosynthetic, anaerobic, autotrophic or heterotrophs
Bacteroides-Cytophaga-Flexibacter group	Wide variety, including soil, dung, decaying organic matter	Aerobic, microaerophilic or facultatively anaerobic, organotrophs, some strict anaerobes (*Bacteroides*)
T hermus/ Deinococcus	High-temperature environments, nuclear waste	
Spirochetes and relatives (Spirochetes and leptospira)	Wide range	Chemoheterotrophic
Fusobacteria	Pathogens	Anaerobic
Proteobacteria	"Classical" gram-negative bacteria	Hetertrophic, chemolithotrophic, chemophototrophic, anaerobic (most) or aerobic, some photosysnthetic, some fix N_2
Adapted from Killham and Prosser (2007)		

Biodiversity and scale of investigations to study function and abundance of soil biota

The idea of biodiversity values, a concept which had previously restricted to the limited aesthetic and touristic aspects of wildlife. In the year 1992, the International Convention on Biodiversity in Rio de Janeiro focused on "the forgotten environmental problem" of biodiversity erosion and made the first clear reference to the values of living species. Biodiversity was defined as "the variability among living organisms from all sources including terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are a part; this includes diversity within and between species, and of ecosystems" (Heywood and Baste, 1995). Thus, biodiversity values refer to direct or indirect, economic or non-economic interests, a given species or ecosystem may represent for human populations (Decaëns *et al.*, 2006). These values are generally split into intrinsic and instrumental (use) values. The instrumental values can divided into direct and indirect economic values. Obviously, each of these values carries different weights, and cannot be considered as being weighted equally in terms of justification for species or ecosystem conservation.

Adequate experimental design and sampling strategy are important considerations before starting any analysis in soil biology. Fine-scale approaches such as pico- and nanoscale investigations related to microbial diversity and microbial eco-physiology are used to reveal the structure and chemical composition of organic substances and microorganisms as well as to investigate the interactions between the biota and humic substances. These fine-scale approaches can identify soil organisms, unravel their relationships, determine their numbers, and be used to measure the rates of physiological processes. Such results gradually boost our understanding of chemical and biological processes and structures at larger scales. Microscale investigations refer to either on soil aggregates or on microhabitats characterised by high turnover of organic materials (e.g. the rhizosphere, drilosphere, and soil-litter interface). High-activity areas are heterogeneously distributed within the soil matrix. Biologically active hot-spots may make up less than 10per cent of the total soil volume, yet may represent more than 90per cent of the total biological activity (Beare *et al.*, 1995). Therefore, interpretation of data on the abundance and function of soil biota must include some physico-chemical and biological properties in the study sites (Table 3), such that up-scaling of data from microscale to the plot or regional scale can be done using the unified concepts in soil biology.

Table 3: Physical, chemical, and biological properties that help to interpret on the function and abundance of soil biota

Physical and chemical properties of soil		Biological properties of soil
Topography	Particle size and type	Plant cover and productivity
Parent material	CO_2 and O_2 status	Vegetation history
Soil type and soil pH	Bulk density	Abundance of soil animals
Moisture status	Temperature: range and variation	Microbial biomass and activity
Water infiltration	Rainfall: amount and distribution	Organic matter inputs and roots present
Adapted from Kendeler *et al.* (2007)		

Criteria for indicators of soil quality

Soil quality is an important component of sustainable agriculture, because a healthy, functioning soil is fundamental to sustainable crop and livestock production and a healthy environment. Soil quality does not depend just on the physical and chemical properties of soil, but it is very closely linked to the biological properties of soil. Many soil properties affect soil quality, and most are influenced by microbiological processes. Soil properties affected by the size and composition of the microbial biomass include water holding capacity, infiltration rate, crusting, erodibility, aggregate stability, susceptibility to compaction, nutrient cycling, available nitrogen, nutrient capacity, and soil organic matter content.

Indicators of soil quality must fulfil several criteria and these criteria are relate mainly to: (i) their utility in defining ecosystem processes; (ii) their ability to integrate physical, chemical and biological parameters; and (iii) their sensitivity to management and climatic variations (Doran, 2000). These criteria apply to soil organisms, which are thus useful indicators of sustainable land management. Ideally, soil organisms and ecological indicators should be:

1. Sensitive to variations in management;
2. Well correlated with beneficial soil functions;

3. Useful for elucidating ecosystem processes;
4. Comprehensible and useful to land managers;
5. Easy and inexpensive to measure.

Management of soil biota community and their activity

At the core of ecosystem health is soil quality, defined as "the capacity of a soil to function within ecosystem boundaries to sustain biological productivity, maintain environmental quality, and promote plant and animal health". The major issues of soil health are:

1. productivity – ability of soil to enhance plant and biological productivity;
2. environmental quality – the ability of soil to attenuate environmental contaminants, pathogens, and offsite damage;
3. plant and animal health – the interrelationship between soil quality and plant, animal, and human health.

A major attribute of healthy soil is the level of soil organic matter (SOM), which controls many of the physical and chemical parameters of soil. For example, SOM can influence bulk density, water holding capacity and retention, and soil temperature, and buffer the soil pH and electrical conductivity and can influence biological activity. However, SOM can be rapidly lost through oxidation and by wind and water erosion. Most of the 1965 million hectares (Mha) of degraded land worldwide suffers from low organic matter content. Thus, single most overriding factor for increasing soil quality and ecosystem health is increasing the level of SOM through apt agricultural management practices. On a global basis, agricultural practices cause significant and extensive soil disturbance and soil contamination, with concomitant contributions to the loss of biodiversity (Wood *et al*., 2000). More sustainable agricultural practices, including organic management and reduced tillage, enhance soil diversity and fertility (Mäder *et al*., 2002); and soil dwelling animals are, in general, more abundant in organic than in conventional farming systems (Bengtsson *et al*., 2005). Reduction in soil disturbance can stimulate soil microbial biomass and improve its metabolic efficiency, resulting in better soil quality, which in turn, can increase crop productivity. Some of the important alternative agricultural management approaches currently practicing throughout the world for promoting biological activities in soils are discussed here:

Organic agriculture

Organic agriculture aims to integrate human, environmental, and economically sustainable production system. The term organic does not necessarily refer to the types of inputs to the system but more to the holistic interactions of the plants, soil, animals and humans in the system. Organic agriculture management promotes maintaining SOM levels for soil fertility, providing plant nutrients through microbial decomposition of organic materials and biofertilizers, and control of pests, disease, and weeds with crop rotations, natural control agents (biopesticides), and pest-resistant plant varieties. Currently, crop and soil scientists from different parts of world are working together to develop crop variety, which can efficiently uptake of organic forms of nutrients from soil. Since, organic systems are often low nutrient systems, with respect to N, P, and K, the cycling of SOM by microorganisms is important because plants rely on nutrients solely from SOM.

Biodynamic agriculture

Biodynamic farming is a system of organic farming that includes crop diversification, use of green manures, and use of compost and manures improved by biodynamic preparations. The biodynamic preparations consist of selected plant and animal substances that undergo fermentation for a year or so and then are used to enhance compost and manure used in the farming operation. These preparations can also be applied directly to soil as a spray to enhance biological activity. The use of biodynamic preparations is the main difference between biodynamic farming and traditional organic agriculture. Part of the biodynamic philosophy is that a healthy, active soil microbial population will enhance plant-microbe interactions and nutrient cycling and reduce soil pathogens.

Integrated plant nutrient supply (IPNS) system

The basic concept of IPNS is the promotion and maintenance of soil fertility for sustaining crop productivity through optimizing all possible resources (both renewable and non-renewable), such as organic, inorganic and biological components in an integrated manner appropriate to each farming situation in its ecological, soil and economic possibilities. The principal aim of IPNS is efficient and judicious use of all major resources of plant nutrients in an integrated manner, so as to get maximum yield without any deleterious effects on physicochemical and biological properties of soil. Major components of IPNS are FYM/compost, green manures, crop residues/recyclable wastes, synthetic fertilizers, biofertilizers, biological control agents, biopesticides.

The performance of IPNS practice in terms of nutrient uptake and balance, soil physical, chemical and biological properties of rice-legume-rice (RLR) rotation in acidic rice soil under rainfed production system in the northeastern alluvial plains of Assam was evaluated recently by Thakuria *et al.* (2009). The IPNS formulation was comprised of *Azospirillum* (Azo), *Rhizobium* (Rh), phosphate solubilizing bacteria (PSB) with phosphate rock (PR), compost and muriate of potash (MOP) and recycled crop residues. The IPNS practice favoured higher cumulative grain yields of crops (by 7-16per cent per RLR rotation), increased uptake of N and P by crops compared to that in compost alone or Urea:SSP:MOP plots. Apparent loss of soil total N and P at 0-15 cm soil depth was minimum and apparent N gain at 15-30 cm depth was maximum in the IPNS plots. The IPNS practice improved Zn nutrition of crops, minimized loss and maximized gain of total organic C content in soil at 0-15 cm and 15-30 cm depth, respectively and also improved water stable aggregation and distribution of soil aggregates in 2000-250 μm and 250-53 μm classes. Authors suggested that fungal/bacterial biomass-C ratio seems to be more reliable indicator of C and N dynamics in acidic soils than total microbial biomass-C. The IPNS plots haboured higher numbers of earthworms' casts compared to Urea:SSP:MOP alone. This study revealed that changes in bacterial community compositions in soils due to differences in nutrient management regimes, and these changes were seen to occur according to the states of C and N dynamics in acidic soil under RLR rotation. Likewise, Ouédraogo *et al.* (2007) also proposed that the effect of soil fauna on soil carbon build-up and crop performance can be optimised by using high quality organic matter or supplementing low quality organic matter with inorganic nitrogen in semi-arid West Africa.

No or reduced tillage

The practice of no/ or reduced tillage counteract the destructive effects of conventional/ or intensive tillage systems. In general, total soil C and N increased in the no-till soils.

Converting fields under conventional tillage to a less disturbed state significantly increased the numbers of fungi and bacteria and dehydrogenase enzyme activity in soils. Nutrient cycling as measured as potentially mineralizable N increased by 35per cent in the no-till system (Doran, 1980). Bacterial-feeding nematodes, fungivore/ saprophyte mites, and predatory nematodes and mites were more abundant in organic-no till plots, supporting a soil food web with abundant organisms at higher trophic levels (Sánchez-Moreno *et al.,* 2009). They also observed that cover crops, crop residues and composts as surface mulches, together with lack of physical disturbance, were sufficient to support and maintain this structure. Conventional farming systems, with high C/N crop residues and much lower organic matter input supported fungal-mediated food webs mainly composed of fungal feeding nematodes and algivorous mites. Hungria *et al.* (2009) studies the impact of soil-tillage systems (no-tillage, conventional tillage, and no-tillage using a field cultivator every 3 years) on soil biological properties. Major differences in biological properties were attributed to differences in tillage practices; on average no-till soil had higher content of total carbon (19per cent), total nitrogen (21per cent), microbial biomass-C (74per cent), and microbial biomass-N (142per cent) over that in conventional tillage. Basal respiration of soil responded promptly to soil disturbance. The authors suggested that the turnover of C and N in microbial communities in tropical soils is rapid, reinforcing the need to minimize soil disturbance and to balance inputs of N and C.

Soil biota as bio-indicator of soil health

Members of the different trophic levels of the soil food-web network have close relationships with their food sources and with other soil animals that may constitute their prey or their predators (Ingham *et al.*, 1985; Yeates and Wardle, 1996; Fu *et al.*, 2005). For example, nematodes exhibit complex and numerous interactions with other soil organisms. In the recent years, soil biologists paid more attentions towards development of soil food web indices (Ferris *et al.*, 2001). Soil food web index is developed based on available knowledge about soil animals' relationships and the food web functions of component taxa. Some soil biota indices viz. the Enrichment Index (EI) and the Channel Index (CI) are indicators of organic matter decomposition pathways. The EI, based on the prevalence of fast-growing enrichment opportunistic nematodes, is an indicator of rapid, bacteria-mediated, organic matter decomposition (high EI) process, while the CI, based on the prevalence of fungal-feeding in relation to other microbivorous nematodes, is an indicator of slower organic matter decomposition mediated by fungi (high CI). The Basal Index (BI) is derived from the abundance of persistent microbial-feeding nematodes; high BI values indicate short and depleted soil food webs. The Structure Index (SI) weights the prevalence of omnivore and predatory nematodes in the soil food web as an indicator of long and complex soil food webs with high connectance and numerous trophic links. Soil food web indices have been used to infer soil food web responses to soil disturbance (Okada *et al.*, 2004). Conventional-standard tillage treatments had high abundances of fungal- and plant-feeding nematodes and algivorous mites, associated with high values of the Basal and Channel Index. Therefore, soil biota-based soil food web indices are useful indicators to predict soil functional processes.

