Natural Resources Management: An Overview

A.K.Singh*, V.K. Singh ** and S.K. Roy*

Abstract

Crop production is the resultant effect of interaction between different natural resources such as soil, water and weather as well as external inputs like seed fertilizer, energy, management etc. Temperature variation in productivity is often witnessed depending upon how these resources are used and managed as reflected in wide spatial and temporal fluctuations with marked peaks and through among different agro-ecological situations or even within the same ecosystem. Over exploitation beyond the resource capability or an imbalanced use not in harmony with local situation in an attempt to augment rapid production for meeting the immediate mounting demands of the burgeoning human and animal population with out long term perspective leads to unabated degradation of resource base, loss of biodiversity, decline in total factor productivity in the farming system, and environment deterioration. With shrinking per capita land, water, the prevalent increasing demographic trend is putting further enormous strain on the already overburdened resource base. This unhealthy situation has become more prominently damaging under intensive agriculture after advent of green evolution era not only in India but elsewhere as well. Unsustainability of higher productivity associated with fast resource degradation at an alarming rate has become a cause of serious concern the world over in the recent years. Green apprehensions are, therefore, voiced about the stability of enhanced productivity and environment safety as also about future gave limitations to feed the teeming millions in present scenario.

1. Introduction

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 poored 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 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.

* Zonal Project Directorate, Zone-II, Kolkata ** Senior Scientist, PDFSR, Modipuram

Summer course on "Conservation of Natural Resources for Sustainable Hill Agriculture" held at ICAR Research Complex, Barapani w.e.f. August 25 to Sept.14, 2009

2. Natural resources in India

2.1. 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%) consisting of net cultivated areas, current follows, other follows and cultivable wastes; (ii) ecological sector (33.56%) comprising forests, miscellaneous, barren and uncultivable waste, and (iii) non agricultural sector (7.17%) 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 was prepared by using GLASOD methodology shows that an area of about 187 M ha, respectively almost 57% 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%) of the total area through the country. Wind erosion is dominant in the western regions, covering 13.5 M ha (representing 4.1 %) of the total area. It causes loss of top-soil in 1.9%, terrain deformation in 1.2 % and over blowing and shifting of sand dune in 0.5% 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 statistics	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)

2.2. Emergence of multi-nutrient deficiency

The emergence of multi-nutrient deficiencies in soils owing to adoption of faulty 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 as if a soil assessed deficient in nutrient X is simultaneously deficient in nutrient Y and Z. The studies conducted in collaboration amongst PDCSR Modipuram, IARI New Delhi and IPNI, India Programme under different Agro-ecological regions and result 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% of the soils were found deficient in either NPKS/ NPK/ NKS/ NK, whereas only 6% soils were found was deficient in NPKSFe (**Figure 1**). Similarly, in Rohilkhand, Awadh and South Bihar Plains 96% soil showed the deficiency of elements. The 38% soil were found deficient in NPKSZn, followed by 22% NKZn, 18% NPK and 18% 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, Stalinization 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 s 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.

2.2. 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 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 estimated that even after achieving the full irrigation potential, nearly 50% 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% of the total ultimate potential through minor irrigation. Uttar Pradesh, Bihar are two states along with Madhya Pradesh, Andhra Pradesh and Maharashtra, which account for 58% 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.

2.3. 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% 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.

2.4. Climate/ weather resources

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

CLAIMATE 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.

2.4.1. 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 results 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.

3. 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 areas 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.

3.1. 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 **Figure 2**. 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.

3.2. Tillage and crop establishment

3.2.1. 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

3.21.1. 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

3.2.2. 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

3.3. Integrated and balanced nutrition

3.3.1. 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.

3.3.2. 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

3.3.3. 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)

3.3.4. 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

3.4. 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).

2.5 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)

3.6. 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

3.6.2 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

3.7. 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)

4. 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%.

5. References

AICRP-CS Reports. (1984-2000). Project Directorate for Cropping Systems Research Modipuram, Meerut, India.

Anonymous, (2000): Natural Resource management for agricultural production in India (J.S.P. Yadav and G.B. Singh Eds)

Dwivedi, B.S. Shukla, Arvind K., Singh, V.K. & Yadav, R.L. (2003). Improving nitrogen and phosphorus use efficiencies through inclusion of forage cowpea in the rice-wheat system in the Indo-Gangetic Plains of India. Field Crops Research 80, 167-193.

Dwivedi, B.S., Dhyan Singh, Chhonkar, P.K., Sahoo.R.N., Sharma, S.K. and Tiwari, K.N. (2006). Soil fertility evaluation- a potential tool for balanced use of fertilizers pp 1-60, IARI, New Delhi and PPI/PPIC- India Programme, Gurgaon.

Singh VK and Dwivedi B.S. (2006).Yield and N use-efficiency in wheat, and soil fertility status as influenced by substitution of rice with pigeon pea in a rice-wheat cropping system. Australian Journal of Experimental Agriculture.46 1185-1194).

Singh, S.P. and Vijayalakshmi (1992). *In:* Technologies for Minimizing Risk in Rainfed Agriculture. pp 70-98, ICAR, New Delhi

Solanki, K.R. and Newaj, R. (1999) *In:* Fifty Years of Dryland Agricultural Research in India. pp 463-474, CRIDA, Hyderabad, India.

Tiwari KN, Sharma SK, Singh VK_ Dwivedi BS and Shukla Arvind K (2006). Site-specific nutrient management for increasing crop productivity in India: Results with rice-wheat and rice-rice system. p-92. PDCSR Modipuram and PPIC India Programme Gurgaon.

******