Exploiting soil biota activities in hill agriculture of the Northeastern region of India

The Northeastern region of India falls under the Indo-Burma mega-biodiversity hot spot and the region habours enormous diversity of native flora and fauna, and also consider as nature's gene centre for several economically important plant species (Bujarbaruah, 2004). Soil biota biodiversity of this region is yet to be explored. At this moment, we do not have data relating to the contribution of soil biota on sustainability of managed systems in the Northeastern region of India. There are opportunities on "How to exploit soil biota activities to maintain soil sustainability in hill agriculture". These are:

1. Several traditional farming systems existed in the northeastern region of India are organic in nature by default except those which are practiced in valley lands. The available 37 million tones (MT) of dung from livestock population, 9 MT crop residues, vast resources of weed biomass, and forest litter from 171.08 lakh hectare forest lands can be utilized for converting into compost/FYM (Bujarbaruah, 2004). Application of these organic matter inputs into soil will enhance soil biota activity and hence, it helps improving soil fertility status.
2. Mechanised agriculture in hill slope is not commonly practiced. Reduced tillage is a common practice in hill agriculture. Growing of cover crops, and residue incorporation and reduced tillage is a common recommended practice in hill agriculture. Implementation of this concept will certainly help in build up of soil biota community as well as enhancement of their activities.
3. Promotion of mixed cropping will certainly enhance soil microbiota and faunal bio-diversity and their activities.
4. Conversion of inorganic input intensive farming practices to systematic organic input intensive farming practices will lead to build up of soil biota biodiversity.

Research priorities

It has been perceived that there is a need to establish long-term trials on representative benchmark sites to evaluate the effects of agricultural management practices on soil biodiversity and ecosystem function at various temporal and spatial scales. Benchmark sites should represent the dominant soil types, major agro-ecological regions including dominant cropping systems. Resulting data on abundances of soil biota will be valuable for identifying the temporal and spatial scales at which biodiversity change most significantly affects ecosystem function. There is also a need for systematic studies which describes relationships between the composition or structure of decomposer soil biota communities and the type and intensity of agricultural management employed. Inventories of decomposer biota in undisturbed natural habitats and adjacent management systems including arable cropping, pastoral lands and forest tree plantations should be undertaken as a first measure. Attention must be given to characterising all dominant groups including microflora and fauna (beyond those assumed to be key functional groups), at different levels of taxonomic resolution.

Results of these descriptive studies should be combined with experiments focused on specific aspects of agricultural management (tillage type and intensity, fertilizer rate and form, crop residue management, crop rotation, etc.) as they influence the diversity-function relationships. This information will be useful in devising agricultural management practices which promote specific functions through management of soil biota. Understanding the links between plant diversity and decomposer biodiversity will be an important step towards exploiting maximum benefits of soil biota on achieving soil sustainability.

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3.3 Problem and Prospects of Tuber Crops in North Eastern Region

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The North-Eastern region comprising of states of Arunachal Pradesh, Assam, Manipur , Meghalaya , Mizoram, Nagaland , Sikkim and Tripura has tremendous potential for cultivation of tuber crops like sweet potato, colocasia, cassava (tapioca), dioscorea (yam), *amophophallus* (Elephant foot yam) etc. With diverse agroclimatic condition, varied soil and high rainfall with wide regional variation, this region is highly suitable for cultivation of tuber crops. The tuber crops provide food and nutritional security to many people of this region. In fact, the tribals of this region are already in the habit of growing these crops, while tapioca, colocasia and dioscorea are common crops grown in the jhum or shifting cultivation fields. Sweet potato and colocasia are grown considerably not only in the hills but also in the plains of Assam and Tripura. In dioscorea, both *Dioscorea alata* and *D. esculenta* are grown mostly in the backyards and the tubers are even collected from the forests. Similarly, different types of *Colocasia, Xanthosoma, Amorphophallus* are found to grow both in nature and in kitchen gardens of the natives. Most of the tuber crops like sweet potato, colocasia, tapioca, dioscorea are grown as mixed crop with ginger, chilli, brinjal, beans etc. However, sweet potato and colocasia are grown as pure crop in some part of the region. Since these crops do not require much attention or care and no serious disease or insect damages are observed, they get preference as risk aversion crops in this difficult region.

Importance of tuber crops

Tuber crops are mainly consumed as food but quite a sizeable portion is also utilised in industries for producing various other items. Tuber crops form a major part of animal feed in our country. Various items like sago, dextrose, glucose, alcohol etc. are other products made out of cassava in India and other countries. Tamil Nadu utilizes over 75per cent of its total produce of cassava in the production of starch and sago. Cassava chips are utilised as cattle feed and poultry feed. However in north eastern region these tuber crops are consumed as food after boiling/cooking by human and as feed for animals. In this region due to lack of processing units, no value addition or processing is being done.

In colocasia, leaves, young shoots and corms are used for consumption. The root and leaves have a particular flavour that can give an acrid or sharp taste because of calcium oxalate crystals. Fortunately, cooking/drying reduces the acridity. The main cultivars are relatively free from calcium oxalate crystals. Taro has a good range of vitamins and minerals. The corm may be boiled, baked, fried or cooked in curries. The leaves are generally not eaten but traditional communities cook these like any green vegetable.

In sweet potato, the tuberous roots are consumed which are sweet in taste and rich in starch. The tuberous roots or the tubers are important mostly as food item. During storage a part of starch gets converted to sugar. During cooking, due to hydrolysis of starch, sweetness increases. In the N.E. region, sweet potato is consumed mostly after boiling and backing in fire. The sweet potato vines can serve as a nutritive and palatable feed for cattle. The unmarketable and poorly developed tubers can also be utilised as animal feed. For this, the tubers may be chipped and dried and then mixed in the feed.

Cassava is principaly used as a food source. Cassava is also used as on-farm feed source. In animal feed industry cassava is one of the most abundatly used feed ingradient in place of cereal grain.A sizeable portion goes into industrial uses or is processed and exported.

Root and tuber crops are also receiving attention because they can be grown on marginal or difficult land. Due to growing population, presure on land has increased and farmers have to move onto marginal lands with difficult soil, weather or other environmental conditions. Cassava can tolerate drought and high level of aluminum in soils. Taro has always received interest because it can be grown in hydromorphic soils or under flooded conditions.

Uses

Human food

The tuber crops like sweet potato, colocasia, yam, cassava, *amorphophallus* etc. are rich source of carbohydrate but they are poor in protein content. They are also rich in mineral and vitamins.

The yellow-orange flesh sweet potato varieties can provide vitamins A and C. However, dioscorea is comparatively rich in protein and amino acids.

Animal feed

Nearly half of the sweet potatoes produced in Asia are used for animal feed. The vines have a lower carbohydrate content but higher in fibre and protein and their principal nutritive value is as a source of vitamins and protein. The content of trypsin inhibitors of the raw sweet potato roots could decrease the protein digestibility in mixed feed. The vines will not produce this effect because they do not contain them in great quantities. This trypsin inhibitor could be destroyed or lowered by preheating raw sweet potato roots. The sweet potato vines can serve as a nutritive and palatable feed for cattle. The unmarketable and poorly developed tubers can also be utilised in animal feed. Cassava chips are utilised as cattle feed and poultry feed. In animal feed industry cassava is one of the most abundatly used feed ingradient in place of cereal grain.

In north eastern region sweet potato and cassava tubers , colocasia corms and petioles are chopped boiled and fed to the pig. However, sweet potato vines and cassava leaves are also fed to the cattles and pig.

Industrial

Sweet potatoes are used in industrial processes to make alcohol and processed products such as noodles, candy, desserts, and flour. A sizeable portion of cassava goes into industrial uses or is processed and exported. Various items like sago, dextrose, glucose, alcohol etc. are other products made out of cassava in India and other countries. Tamil Nadu utilizes over 75 per cent of its total produce of cassava in the production of starch and sago. However, in north eastern region due to lack of processing industries such products are not common.

Medicinal

Amorphophallus campanulatus (elephant-foot yam) is used as a food as well as a medicine. It will not create any gastrointestinal problems. Its various therapeutical application can be seen in diseases like piles, dysentry, gas trouble etc. The cultivated types yam (*dioscorea*) are mainly grown for edible roots however, certain wild types like *D. floribunda, D. deltoidea* are grown for their medicinal value. They are good source of corticosteroids e.g. sapogenins and oral contraceptives. The steroidal hormone, cortisone used in rheumatic illness and ophthalmic problems is derived from *D. deltoidea*. The nutritive values of tuber crops are given in Table 1.

Table 1. Nutritive value of tuber crops

Nutrients	Amorphophallus	Colocasia	Dioscorea	Sweet potato	Xanthosoma	Cassava
Moisture (per cent)	74.4	70.3	67.6	72.5	65.2	65.5
Fat (per cent)	0.1	0.1	0.3	-	0.1	0.2
Protein (per cent)	2.0	3.2	2.1	2.2	1.2	2.5
Starch (per	16.6	21.2	19.3	21	27.6	32.4

cent)						
Energy (Kcal)	75.0	97.0	87.0	-	116.0	135
Vitamin B_1 (mg)	0.06	0.09	0.05	-	0.03	0.04
Vitamin B_2 (mg)	0.07	0.03	0.03	-	0.03	0.05
Vitamin C* (mg)	0.0	0.0	13.0	-	13.6	34
β carotene (μg)	260.2	24.0	28.0	-	54.6	-
Calcium (mg)	12.7	31.0	6.2	30	5.9	26
Phosphorus (mg)	67.0	68.0	33.0	49	53.0	32
Magnesium (mg)	47.0	109.0	25.0	24	26.0	-
Sodium (mg)	4.1	1.6	3.5	13	6.6	2
Potasium (mg)	622	356	351	373	530	39.4
Sulphur (mg)	11.8	7.4	17.1	29	7.9	-
Iron (mg)	0.51	0.63	0.69	0.8	0.47	0.9
Copper (mg)	0.18	0.20	0.16	-	0.19	-
Zinc (mg)	1.05	3.6	0.43	-	0.52	-
Manganese (mg)	0.31	0.34	0.07	-	0.17	-
Boron (mg)	0.07	0.09	0.08	-	0.09	-

Source: Tropical Tuber Crops edited by Balagopalan *et. al* (1999)

* Values are expressed in mg/100 g fresh weight

Diversity of tuber crops in NEH region

The north eastern region is considered to be the richest reservoir of genetic variability of tuber crops i.e. colocasia, *dioscorea* etc. These crops are an integral part of dietary system of tribals of the region and are grown abundantly in their **jhum** land or kitchen garden as mixed cropping. The considerable diversity has been reported in several states like Arunachal Pradesh, Assam, Manipur, Meghalaya, Mizoram, Nagaland and Tripura.

Alocasia occurs in wild in humid tracts being more common. Much diversity occurs in shoot/leaf thickness, shape, colour & size of corm. Local types have more raphides-calcium oxalate content, good cooking quality and better taste. However, in colocasia and xanthosoma wild types vary in leaf size, petiole lengths etc. and possess both green and pigmented forms. More variability in respect of Kalla Kachu, Ban kachu, Ahu-kachu, Dukh kachu, Mukhi, Panch mukhi, Man kachu, Jal kachu, etc.

In *dioscorea* about 28 species and 25 varieties has been reported from NE region mainly in the Garo hills (Sharma and Hore, 1995). The major species found in the region are *D. alata, D. esculenta, D. bulbifera, D. pentaphylla, D. hamiltonii, D. cylindrical, D. sativa, D. oppositifolia* and *D. deltoidea and D. floribunda.* Dioscorea is the crop which is mainly grown by tribal farmers in their **jhum** field.

In sweet potato mainly two types are available in the region i.e. red and white. In tapioca both sweet types and bitter are only available. Tapioca and sweet potato have been introduced long back in this region and they are well acclimatized.

Status of tuber crops in NE Region

The north eastern region has tremendous potential for cultivation of tuber crops. The colocasia, alocasia, xanthosoma and *amorphophallus* are common aroids grown in the region. Total area under sweet potato is 17 thousand hectare with a production of 70.7 thousand tonnes and productivity of 4.16 t/ha. Assam has highest area (9.4 thousand ha.) under sweet potato with an average production of 36.2 thousand tones where as Meghalaya has 5.2 thousand hectare area with total production of 17 thousand tones (Table 2). The total area under cassava in whole north eastern region is 7.8 thousand ha with total production of 55.6 thousand tones and productivity is 7.13 t/ha against the national productivity of 25.28 t/ha.. In cassava maximum area is under Meghalaya (4.0 thousand hectare) followed by Assam (2.5 thousand ha). In case of colocasia the area under Mizoram is 0.30 thousand ha with total production of 1.85 thousand tonnes and productivity is 6.11 t/ha. in Nagaland the total area under colocasia is 2.84 thousand ha with total production of 24.95 thousand tonnes and productivity is 8.8 t/ha. The area, production and productivity in other north eastern states is not available because the cultivation of these tuber crops is limited to kitchen/backyard in mixed cropping system.

Table 2. State wise area, production and productivity of tuber crops in north eastern region

State		Sweet potato	Colocasia	Tapioca
Assam	A	9.4	-	2.5
	P	32.6	-	11.7
	Y	3.47	-	4.68
Meghalaya	A	5.22	-	4.11
	P	17.39	-	21.88
	Y	3.4	-	5.3
Mizoram	A	0.27	0.30	0.11
	P	1.6	1.85	0.96
	Y	5.92	6.11	8.64
Nagaland	A	0.36	2.84	2.84
	P	5.76	24.95	14.22
	Y	16.0	8.8	5.01
Tripura	A	1.3	-	0.5
	P	11.5	-	2.2
	Y	8.85	-	4.4
NE Region	A	16.55	-	10.06
	P	68.85	-	50.96
	Y	4.16	-	5.07
India	A	120.6	-	264.3
	P	1048.1	-	6681.9

	Y	8.69	-	25.28

A= Area in thousand hectare, P= Production in thousand tonne, Y= Yield in t/ha

In case of colocasia Mukhi and Panch mukhi are commonly grown in Assam and Garo hills of Meghalaya. Man kachu and Jal kach types of *Alocasia* are grown in Assam. Apart from this other local types are also cultivated in different areas available with farmers. In *Amorphophallus* local types and Gajendra are generally grown but at limited scale. In sweet potato mostly white and red skinned local types are cultivated in most of the states. Local types of cassava i.e. sweet and bitter types are available but sweet types are normally grown by farmers of Meghalaya, Mizoram, Nagaland, Tripura and Manipur. In yam generally local types are grown in the **jhum** field and kitchen garden. Varieties identified/recommended for different north eastern states have been presented in Table 3.

Table 3. Tuber crop varieties identified/recommended for different north eastern states

Sweet potato (*Ipomoea batatas*)

Place	Variety	Yield (t/ha)
Basar, Arunachal Pradesh	71-OP-219 71-OP-217 H-633	24.34 20.86 19.00
Barapani, Meghalaya	Sree Bhadra Sonipat-2 H-42	37.50 35.80 35.20
Tripura	Cross-4 V-35	25.30 23.90

Colocasia (*Colocasia esculenta*)

Place	Variety	Yield (t/ha)
Basar, Arunachal Pradesh	Kandyam C	32.70
Barapani, Meghalaya	ML-1 ML-9 Kadina Local	20.5 20.0 20.0
Mizoram	MZ-2 MZ-3	- -
Manipur	MR-5	-
Assam	AS-2	-
Tripura	293 TR Local	23.2 21.6

Cassava (*Manihot esculenta*)

Place	Variety	Yield (t/ha)
Barapani, Meghalaya	H-1687 H-312	30.0 34.0
Basar, Arunachal Pradesh	H-312 H-2304	26.8 24.7

Manipur	H-1687 H-165	- -
Nagaland	H-1687 Local	27.5 25.1
Tripura	H-1687 H-3641 H-43	41.0 39.5 36.0

Prospect in North eastern region

Strength

- Soil and climatic conditions are highly favourable
- Rich biodiversity of tuber crops in the region
- Tuber crops are already integral part of food of tribals of the region
- These crops requiers less care
- Can be grown on marginal land

Major weaknesses or problems of tuber crops

Vegetative propagation is probably the most important single limitation because:

- High cost of planting materials
- It requires more labours for handling
- Digging on hill slopes causes heavy soil erosion
- It can not be stored for a longer period
- Lack of processing and value addition
- Tuber crops are generally consumed by tribals or poor people

Constraints

Production constraints

- Germplasm conservation for root and tuber crops is difficult because of heavy dependence on vegetative propagation and non-availability of planting materials of improved varieties
- In case of colocasia disease like Phytophthora blight and corm borer insect and in sweet potato, weevil and rat

Constraints in human diet

- Low protein content in most of the tuber crops
- Presence of cynogenic glycosides in cassava, which on hydrilysis yields HCN
- Presence of calcium oxalate in colocasia and amorphophallus
- Presence of trypsin inhibitor in sweet potato, which reduces the protein digestibility in mixed feed

Processing constraints

- No industry for making sago, alcohol, chips, flour, etc. of cassava in NE Region
- No industry for starch extraction in tuber crops in NE Region

Thrust area

- Identification of short duration, high yielding varieties suitable for inter cropping
- Identification of varieties having high carotene content in sweet potato etc.
- Identification of varieties having low calcium oxalate content in colocasia, *Amorphophallus* and low HCN content in cassava
- Identification of yam varieties with high diosgenin content for industrial uses
- Identification of colocasia varieties resistant/tolerant to *phytophthora* blight
- There is need to establish processing unit for chips, flour etc. in cassava and extraction of starch from cassava, diosgenin from yam
- Standardization of cassava, sweet potato, as feed concentrate along with good supplements. There is also need to prepare, silo from leaves, vines/stem of these tuber crops
- Mixed/inter cropping of tuber crops with legume vegetable like French been (pole type) and cowpea should be advocated
- Need more research work on standardization of package of practices for cultivation in different cropping systems
- There is need for standardization of post harvest handling and processing

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3.4 Technological Options for Improving Nutrient and Water Use Efficiency

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Introduction of high yielding varieties (HYVs) coupled with expansion of irrigation facilities, and increased use of chemical fertilizers and other agro-chemicals have brought about spectacular increases in the yield of crops, particularly rice and wheat. About half of the total increase in food grain era has been attributed to the use of fertilizers and more than one-third of this increase is due to N fertilizes alone. The country has still about 65 per cent area under rainfed, and only about 35 per cent area under under irrigation. Low water use efficiency (WUE) has been the concern as the availability of water for agriculture is decreasing day by day. For saving and effective utilization of this vital resource, proper management strategies involving agro-techniques should be developed.

Inefficient inputs/fertilizer use is a key factor pushing the cost of cultivation and pulling down the profitability in farming. Total factor productivity (TFP) is used as an important measure to evaluate the performance of a production system and its declining trend is a serious issue. A fatigue in the ratio between the inputs and output is indicative of TFP deceleration with concomitant unsustainability of crop productivity. The challenge is how to increase food production in the country by around 60 per cent over next two decades without jeopardizing the soil and water resources which are already under great stress. With increased demand for cereals, pulses and cooking oil, the productivity per hectare or unit input is decreasing. Thus the risks of degradation of natural resources (soil and water) are increasing because of extractive farming practices (Conklin Jr. and Stilwel, 2007).

One of the critical constraints to higher crop productivity is the low efficiency of applied nutrients especially N and P. Nitrogen use efficiency (NUE) is often expressed in terms of agronomic efficiency (kg grain/kg N applied), physiological efficiency (kg grain/kg N taken by crop), chemical efficiency or apparent recovery (per cent of applied N taken by the crop), efficiency ratio (kg grain/kg N uptake, without considering unfertilized control), and also sometimes as partial factor productivity (kg grain/kg N applied without considering unfertilized control). The NUE is thus a function of soil to supply adequate amount of N, and ability of plant to acquire, transport in root and shoot, and to remobilize to others parts of the plant. Use efficiency of applied N as estimated by the difference in N uptake of the above-ground portions of N fertilized and unfertilized plots, and expressed as percentage of N fertilizer applied to the crop is only about 30-40 per cent. The P efficiency ranges from 20-40 per cent only. Hence, there is urgent need to increase nutrient use efficiency from the view point of costs and water quality concerns. The NUE in different countries are presented in Table 1.

Table 1. Nitrogen use efficiencies in different countries

Country	Year	NUE (kg/kg)	Change (per cent)	Rate of change (per cent per year)
USA	1980	42	-	-
	2000	57	+36	+ 1.6
UK	1981-85	36	-	-
	2001-02	44	+23	+1.1
Japan	1985	57	-	-
	2001	75	+32	+1.8
India	1970	60	-	-
	2004	20	-60	- 1.7

Source : Patil (2009).

Nutrient use efficiency

Nutrient use efficiency can be defined many ways, but the definition used most commonly by farmers and crop advisers is the crop output per unit of nutrient input. We are all interested in improving the efficiency with which we simultaneously accomplish all system level objectives: productivity, profitability, sustainability, and environmental protection.

There have also been genuine concerns over nutrient use efficiency, in general, and N use efficiency (NUE) in particular, for economic as well as environmental reasons. Worldwide, NUE for cereal production is as low as 33 per cent. The unaccounted 67 per cent represents an annual loss of N fertilizer worth up to Rs. 72,000 crores (NAAS 2005). The manufacture of nitrogenous fertilizers involves huge amounts of foreign exchange and consumes large quantities of nonrenewable energy resources such as naphtha, natural gas, coal etc. Poor utilization of fertilizer N by plants also adds to the pressure on these finite resources. Low NUE for crops implies higher costs to producers and consumers and, therefore, reduced competitiveness. Loss of N from soil plant system results from gaseous plant emission, nitrification, denitrification, surface runoff, volatilization and leaching beyond rooting 15 zones of crops. Many N recovery experiments conducted in the country on different crops have reported unaccounted losses of fertilizer N from 20 to 50 per cent depending on the local conditions. These losses of fertilizer N, or in general, the leakages of the reactive N from the agricultural systems into the environment are a cause of serious concern. Nitrogen on its own rarely increases yield much and for long; other nutrients, water, crop variety, weed and pest control must all be in proper proportion and available before fertilizer N can do its best. Harvesting high yields by applying only N is at best a short-lived phenomenon, as was shown in the early years of the green revolution. Clearly "N-driven systems" are not sustainable, as N becomes a 'shovel' to mine the soil of other nutrients, with the result that soils initially well supplied in other nutrients become deficient in them and productivity declines. Researchers have shown that the production practices that have resulted in increased N use efficiency relative to conventional or standard practices are those that will counter conditions or environments that contribute to N loss from soil-plant systems. The challenge is to make such modern farming systems accessible and affordable to the farmers, who are constantly under pressure to cut input costs (NAAS 2005).

Nitrogen is often the most limiting nutrient in agro-ecosystems and is therefore applied in the highest quantities. According to FAO (2001), about 82 million tonns of nitrogen fertilizer were applied in 2001 globally. Of that 60 per cent was used for cereal production. Raun and Johnson (1999) estimated world-wide nitrogen efficiency (NUE) for cereals production to be 33 per cent meaning that in 2001 alone, approximately 33 million tons of N fertilizer was lost.
The cause for low NUE and declining response to N fertilizers can be grouped as follows (NAAS 2005)

1. Nutrient Supply and Soil Fertility

- Susceptibility of N fertilizers to losses by various mechanisms.
- Imbalanced use fertilizers.
- Poor management for secondary and micronutrients, especially S, Zn, Mn, Fe and B.
- Use of high analysis fertilizers like urea and diammonium phosphate (DAP) and inadequate addition of organic manures.
- Inappropriate rate, time and method of application.

- Low status of soil organic carbon and soil degradation due to high salinity, sodicity, acidity, waterlogging and having adverse effect on below-ground biodiversity, especially of agriculturally-important micro-organisms.

2. Agronomic Practices

- Delayed sowings/plantings.
- Low seed rate resulting in poor crop stands.
- Poor weed management.
- Inefficient irrigation and rainwater management.
- Large scale monoculture and non-inclusion of legumes in cropping systems.
- Lack of consideration of previous cropping in the same field.
- Lack of capturing water x nitrogen synergistic interaction.
- Inadequate plant protection.
- Non-availability of seeds of HYVs at affordable price and at the appropriate time.
- Lack of more efficient N using genotypes.

The suggested approaches to minimize N losses and increase use efficiency include the following option (Roy and Pederson 1992):

- Identification of the most suitable fertilizer material.
- Manipulation of the application techniques including split application and placement.
- Manipulation of particle size, use of coating materials and other chemicals.
- Judicious and economical application of fertilizers for synergistic interactions.
- Application of organic sources along with mineral fertilizers.
- Efficient agronomic management practices such as tillage, irrigation, mulching, weed control, plant population and use of varieties with higher NUE.

Efficient input use can be achieved by assessment of available inputs and conservation against possible losses, integrated use of inputs in a synergistic manner, optimal allocation of inputs among the competing demands to achieve maximum return, maximizing input use efficiency by developing suitable site specific technologies.

Efficient nutrient management

Nutrient plays a key role in increasing agricultural production through intensive cropping. Sustainable agriculture can be achieved by efficient utilization of this costly input. Nutrient use efficiency can be improved by checking the path ways of nutrient losses from soil-plant system, making integrated se of nutrients from all possible sources, optimal allocation of nutrients to cops and maximizing the utilization of applied and native nutrients by the crops.

Checking the pathways of nutrient losses

Nutrient present in soil and added through fertilizers and manures are lost by gaseous loss, leaching loss, runoff/erosion losses and fixation in soil. Efficient nutrient management demands understanding the pathways of nutrient losses and developing technologies to minimize these losses.

Reducing gaseous loss

Part of the applied N is lost from soil by volatilization of ammonia and part of the nitrogen is lost as N_2O and N_2 gas by denitrification. Volatilization loss of ammonia can be minimized by mixing of nitrogen fertilizers in soil rather than broadcasting on soil surface, deep placement of urea super granules (USG) in puddle rice field, using urease inhibitors like thiourea, methyl urea, caprylohydroxamic acid, phenyl phosphorodiamidate (PPD), ammonium thiosulphate etc. and adding inorganic salts of Ca, Mg or K with urea. Some coated material like sulphur coated urea (SCU), gypsum coated urea (GCU), plastic coated urea (PCU), mud ball urea and synthetic slow release urea based fertilizers viz., isobutylidene diurea (IBDU) and crotobylidene diurea (CDU) etc. may be used to retard the rate of urea hydrolysis and thereby, reducing ammonia volatilization.

Nitrous oxide (N_2O) is mainly produced by denitrification of NO_3-under anaerobic condition, as in lowland rice fields. Nitrous oxide is one of the greenhouse gases that are believed to be forcing global climate change. Dentrification loss can be minimized by avoiding the use of NO_3^{-}form of nitrogenous fertilizer (e.g. calcium ammonium nitrate, potassium nitrate etc.) in rice and use of nitrification inhibitors viz., Dicyandiamide (DCD), N-serve (2-Chloro, 6-Chloro methyl pyridine), AM (2-Amino, 4-Chloro, 6-methyl pyrimidine), coated calcium carbide (CCC), neem-coated urea, deep placement of urea sugar granules (USG) in flooded rice field and efficient and efficient water management.

Reducing leaching loss

Mobile nutrients (e.g. NO_3^{--}) are lost from the soil-plant system with the percolating water. Besides reducing the nutrient may pollute the groundwater. The groundwater having more than 10 mg NO_3^{--}, N per litre is unfit for drinking purpose (WHO). Leaching loss of NO_3^{-}can be minimized by balanced fertilization, split application of urea synchronizing with crop demand, manipulation of water application and rooting depth, appropriate crop rotations and use of slow release fertilizers and nitrification inhibitors like N-serve, DCD, AM, CCC and neem-coated urea.

Despite the success of synthetic nitrification and unrease inhibitors in research farms they have poor acceptability among farmers because of high cost. However, the use of products plants like neem for coating urea can be popularized among the farmers to affect N economy and minimize long-term environmental consequences of denitrification and nitrate leaching.

Reducing runoff and erosion losses

Many water-soluble nutrients are lost through runoff. This loss can be minimized by proper crops land management and selection of proper crops and cropping systems, tillage and mulching. Nutrients sorbed on the surface of soil particles-clays and silts and soil organic matter are lost when the top soil is eroded by water or wind. Proper soil conservation measures should be adopted to minimize this loss.

Reducing fixation of nutrients in soil

In acid soils phosphorus is fixed as Fe^{++} and Al^{++} phosphates and in neutral and calcareous soils it gets fixed as Ca^{++} phosphate. The availability of these fixed phosphates is very low. Phosphate-fixation in acid soil can be reduced by combined application of rock phosphate and single super phosphate and liming of acid soils. In both acid and calcareous soils phosphorus-fixation can be minimized by band placement of phosphatic fertilizers along with crop rows. Use of rock phosphate along with acid forming materials like pyrites or phosphate-solubilizing microorganisms help in solubilizing of sparingly soluble rocks. Vesicular-arbuscular mycorrhizal (VAM) fungi are helpful in mobilizing both applied and native P reserves.

K^{++} and NH_4^{++} ions are also fixed in the interlayer of 2:1 clay minerals like illite, vermiculite etc. nutrients fixed on soil-plant system but are not available to the crop in a short-term period. However, these are released at later stages of crop growth.

Integrated plant nutrient management system

The high cost of fertilizers coupled with relatively greater losses of fertilizer N leading to environmental pollution and yield decline over the years calls for a cheaper and more sustainable measure to improve productivity by substituting part of the inorganic fertilizers by organic sources of nutrients. Organic sources of nutrients alone cannot sustain the crop yield at higher level to meet the demand of growing population. There is need to combine the use of inorganic fertilizers and organic sources of nutrients viz., manures, green manures, crop residues, biofertilizers etc. in a synergistic manner, which is referred as Integrated Plant Nutrient Supply (IPNS) System.

Integrated nutrient supply system sustains and improves the physical, chemical and biological health of soil and enhances the availability of both applied and native soil nutrients during growing season of the crops. This helps in retarding soil degradation and deterioration of water and environmental quality by promoting carbon sequestration and checking the losses of nutrients to water bodies and atmosphere. Besides, organic sources of nutrient acts as slow release fertilizer as it synchronizes the nutrient demand set by plants, both in time and space, with supply of the nutrients from the labile soil and applied nutrient pools.

Application of N, half as urea and half as farmyard manure, resulted in higher fertilizer N recovery by Pusa Basmati-1 rice, higher retention of fertilizer in soil and lower unaccounted for fertilizer N than sole urea application in a sandy loam soil.

Green manuring crops grown in-situ (e.g. clover, vetch, cowpea, sesbania etc.) or brought from outside (e.g. Gliricidia) can be incorporated in soil to improve the crop productivity. For example 50-60 days old *Sesbania aculeate*, on an average, accumulates 4 to 5 t/ha dry matter or 100 to 130 kg/ha/N. The major constraint in green manuring is fitting it to crop rotation and managing the extra inputs i.e. fertilizer and water for it by the resource poor farmers. When the crops are harvested mechanically a sizable quantity of crop residues are left in field that can be recycled for nutrient supply. Out of the nutrient taken up by cereals, on an average, 25per cent of each N and P, 50per cent of S and 75per cent K are retained in crop residues making them available sources of nutrients. The low decomposition rate because of high C:N ration and immobilization of nutrients by cereal residues are some of the constraints in using them as source of nutrients. The major problem in using crop residues lies with the demand of these materials for other competing purposes e.g. animal feed and thatching of root etc. The NUE is considered altered when N fertilizers are applied in combination with organic manures, green manures, crop residues and biofertilizers (Sharma and Mitra 1990).

Biofertilizer help in improving soil fertility through biological nitrogen-fixation, solubilizing P from native soil and applied sources and mobilizing the micronutrients like Zn++ and Cu++ for plant-uptake. Rhizobium strains play a major role in symbiotic N-fixation in legumes. Similarly blue-green algae, Azotobacter sp. and Azospirillum sp. Help in N-fixation in cereals. The vesicular-arbuscular mycorhizal (VAM) fungi have an extensive mucellial network that increase the transport and uptake of P and micronutrients like Zn++ and Cu+_+. Bphosphate solubilizing microbes e.g. Pseudomonas striata, Bacillus polymyxa and Aspergillus awamori help in solubilizing of native soil P and rock phosphates.

Despite all the positive aspects of biofertilizers their use efficiency is highly soil, crop, location and management specific. It requires reliable system of storage, transportation and management in field to increase its acceptability among farmers.

Legumes are known to increase soil fertility through their capacity to fix atmospheres N and hence the soil fertility can be improved by inclusion of a legume in the cropping system. Yields of cereals following legumes are reported to be 0.3 to 3 mg/ha; or 30-35per cent higher than those following a cereal in cropping sequence. Besides N-fixation, legumes also help in solubilizing of occluded P, soil conservation, increase in soil microbial activity, organic matter restoration and improvement of physical health of soil.

Optimal allocation of nutrients

The available nutrients should be optimally allocated among the competing crops to get the maximum returns by following optimizing of nutrient production functions which relate crop responses to applied nutrients under given soil, climate and management factors. Fertilizer allocation to crops based on soil test crop correlation approach for targeted yield can help in improving the nutrient use efficient by crops.

Enhancing recovery of added nutrients by crops

The nutrient management practices that help in enhancing nutrient recovery by crops, maximizing yield and minimizing losses of nutrient lead to enhanced nutrient use efficiency. Some of these practices include selection of crops and cropping systems, balanced nutrition application and selection of proper, rate, time and method of nutrient application, optimum interaction with other inputs and amelioration of problem soils.

Selection of crops and cropping systems

Proper genotype of a crop should be selected which can mine the nutrients from soil and applied sources and converts them into desired output. Crops and cropping systems should be selected such that the residual nutrient left by one crop is efficiently utilized by the following crops. From a 10 years study in an Ustochrept in Punjab, it was seen that the apparent recovery of P declined rice-wheat>rice-berseem>cotton-wheat>corn-wheat>groundnut-wheat>pearl millet-berseem.

Balanced fertilization

Major factor responsible for the low and declining crop response to fertilizers is the continuous mining of soil without adequate replenishment to a desired extent (NAAS, 35). The continuous use of N fertilizers alone or with inadequate P and K application has led to mining of native soil P and K. it is estimated that about 28 million tones of NPK are removed annually by crops in India, while only 18 million tonnes or even less are added as fertilizer, leaving a net negative balance of 10 million tones. Further, soil are getting continuously depleted of S and micronutrients like Zn, B, Fe and Mn due to continued adoption of intensive cropping systems and use of high analysis fertilizers without adequate addition of organics.

Balanced fertilizer use at the macro level in India is generally equated with a nutrient consumption ration of 4:2:1 (N: P_2O5:K_2O). The N: P_2O5:K_2O ratio is as wide as 30.8:8.8:1 in Punjab, 48.2,14.9:1 in Haryana and 53.0:19.3:1 in Rajasthan compared with all India average of 6.9:2.6:1 (FAI.2004-05).

Blanced fertilizer i.e., use of fertilizer nutrients in right proportion and in adequate amount are considers as promising agrotechniques to sustain yield, increase fertilizer use efficiency and to restore soil health (Yadav *et al*. 1998). Continuous heavy application of only one nutrient disturbs the nutrient balance and leads to depletion of other nutrients as well as to under-utilization of fertilizer N. the response of a crop to N not only depends on the status of N but also on the deficiency or sufficiency of other associated plant nutrients (Yadav *et. al.,* 1998). Thus, balanced use of all nutrients is essential because no agronomic manipulation can produce high efficiency out of an unbalanced nutrient use.

Organic manure

Organic manures are important to enhance use efficiency of fertilizer inputs and also serve as alternative source of nutrients to chemical fertilizers. Combined use of organic manure and N fertilizer maintains a continuous N supply, checks losses and thus helps in more efficient utilization of applied fertilizers. Incorporation and decomposition of organic manures has a solubilising effect on native soil N and other nutrients including micronutrients. Further, such integrated plant nutrient supply (IPNS) systems also help in mitigating the adverse effects of acidity due to chellation of excess Al^{++} and/or Fe^{++} by the organic molecules liberated from FYM in the course of mineralization. The effect of FYM was found to be similar to like amendment in these acid soils, which seems mainly due to the formation of Al-organo chellates or complexes, resulting in the reduction of Al^{++} ion concentration in soil solution to levels beneficial to plant growth. In another study, apparent N recovery was increased when N fertilizer was applied along with organic manures such as biological study, FYM and *Eupatorium adenophorum* (Mahajan *et. al.* 2002).

Green Manuring

Inclusion of legumes in cropping systems for green manuring, fodder or grain purposes is an assured agro-technology to improve nutrient-use efficiency, especially that of N. The advantages of green manuring are indicated by increased N availability in soil, higher recovery of green manure N and its greater contribution towards grain production of crop.

Selection of source, rate, and time and method of nutrient application

The nature of fertilizer used and the rate, time and method of its application influences the recovery of the added nutrient by crop plants and it varies with the crop and root type.

Ammonium nitrate is considered to be a better source of nitrogenous fertilizer for upland crops whereas ammonical and amide form of N are superior to the nitrate containing sources for lowland rice crop. However, urea is the most economic source of nitrogeneous fertilizer. Fertilizer rates greater than the optimum level lead to lower utilization efficiency. Timing of fertilizer application should match with the crop demand. Split application of N is superior to basal application. P is usually applied as basal and in some light textured soils split application of K is advisable.

Method of applying fertilizers greatly affects their agronomic efficiency by influencing nutrient losses and their availability to plant roots. Superiority f fertilizer application before pre-sowing irrigation over application of the same at the time of seeding for enhancing fertilizer use efficiency was reported by many workers. Similarly in rice, basal application os urea with no standing water is superior to broadcast application of urea into standing floodwater at 10 days after transplanting in reducing the volatilization losses of ammonia.

The efficiency of water-soluble phosphatic fertilizers can be improved by band placement with, below or to the side of the seed row. This can improve the physical fertility of soil as the plants roots can easily take up nutrients from these sources.

Many soils have large reserves of total phosphorus, but low levels of available phosphorus. Total P is often 100 times higher than the fraction of soil P available to crop plants. Most cereal growing areas in the developed world will overcome the problem of low P availability through management practices such as the application of phosphorus-based fertilizer/manure (Ortiz-Monasterio *et. al*., 2002). P availability is strongly influenced by soil pH. Availability of P is maximized when soil pH is between 5.5 and 7.5. Acid soil conditions (pH < 5.5) cause dissolution of aluminum and iron minerals which precipitates with solution P effectively "tying" it up. Basic soil conditions (pH > 7.5) cause excessive calcium to be present in soil solution which can precipitate with P decreasing P availability.

Land configuration and soil tillage have tremendous potential for its further exploitation and improving TFP. Yield enhancement is also possible by sowing crops in more innovative spatial patterns, such as in clumps rather than in rows (Bandaru *e.t al.,* 2006).

Crop rotation involving legumes

There is need to develop crop rotations involving legumes to tap the benefits of biological nitrogen fixation (BNF). Nitrogen use efficiency for cereals following legumes is greater than that for cereals following cereals or fallow. The role of legumes in N economy is well researched but the problem is how to increase N input and the options are increased system efficiency or increase in the area under the system. N derived from BNF in legumes varies from 40-80 per cent and residual effect on succeeding crops is variable and depends on several factors. The more intensive systems (growing more crops in a given period of time) require greater fertilizer N inputs but are economically advantageous to farming community. More intensive dry land cropping systems involving legumes in rotation lead to increased water use efficiency and also better maintain soil quality. The research has shown a positive impact of BNF on nitrogen economy of cropping systems but the vast potential of BNF has remained unrealized at the farmers' level due to many reasons and needs to be looked into from the holistic approach on nitrogen use in agricultural production systems. Some aspects which need immediate attention are: increasing public investment in microbiology for teaching, research and training, encouraging private investment in manufacture of biofertilizers, constitution of nodal agency for registration of manufacturers, establishment of quality control laboratories and act as a watch dog and promoting products through DAVP and media. The private sector needs to play a crucial role and set an example by employing qualified microbiologists for production, assuring quality through creation of brand equity, ensuring *niche* marketing through entrepreneurship ventures and providing dealers' involvement as advisor and friend on product and proper application.

There is an urgent need to improve the inputs of organics and BNF and to increase the production of quality inoculants and popularize their use in Indian agriculture rapidly. Development of effective and competitive strains tolerant to high temperature, drought, acidity and other abiotic stresses are of high priority. Newer formulations of mixed biofertilizers, improvement of inoculant quality and devising effective delivery systems are crucial for making further progress in taking the BNF technology to farmers' fields.

Breeding input efficient crop varieties

Breeding and selecting crop cultivars that make more efficient use of water and fertilizer N (including higher N fixation and N partition) while maintaining productivity and crop quality has been a long-term goal of production agriculture. Development of nitrogen-efficient cultivars could help decrease fertilizer N inputs and resulting reactive N losses to air and ground water. These nitrogen-efficient cultivars could also be useful in regions where limited-resource farmers are unable to afford synthetic N fertilizers. Selection of N efficient genotypes that is the varieties which can extract more N from soil at lower availability will enhance the production in these regions. Molecular and biotechnological approaches for searching for regulatory targets for manipulation of N use efficiency be strengthened. Unraveling the details of N signal transduction to provide additional clues to improve N uptake and assimilation efficiency.

Collaboration and accurate measurement

Improving N-use efficiency in major food crops will require collaboration among ecologists, agronomists, soil scientists, agricultural economists, and politicians. Great needs exist for accurate measurements of actual fertilizer N-use efficiency, N losses, and loss pathways in major cropping systems. Only in this way we can: a) identify opportunities for increased N-use efficiency by improved crop and soil management; b) quantify N-loss pathways in major food crops; and c) improve human understanding of local, regional, and global N balances and N losses from major cropping systems. The starting point for any improvement has to be a clear understanding of the fluxes and balances of nitrogen at the farm level. Direct on-farm measurements are necessary because estimates from small plots on research stations overestimate field-scale fertilizer N-use efficiency (NAAS 2005).

Holistic crop management for improving nutrient use efficiency

Some suggestions for holistic management of crops include:

- Adopt proven methods of individual nutrient use, with knowledge-intensive nutrient management.
- Harness the positive nutrient interactions and control negative nutrient interactions
- Maintain natural resource base, the soil quality and prevent environmental degradation.
- Use biotechnological tools for reducing the nutrient use, viz. selective ion uptake or exclusion, herbicide tolerance, Bt crops, efficient strains of bio-inoculant and bio-control agents and tolerance to abiotic stresses (drought, salinity, low photo- and thermo-sensitivity).

Multi-nutrient deficiencies are emerging and hidden hunger status for secondary and micronutrients is evident. Nutrient-use efficiency depends on several agronomic factors including tillage, time of sowing, appropriate crop variety, proper planting or seeding, adequate irrigation, weed control, pest or disease management and balanced and proper nutrient corrects nutrient use. Balanced use of plant nutrients corrects nutrient deficiency, improves soil fertility, increase-nutrient and water-use efficiency, improves crop yield and farmers' income, and better the crop and environmental quality. These factors largely influence the use efficiency, either individually or collectively. The entire crop, management practices that promote better crop growth will invariably increase the nutrient-use efficiency. Adoption of best crop management practices on system basis is essential to get higher input-use efficiency and profitability. To reap the benefits of balanced use of plant nutrients, it is important to have good-quality seed, adequate moisture and better agronomic practices with greater emphasis on timeliness and precision in farm operations.

Efficient Water Management

Water is the most crucial input for agricultural production. Vagaries of monsoon and declining water-table due to its overuse resulted in shortage of fresh water supplies for agricultural use, which calls for an efficient use of this resource. Strategies for efficient management of water for agricultural use involves conservation of water, integrated water use, optimal allocation of water and enhancing water use efficiency by crops.

Conservation of water

In-*situ* conservation of water can be achieved by reduction of runoff loss and enhancement of infiltrated water and reduction of water losses through deep seepage and direct evaporation from soil. Runoff is reduced either by increasing the opportunity time or by infiltrability of soil or both. Opportunity time can be manipulated by land shaping, tillage, mechanical structures and vegetative barriers of water flow and infiltrability can be increased through suitable crop rotations, application of amendments, tillage, mulching etc. Water loss by deep seepage can be reduced by increasing soil-water storage capacity through enlarging the root zone of crops and increasing soil-water retentively. Direct evaporation from soil can be controlled with shallow tillage and mulching.

Ex-*situ* conservation of water can be achieved by harvesting of excess water in storage ponds for its reuse for irrigation purpose.

Integrated water use

Efficient utilization of water resources and minimization of detrimental effect of water management on soil and water resources can be achieved by the integrated use of water from different sources viz., by irrigation to supplement profile stored rainwater, conjunctive use of surface-water and groundwater, poor and good quality water and recycled (waste) water for irrigation. Supplemental irrigation for growing crops is an integrated use of rainwater stored in the profile and the irrigation water regardless of its source.

Small (30-50 mm) early post-emergence irrigation stimulates root extension into deeper layers thus causing greater use of profile-stored water. So the water extraction obtained from the supplemental irrigation at crucial crop growth period is more than the proportionate increase in the level of supplemental irrigation, which is referred as priming effect of the supplemental irrigation. The priming effect varies with soil type, fertility level and amount of irrigation. It generally increases with the increase in the N rate, soil water retentively and decreases with the increase in the amount of irrigation after a certain threshold value.

Optimal allocation of water

Optimal allocation of available water among the competing crops and optimum timing of application is to be decided under adequate and limited water supply situation so as to maximize economic returns from available water. Under adequate water supply situation optimal allocation involves timing of irrigations so that crop yields are maintained at their achievable potential, as per climatic conditions of the location. Under limited water supply situation irrigation water must be allocated so that periods of possible water deficits coincide with the least sensitive growth periods. Thus irrigation scheduling should be decided based on the water availability. The procedure for optimal allocation of water under limited water supply condition includes quantifying water use (ET or T) *vs* crop biomass relations and employment optimizing models with operational constraints. Crop simulation models can be used to schedule irrigation under different water availability conditions.

Enhancing water-use efficiency crops

Water-use efficiency by crops can be improved by selection of crops and cropping systems based on available water supplied and increasing seasonal evapotranspiration (ET). The later can be achieved by selection of irrigation method, irrigation scheduling, tillage, mulching and fertilization.

Water use efficiency

The water utilized by crop is evaluated in terms of Water Use Efficiency. This water use efficiency can be classified into

1. **Crop Water Use Efficiency (CWUE)**

   It is the ratio of crop yield (Y) to the amount of water used by the crop for evapotranspiration (ET)

$$CWUE = \frac{Y}{ET}$$

2. **Field Water Use Efficiency (FWUE)**

   It is the ratio of crop yield (Y) to the total amount of water used in the field (WR)

$$FWUE = \frac{Y}{WR}$$

3. **Physiological Water Use Efficiency (PWUE)**

   The physiological WUE is calculated in terms of the amount of C_2O fixed per unit of water transpired

$$PWUE = \frac{\text{Rate of Photosynthesis}}{\text{Rate of Transpiration}}$$

Strategies to increase water use efficiency

Water-use efficiency (WUE) of crops can be improved by selection of crops and cropping systems based on available water supplies and increasing seasonal evapotranspiration (ET). The later can be achieved by selection of irrigation method, irrigation scheduling, tillage, mulching and fertilization.

Selection of crops and cropping system

Selection of crops and cropping systems for high water-use efficiency should be done on the basis of availability of water under rainfed crops, limited irrigated crops and fully irrigated crops. The average WUE of different crops varies from 3.7 to 13.4 kg/ha/mm of water.(Tables 2 and 3)

Table 1. WUE of some important field crops in India

Crops	WUE (kg-ha/mm)
Rice	3.7
Finger millet	13.4
Wheat	12.6
Sorghum	9.0
Maize	8
Groundnut	9.2

Table 2. WUE of some important field crops in India

High	Medium	Low
Maize	Wheat	Green
Sorghum	Barley	Gram
Pearl millet	Oats	Pigeonpea
Finger millet		Soybean
Sugarcane		Peas

Rainfed crops

The amount of rainfall converted into plant-available soil water is determined by the amount and intensity of rainfall, topography, infiltrability and water retentivity of soil, depth of root zone and soil depth. Depth of soil due to its effect on the available water storage capacity decides the type of cropping locality. On medium soil depth monocropping or intercropping can be practiced whereas in deep soil with 200 mm available soil moisture status double cropping can be practiced.

Limited irrigated crops

Selection of crops and cropping sequences under limited irrigation situation should be done as there should be minimum water stress during the growing season although some water-stress to the crops and associated yield reduction is inevitable. Therefore, along with selection of crops special care should be taken for irrigation scheduling of these crops.

Fully irrigated crops

Under fully irrigated condition selection of crops is not constrained by water availability but by adoptability of the crops to prevailing climatic and soil condition. In general, water use efficiency of C_4 plants is higher than C_3 plants, particularly under semi-arid environment.

Increasing seasonal evapotranspiration

Seasonal evapotranspiration (ET) is a measure of consumptive water use by the crops. Increasing the transpiration (T) component of ET, results in higher utilization of water by the crops to increase the productivity. The T can be increased by following improved irrigation methods, irrigation scheduling, tillage, mulching and fertigation.

Irrigation method

Efficient micro-irrigation methods like sprinkler and drip irrigation for utilization of available water in case of scarce in lean season developed mainly for high value horticultural and plantation crops could save up to 50per cent of water and also increase the crop yield and quality substantially.

Irrigation scheduling

Under adequate water availability the main emphasis is on securing potential yield of the crops without wasting water. Whereas, under limited water supply, the objective is to achieve maximum WUE. There are different methods for irrigation scheduling viz., critical crop growth stages, feel and appearance method, soil moisture depletion approach, irrigation water at different cumulative pan evaporation method.

Tillage

Tillage practices mainly influence the physical properties of soil viz., soil moisture content, soil aeration, soil temperature, mechanical impedance, porosity and bulk density of soil and also the biological and chemical properties of soil which in turn influence the edaphic needs of plants viz., seedling emergence and establishment, root development and weed control. Tillage also influences the movement of water and nutrients in soil and hence their uptake by crop plants and their losses from soil-plant system.

Tillage affects the WUE by modifying the hydrological properties of the soil and influencing root growth and canopy development of crops. Tillage methods influence wettability, water extraction pattern and transport of water and solutes through its effect on soil structure, aggregation, total porosity and pore size distribution. Tillage system suitable for a soil depends upon soil type, climate and cropping system practiced. Shallow inter-row tillage into growing crops reduces short-term direct evaporation loss from soil even under weed-free condition by breaking the continuity of capillary pores and closing the cracks.

Deep tillage to a depth of 30-45 cm at 60-120 cm intervals helps in breaking subsoil hard pans in alfisols facilitating growth and extension of roots and improving grain yield of crops as well as increasing residual soil moisture. However, the benefit is absent in suboptimal rainfall years and restricted to only deep-rooted crops in high rainfall years.

Conservation tillage practice normally stores more plant available moisture than the conventional inversion tillage practices when other factors remain same. The high soil moisture content under conservation tillage is due to both improved soil structure and decrease in the evaporation loss under continuous crop residue mulch cover. Increase in the available water content under conservation tillage, particularly in the surface horizon, increases the consumptive use of water by crops and hence improves the water use efficiency.

Off season tillage or summer ploughing opens the soil and improves infiltration and soil moisture regimes.

Mulching

Mulching influences WUE of crops by affecting the hydrothermal regime of soil, which may enhance root and shoot growth, besides it helps in reducing the evaporation (E) component of the evapotranspiration. Under moisture stress conditions, when moisture can be carried over for a short time or can be conserved for a subsequent crop, mulching can be beneficial in realizing better crop yield.

Fertilization

There is strong interaction between fertilizer rates and irrigation levels for crop yield and WUE. Application of nutrients facilitates root growth, which can extract soil moisture from deeper layers. Furthermore, application of fertilizers facilitates early development of canopy that covers the soil and intercepts more solar radiation and thereby reducing the evaporation.

Weed control

Weed management is the most efficient and practical means of reducing transpiration. Weeds compete with crops for soil moisture, nutrients and light. Weeds transpire more amount of water compared to associated crops plants.

Cultural manipulations

A timely –sown crop result in good stand and vigour and thereby higher efficiency of the basally-applied N fertilizer. On the other hand a crop sown late requires additional inputs like seed, fertilizer, irrigation etc. to compensate for the loss in crop stand and yield. In adequate crop stand is the major cause of low crop productivity under stresses environment like rainfed, drought and flood-prone conditions. Weed competes with crop plants for water, nutrients, sunlight and thereby reduce crop yields and consequently NUE.

Varieties

Breeding and selecting crop cultivars that make more efficient use of soil and fertilizer N (including higher N fixation and N portioning) while maintaining productivity and crop quality has been a long-term goal of production agriculture. Development of nutrient efficient cultivars could help decrease fertilizer inputs and resulting nutrient losses to air and groundwater..

Incidence of insects and diseases

Plant health is government by diseases, insects and weeds that compete for water and nutrient resources and low NUE. Incidence of insects and diseases generally increases at higher levels of N application. Stem-borer infestation in rice was 42per cent more than application of 40 kg N/ha than without N under lowland conditions (Sharma, 2002). At higher levels of N, the rice crop lodged and showed greater susceptibility to bacterial leaf blight and bacterial lead, streak, resulting in low grain yield.

Precision farming techniques

Application of N on the basis of soil test valued is essential to economize on the cost of fertilizer application. Land leveling and root zone wetting through micro-irrigation systems also lead to efficient use of water and N fertilizer inputs. Employment of drip irrigation and fertigation techniques have grained popularity in recent years, particularly in the widely-spread high-value crops. Precisely in controlled quantity and at appropriate time directly to the root zone as per crop needs at different growth stages. This nor only enhances WUE but also enables efficient use of nutrients, particularly N for higher productivity. Using N in accordance with chlorophyll meter has been found to be more efficient than fixed schedule N fertilizer splits as key growth stages. Precision land leveling has tremendous impact on agronomic efficiency of N, P and K (Jat *et al.* 2004). Under irrigated agriculture, precision water management has large bearing on the water productivity, higher yield and income. Higher water productivity and NUE was reported under precision drill seeding compared to broadcasting and traditional drill (Pal *et al.* 2004).

Interaction with other inputs

The utilization of nutrients can be improved by optimum and synergistic interaction with other inputs viz., water, tillage and mulches. These inputs modify the physical, chemical and biological environment of soil, which influence the nutrient recovery by crop plants.

Significant and positive interaction between applied N and water supply was observed on wheat yield and water and nutrient use efficiency by wheat (Bhale et al., 2009). With 80 kg N/ha, N use efficiency increased up to 300 mm water supply in sandy loam soil. Interestingly, with 120 kg/ha, it did not increase when water supply was increased from 50 mm to 125 mm, but increased markedly when water supply was further increased to 300 mm (**Table No** 3). This implied that the balance between these two inputs influenced input use efficiency.

Table 3. Nitrogen and irrigation effects on water use efficiency (kg/grain/mm) and nitrogen use efficiency (kg grain/kg fertilizer N) in sandy loam soil

Irrigation (mm)	WUE				NUE		
	N rate (kg/ha)				N rate (kg/ha)		
	0	40	80	120	40	80	120
0	5.3	7.6	8.1	6.0	8.5	5.5	1.5
50	6.3	9.5	11.3	13.3	20.2	18.4	17.8
125	5.7	10.3	11.9	11.8	33.2	25.5	17.0
300	4.6	7.4	9.5	10.2	30.2	30.3	23.7

Source: Bhale *et al.* (2009)

Application irrigation and nutrient in conjunction through pressure irrigation system result in efficient utilization of both resources. This will save water as well a reduces nutrient leaching losses and thereby increased WUE as well as NUE. This will increase the yield and quality f crops. There is saving of water and nutrient to the extent of 35 and 22 per cent, respectively. fertigation is most commonly used for plantation crops like banana, sugarcane and orchards of Maharashtra.

Amelioration of problem soils

Soil related constraints affecting crop production influence the nutrient use efficiency crops. For example liming of acid soils with calcite, dolomite or paper mill sludge improves the phosphorus use efficiency. Similarly amelioration of alkali and saline-alkali soils with gypsum helps in improving nutrient use efficiency. Any other physical constraint like sub-soil compaction should be ameliorated using appropriate tillage practices to improve the nutrient use efficiency.

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3.5 Resource Conserving Technologies in Rice Cultivation

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Rice (*Oryza sativa* L.) is staple food of more than 60 per cent of the world's population. Rice is the most important crop of India with highest area of 45 million hectares and second to china in production with 95 mt in 2008. The productivity of rice in India has been between 2 –3 t/ha which is satisfactory level considering the global standards with a scope for further improvement.However, the surplus production scenario has no room for complacency as growth rate is only about 1.4 –1.5 per cent (Subbaiah, 2005). Considering population growth at about 1.8 per cent, the demand for rice is going to be about 140 mt by 2025 AD (Subbaiah, 2005). .

Area under rice is expected to be reduced to about 40 m ha in the next 15-20 years owing to water shortage and urbanization in India. More than 80 per cent of fresh water is consumed for agriculture and 50 per cent of it goes for rice cultivation. Rice consumes about 3000 –5000 litre of water to produce 1 kg of rice (IRRI 2001). The per capita availability of water sources declined by 40-60 per cent in many Asian countries between 1955-1990 (Glieck 1993) and expected to decline by 15-45 per cent by 2025 compared to 1990 (Guerra *et al.* 1998). Therefore, rice could face a threat due to water shortage and hence there is need to develop and adopt water saving methods in rice cultivation so that production and productivity levels are elevated despite the looming water crisis.

Rice is also the main staple food of people in the North Eastern Region of India. The productivity of rice in the region is only about 1.6 t/ha compared to national average of 2 t/ha. The demand for rice is growing with ever-increasing population. The region is in deficit of about 1 million tonne of rice. Therefore, there is need for steady increase in productivity with limited resources like land, water etc.

Soil (land) health degradation is another such problem, especially in intensive agriculture including in North East India. Physical and biological deterioration of land with associated fertility depletion occurs due to poor agronomic management, waterlogging, acidification, salinization, alkalininization etc. Intensive cultivation along with poor or no addition of manure, residue removal/burning etc. are further aggravating the situation. Rice cultivation is becoming uneconomical due to higher input cost, low input responsiveness, high labour requirement and poor diversification.

Therefore, it is essential to develop suitable system of cultivation, which is not only economical and helpful for better growth and development but also enable to utilize valuable resources efficiently and conserves them. Blending of modern technology with indigenous resource conserving technologies would help to achieve such goals with people's participation. In the recent years, a lot of emphasis has been given in resource conservation in agriculture, as a result of which a number of technologies are developed /evaluated in agriculture with the ultimate objective of improving productivity and conservation of ecosystems. Some of such technological options suitable for rice cultivation are discussed in this chapter.

System of Rice Intensification

Water is the most important input in agriculture and rice consumes most of the available water resources of the country. The farmers are habituated to irrigate rice as much as possible and maintain high submergence throughout the crop period with wrong notion that yield could be increased with increased water input. The continuous land submergence leads to considerable loss of water through deep percolation and other means (Bouman, 2001). On the other hand, submerging rice fields brings a series of physical, chemical and microbilogical changes in the soil, which profoundly affects growth of rice plant as well as availability, loss and absorption of nutrients (Ghildyal, 1978). It is well documented that rice root degenerates under flooded condition and deprive healthy crop growth due to decreased feeding zone of the crop caused by lodging and death of the plants after water receded (Chaturvedi *et al.* 1995).

The System of Rice Intensification (SRI) is an improved method of rice cultivation developed through participatory on-farm research conducted at Madagascar during 1980s by Father Henri de Laulanie, a Jesuit priest in close collaboration with farmers to overcome the problem of rice cultivation in predominantly acidic soils of Madagascar. SRI is a system of growing rice that involves principles that are at times radically different from traditional ways of growing rice. It involves single seedling transplantation of young seedlings with care instead of the conventional method of transplanting multiple and mature seedlings from the nursery. SRI spaces rice plants more space and does not depend on continuous flooding of rice fields, uses lesser seed and chemical inputs, and promotes soil biotic activities in and around plant roots through liberal applications of compost and weeding with a rotating hoe that aerates the soil (Plate 1). These changed practices with lower inputs counter-intuitively lead to the yields of 7-8 t/ha, about double the present world average of 3.8 t/ha.

Tripura, a small state in the North Eastern region with SRI approach, has shown the way to the nation in improving the productivity of rice from 2.5 tonnes per hectare to about 3.5 tonnes per hectare (Uphoff, 2007). This is highly encouraging and it has a long way to go. The other states also have the similar opportunities.

- SRI involves the use of certain management practices which together provide better growing conditions for rice plants, particularly in the root zone, than those for plants grown under traditional practices
- SRI is a system rather than a technology because it is not a fixed set of practices. While a number of specific practices are basically associated with SRI, these should always be tested according to local conditions rather than simply adopted.

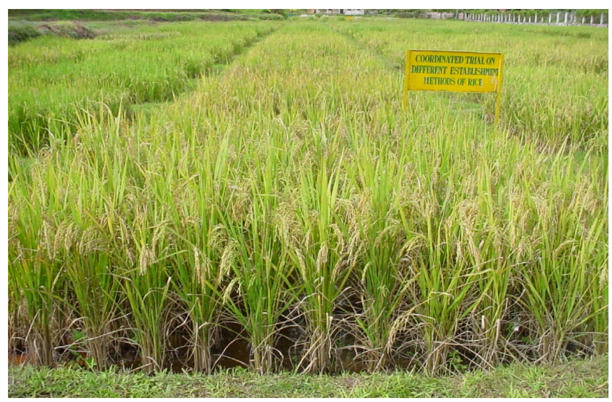

Plate 1. Rice under SRI at ICAR, Umiam, Meghalaya

Global SRI scenario

Until 1999, the only country in which the System of Rice Intensification (SRI) was known and practiced was Madagascar, an island nation off the southern coast of Africa. In Madagascar, methods of rice cultivation had remained quite 'traditional' as Malagasy farmers transplanted seedlings 5-6 weeks old in clumps of 5-6 plants, keeping their fields continuously flooded, with only casual weeding. Paddy yield in Madagascar was around 2 t/ha for many years. Soil was strongly acidic (pH 3.8-5.0) with low to very low in cation exchange capacity (CEC). There were serious problems of iron and aluminium toxicity, and less than half as much phosphorus was available as usually considered necessary for good crop yields. Farmers were too poor or isolated to purchase chemical fertilizers or new seeds.

A French priest, Father Henri de Laulanie (1993), who spent three decades in developing SRI through careful observation and experimentation, developed, refined and tried to explain the major increases in yield and factor productivity that his SRI practices induced, how they evoked more productive phenotypes from any rice genotypes.

Rather than pursue a strategy that relied primarily on external inputs, Laulanie started with whatever rice varieties farmers were already planting, and with whatever soil they cultivated. He figured out how farmers could improve their production just by changing the way that they managed their rice plant, their soil, their water and organic nutrients. To enhance the structure and functioning of their soil systems, farmers were advised to utilize compost, any decomposed biomass, since most households were too poor to have cattle and had little access to farmyard manure and could not afford to purchase and apply chemical fertilisers.

Cornell International Institute for Food, Agriculture and Development (CIIFAD) first started to work in Madagascar in 1993-94. SRI was being promoted by an NGO that Laulanie had established with Malagasy colleagues in 1990, Association Tefy Saina. This NGO trained farmers growing rice on small plots in the peripheral zone around Ranomafana National Park. Through SRI methods, it was hoped to reduce the slash and burn cultivation that was encroaching on the remaining rain forest ecosystems. By 1997, farmers around Ranomafana practising SRI had average yields of 8 t/ha for three consecutive years, a four fold increase from 2 t/ha.

In India also SRI technology started picking up. States like Andhra Pradesh, Tamil Nadu has done a good progress in this technology. Even in North East a lot of works are undertaken in SRI and ICM. Recently second National Symposium on SRI was held at Agartala, Tripura from 3-5 October, 2007 to popularise the technology in the region. ICAR Research Complex for NEH Region, Umiam, Meghalaya also initiated work on SRI and ICM since 2004. A number of demonstrations and on-farm trials are conducted by the Institute on SRI. Recently a subproject on SRI and ICM has been undertaken by Division of Agronomy, ICAR Research Complex for NEH Region, Umiam, Meghalaya under National Agricultural Innovative Project (NAIP) to popularise these technologies in South Garo Hills of Meghalaya.

Phyllochron Concept in Paddy

In SRI method, initially (2-3 weeks after transplantation) the field would looks terrible, as the seedlings are small and widely spaced. As there is no standing water in the field, the land looks dried up. At this stage the rice plant is preparing itself to tiller. To understand the concept of tillering, one has to know about phyllochron in paddy. Phyllochron is the time taken to form a new tiller with a leaf and root. This is mainly influenced by the temperature followed by day length, humidity, soil moisture, soil texture, availability of nutrients, aeration and sunlight. If all the conditions are favourable one phyllochron is completed in 5 days. Or else it might take 6-7 days or even more. It is ideal that the rice plant completes 12 phyllochrons by the time vegetative phase is over and panicle initiation has taken place. A new tiller after completing two phyllochrons also starts tillering. This means that the number of new tillers increases geometrically. If germination is considered as the first phyllochron stage, then it is ideal to transplant it in 2nd or 3rd phyllochron stage. This would not disturb the phenomenal growth that would take place from the 4th phyllochron. For maximum tillering plants has to complete as many phyllochrons as possible during their vegetative phase, which is only possible when seedlings are transplanted at 2nd or 3rd phyllochron stage. The same thing happens in SRI method. Whereas, in case of conventional transplanting seedling roots are traumatized when they are exposed to the sun and dry out (mainly feeder roots) results slow in subsequent growth and not as many phyllochrons are completed before PI. If seedlings are three or four weeks old when transplanted (as in case of conventional practice), the most important (late) phyllochrons, the stage when optimum tiller growth is attained, will never be reached.

In medium duration (125 days) variety, which has about 60 days of vegetative phase under normal growth condition, plants prepare to tiller in about 8-10 days after transplanting (DAT). Rapid tillering begins at 20-30 DAT. The field seems to explode with rapid tillering at 30-40 DAT. In medium duration varieties, about 60, 35 and 30 days are required for vegetative, reproductive and ripening phase, respectively.

Key differences among various rice cultures

There are some key differences among SRI, ICM and Conventional rice cultures (Table 1).

Table 1. SRI and ICM vs. Conventional methods of rice cultivation

Parameters	SRI	ICM	Conventional
Seed rate (kg/ha)	5 - 6	15 - 20	40 - 50
Seedling Age (days)	10 - 12	18 - 20	25 - 30
Spacing (Row x Plant) cm	25 x 25	20 x 20	20 x 15
Seedlings/hill	1	2	3 - 4
NPK + FYM	20:15:10 kg/ha + FYM 10 t/ha	40:30:20 kg/ha + FYM 5 t/ha	80:60:40 kg/ha
Water management	Only moist condition	Intermittent irrigation	Continuous flooding
Water requirement (mm)	900	1400	1800
Weed management	Weeds turn down into the field by a weeder	Manual and mechanical weeding	Weeds manually removed from the field/herbicides
Grain Yield (t/ha)	6.0 - 6.5	5.5 - 6.0	4.5-5.0

Warning

At the initial stage, the field will look barren and disappointing. There will be little green to see as plants are very few and spaced widely. But from fourth week onwards, the plants will show accelerated growth that attracts viewers and farmers curiosity.

Limitations of SRI

The main limitations for SRI are controlled release of water i.e., ability to control water and to apply water to the field when it is needed. The uprooting and transplanting of young seedlings need expertise and utmost care. When the fields are not kept flooded, there will be opportunity for greater weed growth.

Integrated Crop Management (ICM) - an Alternative to SRI

To overcome the above limitations and to begin with one can go for Integrated Crop Management. Here 15 - 20 days old seedlings are planted in wide spacing (20cm x 20cm or 25cm x 25cm). However, here for nursery preparation MMN (Modified Mat Nursery) is followed. Combined use of organic manure/compost and chemical fertilizer has shown to produce higher yields than either alone. Adoption of IPM will also be very effective for crops under ICM, as fewer incidences of disease and pest is expected due to healthy plants. Thus farmer can reduce or avoid pesticide application.

Advantages of ICM

- Seed requirement is less than conventional practice
- Saving on water as intermittent Irrigation is followed
- Cost of external inputs gets reduced as organic manures and fertilizers are used in integration
- Especially good for high rainfall areas like North East India
- It is easy to handle 15-20 days old seedlings compared to 10-12 days
- Incidence of pests and diseases is low as the soil is allowed to dry intermittently
- Higher yields due to increased tillering, panicle length and grain weight

Preparation of Modified Mat Nursery (MMN)

In MMN, the seedlings are raised in a 4 cm layer of soil mix arranged on a firm surface. A nursery of 100 sqm area and 10 – 12 kg of good quality seeds are sufficient for transplanting one hectare area. The soil mix (4 m^3 for 100 sqm of mat nursery) is prepared by mixing 75 – 80per cent soil, 15 - 20per cent well decomposed manure and 5per cent rice hull ash. To this soil mix, add 1.5 kg of powdered diammonium phosphate or 2 kg compound fertilizer (15-15-15) and mix well.

Plate 2. Wooden frame for MMN

A wooden frame of 1.0 m width, 0.04 m height and suitable length divided into equal segments of 0.5 m each is placed over the plastic sheet spread over even firm floor/surface (Plate 17). Each segment of the frame is filled with soil mix almost to the top. Pre-germinated seeds are sown uniformly, covered with the soil mix, and firmed gently with the hand. The seedbed is sprinkled with water. The bed must be protected from heavy rains for first 5 days. The bed can be kept moist by regular watering with rose cans until seedlings are ready for transplanting in 15 days. In warm weather, the seedlings reach 16 - 20 cm height with 4 leaves and no tillers in 15 - 16 DAS. Alternatively farmers can use locally available materials like bamboo, banana leaves for preparation of MMN. Even traditional nursery practice with slight modification e.g. use of sufficient amount of organic manures like FYM or vermicompost with sparse seeds rate of 100 – 150 g/m^2 would be adequate for SRI and ICM practice. Alternatively the nursery can be prepared on any compact surface in an open area (Plate 18 - 36). But care should be taken to give some support to the nursery bed by providing wooden plank as shown in Plate 16 or use any other locally available materials. In the absence of any such support, the soil mixture along with nutrients will be washed away by the heavy rains especially in North East. This would produce weak seedlings instead of robust seedlings. Plastic tunnels could be used in high rainfall areas like North East especially to avoid damage due to heavy rains.

Research achievements on SRI and ICM practice

Field trials on comparative performance of SRI, ICM and conventional rice culture (CRC) have revealed that SRI and ICM have recorded 10 - 30per cent more grain yield in comparison to conventional rice cultivation practice at different locations in India (Balasubramanian *et al.* 2006). Balachandran and Louis (2007) reported superiority of ICM over SRI, dibbling and conventional transplanting in enhancing grain and straw yield of rice at Pattambi, Kerala. Field experiment conducted at ICAR Research Complex for NEH Region, Umiam, Meghalaya (low in soil available N, P & high K) also revealed the similar results (Munda *et al.* 2007). SRI recorded the higher percentage of effective tillers, grain per panicle, ripening ratio and test weight but these values were at par with ICM. On the other hand significantly higher number of tiller per m^2 and panicles per m^2 were recorded with ICM compared with SRI and conventional practice. As a result of this the significantly highest grain yield was recorded with ICM, which was found at par with SRI (Table 2). Contrary to the yield, the Harvest Index was found slightly higher with conventional practice. This was mainly due to higher biomass production under SRI and ICM compared to conventional rice culture. A number of field visits were organised for the farmers to popularise the technology in the region.

Plate 3. Farmers visiting SRI/ICM experiments at ICAR Complex, Umiam

Table 2. Effect of stand establishment methods and nutrient management on performance of low land rice

Treatment	Grain yield (q/ha)	Straw yield (q/ha)	Harvest Index	Available Soil Nutrient at harvest (kg/ha)		
Establish methods				N	P_2O_5	K_20
SRI	52.93	69.68	43.17	276.8	13.08	191.1
ICM	54.48	71.37	43.29	271.2	12.14	186.7
CRC	49.95	65.52	43.26	262.3	11.29	174.4
SEd ±	0.74	0.97	0.27	2.24	0.47	5.76
CD (P=0.05)	2.05	2.69	NS	6.22	1.31	15.99

The significantly higher values of root length, root volume and root dry weight was recorded with SRI compared to control but remained at par with ICM practice (Table 3). SRI roots were found more active and healthy at harvest, whereas the roots under conventional practice were weak, thin and degenerated.

Table 3. Root parameters of rice as influenced by stand establishment methods

Establishment methods	Root volume (cc)	Root dry weight (g)
SRI	59.15	12.10

ICM	52.89	10.33
Conventional	42.40	7.78
SED ±	3.00	1.20
CD (P=0.05)	6.14	2.44

Effect of various nutrient management practices on different rice cultures were studied at ICAR Research Complex for NEH Region, Umiam, Meghalaya under low land condition for three consecutive years (2005-07). The experiment soil was low in available N and P and medium in K. The result of final year revealed that integrated application of fertilizer and organic manures recorded higher yield compared to individual application of either organic manure (FYM) or fertilizer. The SRI crop matured about 15 days earlier to conventional practice.

Field experiments on plant density and weed control measures under SRI at Dapoli, Maharashtra revealed that close spacing of 20 x 20 cm produced maximum grain yield (59.19 q/ha) and straw yield of rice which was followed by 25 x 25 cm and 20 x 15 cm spacing (Thorat *et al.* 2007). Under weed control measures, hand weeding thrice (at 15, 30 and 45 DAT) produced maximum grain yield (64.14 q/ha) and straw yield (Table 4).

Table 4. Grain yield and straw yield as influenced by planting density under SRI at Dapoli, Maharashtra

Spacing (cm)	Grain yield (q/ha)	Straw yield (q/ha)
20 x 15	52.16	54.73
20 x 20	59.19	60.40
25 x 25	53.01	59.03

Crops under SRI produced more number of tillers per hill compared to ICM and conventional methods (Fig 5). Tillers production in SRI increased at higher rate and reached at peak 50days after transplanting (DAT) and started decreasing from 60DAT but remained superior to ICM and conventional practice.

Modification of SRI for North Eastern Region

Since North Eastern region receives a very high rainfall during monsoon season, it is very difficult to practice all the principles of SRI as suggested for controlled irrigation condition. Results of field experiments conducted at ICAR Research Complex for NEH Region, Umiam, Meghalaya during 2004-2007 on SRI revealed that closer spacing of 20 x 20 cm with10-12 day's old seedlings were found better as this produced more number of tillers/m^2 compared to 25 x 25 cm spacing (Munda *et al*. 2007). Intermediate practices of 15-20 days old seedlings were found better under Meghalaya condition as this can resist damage from sudden heavy rain and also it is easier to transplant. Immediately after transplanting 10-12 days old seedlings, if there is a heavy rainfall, may cause damage to the seedlings.

Aerobic Rice

International Rice Research Institute (IRRI) developed the "aerobic rice technology" to address the water crisis problem in tropical agriculture. In aerobic rice systems rice is grown like an upland crop with adequate inputs and supplementary irrigation when rainfall is insufficient (Bouman 2001).

The new concept of aerobic rice may be an alternate strategy, which combines the characteristics of rice varieties adopted in upland with less water requirement and irrigated varieties with high response to inputs. In China, the water use for aerobic rice production was 55 - 56 per cent lower than the flooded rice with 1.6 - 1.9 times higher water productivity. Net returns to water use were also two times higher (Bouman 2001). It indicates that aerobic rice may be a viable option where the shortage of water does not allow the growing of lowland rice. Lafitte *et al.*, (2002) reported that most lowland cultivars could survive in well-watered aerobic soils. Several technologies have been developed to reduce water loss and increase the water productivity of the rice crop. They are saturated soil culture (Borell *et al.,* 1997), alternate wetting and drying (Li 2001; Tabbal *et al.* 2002), ground cover systems (Lin *et al*. 2002) and system of rice intensification (Stoop *et al*. 2002). However, the fields are still kept flooded for some periods in most of these systems, so water losses remain high. Aerobic rice is high yielding rice grown under non-flooded conditions in non-puddled and unsaturated (aerobic) soil. It is reported that these rice are responsive to high inputs and tolerates (occasional) flooding (Bouman and Tuong 2001). Aerobic rice promises substantial water savings by minimizing seepage and percolation and also greatly reducing evaporation (Bouman *et al.,* 2002). Experimentally growing high-yielding lowland rice varieties under aerobic conditions has shown great potential to save water, but with severe yield penalty (McCauley 1990; Peng *et al*. 2006). High yields could be sustained when aerobic rice is grown once in four crops, but not under continuous monocropping in Brazil (Guimaraes and Stone 2000) and Philippines (Ventura and Watanabe 1978). Yield decline under monocropping of aerobic rice has also been reported by George *et al*., (2002) and Peng *et al.,* (2006).

Field experiment was conducted at the ICAR Research Complex for NEH Region farm at Umiam (950 m msl), Meghalaya during rainy seasons of 2006 and 2007 revealed that the yield difference between aerobic (average yield, 1.67 t/ha) and flooded rice (average yield, 2.31 t/ha) ranged from 18.4 to 37.8 per cent (P<0.05) depending on varieties. Cultivation of rice under aerobic condition resulted in 27.5 per cent yield reduction over flooded rice. Among the yield components assessed, sink size (spikelets per panicle) contributed more to the yield and is considered to be most important factor responsible for yield gap between aerobic and flooded rice. The study suggests that, variety Sahsarang 1 with its moderate values of photosynthesis rate, transpiration rate and water use efficiency (WUE) along with higher grain yield seems to be better choice for both stress (aerobic) as well as normal condition.

Green leaf manuring in rice

The fresh N-fixing tree leaves @ 10 t/ha was incorporated into the rice soil as green leaf manure manually 20 days before transplanting. The nutrient and moisture content of different tree leaves are presented in Table 5. In the first year, highest grain yield (4.82 t/ha) was recorded with recommended NPK (80:60:40 kg/ha) followed by incorporation of *Erythrina* (4.48 t/ha) and *Parkia* leaves (4.13 t/ha). In the following year though the trend remained almost same, the gap between yield obtained with NPK (5.08 t/ha) and tree leaves incorporation reduced. Surprisingly, in the third year, all the tree leaves except alder surpassed the grain yield level that obtained with recommended NPK (5.13 t/ha). Significantly highest grain yield of rice in third year was recorded with incorporation of *Erythrina* leaves (5.67 t/ha) that remained at par with *Acacia, Parkia* and *Casia* leaves. The result indicated that green leaf manuring with N-fixing tree leaves left marked residual effect and therefore improved productivity level due to cumulative effect (Das *et al.* 2009a).

Table 5. Effect of different N-fixing tree leaves on productivity of lowland rice

Treatments	Nutrient composition (per cent)				Grain yield (q/ha)		
	N	P	K	Moisture	2003	2004	2005
Erythrina	3.24	0.47	1.54	73.62	4.48	4.83	5.67
Alder	2.24	0.41	1.37	66.22	3.50	4.10	4.67
Parkia	2.54	0.40	1.52	69.28	4.13	4.40	5.23
Acacia	3.19	0.43	1.36	65.37	3.92	4.66	5.30
Cassia	2.50	0.39	1.17	65.80	3.99	4.55	5.58
Recommended NPK	-	-	-	-	4.82	5.08	5.13
Control	-	-	-	-	2.80	3.13	3.35
CD (P = 0.05)	-	-	-	-	0.60	0.46	0.53

Source: Das *et al.* (2009a)

***Azolla* in Rice Production**

Use of Azolla (a water fern used as biofertilizer) in rice production is probably one of the most economical and eco-friendly approach. It not only improves productivity and income but also saves fertilizer and improves soil health. The experimental results on *Azolla* indicated that *Azolla* compost (harvesting fresh and excess *Azolla* from tank and allowing it to decompose for about 45 days) @ 10 t/ha enriched with Rock Phosphate (RP) recorded highest grain yield of rice (42.6 q/ha) followed by application of recommended dose of NPK (40.2 q/ha). Sole treatment of *Azolla* dual cropping and *Azolla* compost also recorded significantly higher grain yield that was 57.6 per cent and 40.8 per cent higher than control, respectively (Hazarika *et al.* 2006).

In-*situ* residue management

Effective management of residues, roots, stubbles, and weed biomass can have a beneficial effect on soil fertility through addition of organic matter and plant nutrients, and improvement in soil condition (Munda *et al*. 2006 and Singh 2003). Rice straw contains organic materials and nutrients such as N 0.5–1.5per cent, P 0.2–1.0per cent and K 0.8– .0per cent (Mongkol and Anan 2006). It is well documented that the incorporation of organic manure or crop straw into soil improves soil fertility and increases crop yield (Gill and Meelu 1986; Eneji *et al*. 2001; Singh et al. 2001). The residual effect of incorporating rice straw into the soil provides a significant increase in grain yield after three years of practicing this method (Prasert and Vitaya 1993). Chutiwat and Direk (1997) have reported that incorporating rice straw into soil has increased grain yield 15–18per cent over burning. It has been reported that the application of cattle manure to low fertile soil at a rate of 10 ton/ ha has increased grain yields by 108–106per cent over no-fertilizer application in long term (Kanika 1998).

Plate 4. Rice under in-*situ* fertility management

In a study at Umiam, Meghalaya (Subtropical condition) rice-vegetables were grown with minimum tillage. All the weed biomass and crop residues available were recycled into the field.

Highest grain yield was recorded in cv. Sahsarang 1 (37.0 q/ha) followed by cv. Vivek Dhan 82 (31.99 q/ha) and Mendri (30.9 q/ha) and found significantly superior to cv. Manipuri (26.60 q/ha) (Munda *et al.* 2006). The nutrients recycled though rice straw ranged from 35.1 kg N/ha with rice –carrot sequence to 42.5 kg N/ha with rice-frenchbean, 9.6 kg P/ha with rice-carrot to 12.5 kg P/ha with sole crop of rice and 78.6 kg K/ha with rice-carrot to 91.9 kg K/ha in-case of a sole crop of rice. The nutrient recycled through vegetables residue varied from 3.3 kg N/ha with rice-carrot to 87.9 kg N/ha with rice-potato. In other hand, the nutrient recycled through incorporation of weed biomass ranged from 53.6 to 75.9 kg N, 7.1 to 9.6 kg P and 45.7 to 61.7 kg K/ha. Microbial population (cfu/g dry soil) in in-*situ* fertility management experiments (Bacteria, 129 x 10^4/g, *Rhizobium*, 61.6 x 10^4/g and PSM, 39.9 x 10^4/g) were found much higher than that found under inorganic fertility management (Das *et al.* 2008).

Conservation tillage

Traditionally, wet cultivation or puddling is used to reduce water percolation and to soften soil to assist transplanting of seedlings (So *et al.* 2001). Sharma and De Datta (1985) concluded that the only relevant benefits of puddling are the creation of soil tilth, reduction of water and nutrient losses and weed control and that other tillage operation that create similar conditions should produce identical rice yields.

Tillage often excessive as practiced in conventional agriculture is one of the most important drivers of land degradation (Reichert and Norton 1994, Papendick and Parr 1997, Solonius 2008). Continued and widespread use of tillage based production system along with removal, grazing and/ or burning of crop residues would further cause land degradation and unsustainable agriculture (Lumpkin and Sayre 2009). Soil puddling, which is done to facilitate transplanting and reduce percolation loss in rice culture (Tripathi 1992a), has been credited to the ill effects on soil structure (Cass *et al.* 1994, Bajpai and Tripathi 2000). Lal (1994) showed that the yield of rainfed agriculture may decrease by 29 percent over next 25 years because of erosion and other problems in conventional tillage based agriculture. On the other hand, systems based on high crop residue addition and no tillage tends to turn the soil in to a net sink of carbon (Reicosky *et al.* 1995, Bot *et al.* 2001). The minimum tillage could produce rice yield similar to that under conventional puddling with reduced expenses on field preparation (Bajpai and Tripathi 2000). The minimum tillage is aimed to least deterioration of soil physical condition and to reduce turn around time (Singh *et al.* 2004). Conservation tillage (CT) is seen as more appropriate strategy for rainfed production systems to promote conservation agriculture (CA). Minimal soil movement by dramatic reduction in tillage and retention of crop residues on the soil surface along with possible crop rotation to economically benefit the farmers are the key principles of CA (Lumpkin and Sayre 2009). Potential of zero tillage under rainfed condition of North East in rice and rice based cropping system with appropriate residue management has been reported by Ghosh *et al.,* (2009)

Rice can be transplanted after puddling involving single tractor operation or dry field preparation by rotavator followed by ponding of water and planking involving two tractor passes compared to 6-9 operation being followed by the farmers. In the presence of crop residues, green manuring or excessive weeds, we may require one more tractor operation by either harrow or rotavator with and without planking. For comparison, 7 tractor operations i.e. cross harrow, cross cultivator, planking, puddling harrow and planking we considered. Time and fuel consumption was evaluated at farmers field at 2 to 4 locations for three years and averaged. A savings of about

32 to 77 per cent in time and 39 to 85 per cent in fuel were observes under rotary in combination with harrow and/or planking and rotary tillage alone (Sharma *et al*. 2002).

The experience with the resource conservation technologies especially adoption of zero tillage on large scale by the farmers indicates the benefits and the next logical step is conservation agriculture (CA) leaving crop residues on the soil surface leading to improvement of soil health and to avoid environmental pollution and associated animal and human hazards caused by crop residue burning (Sharma *et al.* 2002).

Direct dry seeded and unpuddled transplanted rice

Direct seedling has advantages of faster and easier planting, reduced labour and less drudgery with earlier crop maturity by 7-10 days, more efficient water use and high tolerance of water deficit, less methane and often higher profit in areas with an assured water supply. Thus the area under direct seeded rice has been increasing as farmers in Asia seed higher productivity and profitability to offset increasing costs and scarcity of farm labour (Balasubramanian and Hill 2002). Weed control is a major issue in direct seeded rice and to overcome this problem, intensive efforts are being made by the agricultural scientist. In some soil, spray of micronutrient like Zn and iron may be needed to remove their deficiency.

Direct seeding of rice using zero till drill, rotary till drill, drum seeder as well as broadcasting under various field preparation or puddling options was tried at DWR research farm. Seeding depth was kept at 2-3 cm while using drill for seeding. For comparison purposes transplanting was also done under conventional puddling as well as under zero tillage and after field preparation with rotary tiller (Sharma *et al.* 2003a). The rice variety used was IR 64. Direct seedling was done in the first week of June on the same day when nursery was sown for transplanting. For weed control Sofit @ 1500 ml/ha was applied after four days of direct seeding followed by one weeding at around 35 days after seeding. Among the direct seeding options, the yield recorded was highest where rice was seeded using rotary till drill followed by broadcasting sprouted rice seed after preparation by rotary tillage and lowest when broadcasted under zero tillage. The mean yield in rotary tillage was significantly higher compared to zero tillage. Direct drilling by zero till drill and rotary till drill was at par and as good as transplanting under zero tillage or after file preparation by rotary tillage wand was significantly better than broadcasting and drum seeder but statistically at par with other transplanting or seeding options. The yield was marginally higher in conventionally puddle conditions compared to transplanting without tillage. After field preparation by rotary puddle conditions compared to transplanting without tillage, after field preparation by rotary tillage or direct drilling by zero or rotary till drill.

Direct wet seeded rice

In this system sprouted seeds are broadcasted or placed with drum seeder under puddle or unpuddled conditions. Wet direct seeded rice also reduced labour costs and effective herbicides for weed control have helped making this technology more popular. Seed rate in drum seeded rice varies from 50-75 kg/ha whereas in broadcasting method of seeding 20-30 kg/ha is sufficient. In wet seeded rice puddling can be avoided without any adverse effect o n rice yield. The observations at farmers field showed that mortality or sprouted seeds are higher under puddle compared to unpuddled conditions. A field trial on direct seeded rice was conducted with different seed rates varying from 30 to 80 kg/ha during 2002. Similar yield was recorded at varying seed rates suggesting that the seed rate can be further reduced. In 2003 rice season, an additional treatment of 20 kg/ha was include. The varying seed rates were kept based on earlier recommendation of the Directorate of Rice Research of 75-100 kg/ha. The variety used was IR 64 having a 1000 grain weight of about 26 grams. For a population of about $0.33x10^6$ plants/ha recommended for transplanting rice, the seed requirement is likely to be around 11 kg/ha after giving an allowance of 20 percent loss in germination percentage of seed. Of rodent and bird damage are further added to the estimates, almost double the seed requirement (20 kg/ha) should be good enough. The trial was sown in the first week of July during 2002 and second week during 2003 when the transplanting is generally dome. The yield recorded was almost similar at seed rates of 20 to 80 kg/ha (Sharma *et al.* 2003b).

Leaf colour chart

Leaf colour is a fairly indicator of the nitrogen status of plant. Nitrogen use can be optimised by matching its supply to the crop demand as observed through change in the leaf chlorophyll content and leaf colour. The leaf colour chart (LCC) developed by International Rice Research Institute (IRRI), Phillipines can help the farmers because the leaf colour intensity relates to leaf nitrogen status in rice plant. The monitoring of leaf colour using LCC helps in the determination of right time of nitrogen application. Use of LCC is simple, easy and cheap under all situations. The studies indicate that nitrogen can be saved from 10 to 15 percent using the LCC (Sharma *et al.* 2008).

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