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Review

Innovations in resource management for sustainable rice based farming

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Agricultural practice cannot be sustainable unless and until it is improving or at least conserving the natural resource base. There is need for a shift in outlook of viewing only the immediate benefits of farming practices. Rather, farming practices should be judged in terms of its effects on natural resources and environment, besides benefits in terms of yield and quality. Some ways and means of managing external resources, natural resources and stakeholders are discussed for resource conservation, in the context of agriculture and betterment of the environment as a whole. Knowledge on natural resources for farming and means of their conservation, need to be enriched and linked to stake holders through information technology. A few success stories in natural resource management under rice based farming around the globe are reviewed in this article.

Key words: Farming practices, natural resources, environment.

INTRODUCTION

Consultative Group on International Agricultural Research (CGIAR) defines integrated natural resource management as “the responsible and broad-based management of the land, water, forest and biological resources base, including genes needed to sustain agricultural productivity and avert degradation of productivity (Douthwaite et al., 2003). Natural resource in the context of agriculture includes plant genetic resources, water, land, soil mineral nutrients, weather elements and naturally occurring beneficial biological organisms. Natural resource management for agriculture encompasses all activities that enable farmers to grow a healthy crop and reap a stable and profitable harvest to meet household food needs and earn a reasonable income (Kam, 2003). Environmentally friendly farming practices require accomplishing productivity enhancement goals, without compromising the capacity of natural resource base and its underlying ecological processes. Natural resources are managed in a system perspective so that they continue to support future agricultural production. For enhancing the environmental quality and the resource base on which agriculture depends, there is a need for management of external resources, natural resources and the people. There is a need for the documentation of benefits from natural resource management and their dissemination.

Abbreviations: CGIAR, Consultative Group on International Agricultural Research; **LCC,** leaf colour chart; **SSNM,** site specific nutrient management; **N,** nitrogen; **P,** phosphorus; **K,** potassium; **RRLRRS,** Regional Rainfed Lowland Rice Research Station; **NGOs,** non governmental organizations.

MANAGING EXTERNAL RESOURCES FOR SUSTAINABLE AGRICULTURAL PRODUCTION

Applying just enough inputs as at when needed by the crop would avoid overuse and misuse of fertilizers and pesticides, land degradation and erosion of biodiversity. Timely crop oriented nutrient management technologies such as the leaf colour chart (LCC) for nitrogen management of rice (Yang et al., 2003) and site specific nutrient management (SSNM) approach for tailoring P and K application rates as per yield target and soil nutrient supplying capacity (Fairhurst and Witt, 2002) to be adopted in large scale by the farmers.

In post-flood situation, a substantial quantity of fertilizer can be saved, if plant nutrients are managed on real time basis. Some cultivated varieties of rice like Durga and Padmini require low amount of nutrients. Even fertilizer responsive varieties like Ranjit, Tapaswini, Chandrama, etc, require only 25% of their nutrient requirement. Winter crops grown in post flood situation also get the nutrient benefit from floodwater.

Safe limit of trioxonitrate (iv) ions (NO_3^-) in drinking water is about 45 mg l^{-1} (United States Environmental Protection Agency). Adverse effects of nitrates and nitrites leading to "Blue baby syndrome" and nitrosamines on carcinogenic tumours are well known. Ground water nitrate pollution can be restricted, if required quantity of fertilizers are applied in conjunction with cultural practices like split application and growing of deep-rooted crops such as alfa-alfa in crop rotation as nitrate catchers. About 30% of P and 60 to 70% of K fertilizers were utilized by the immediate crop to which it was applied. Accounting residual nutrient from applied fertilizers in a cropping system perspective, may curtail their rate of application. Eutrophication, resulting from the excessive growth of algae and other aquatic plants in water bodies, can be prevented to a large extent through application of phosphatic fertilizer in the root zone only followed by soil covering. This helps in minimizing the loss of phosphatic fertilizers through the run-off water. Similarly, early stage pest control using pesticides against leaf folders of rice can be avoided because at this stage, plants possess enough recouping capacity. Moreover, avoidance of pesticide may be beneficial in encouraging natural enemies against the leaf folders. Potassium is labile in soil and its split application reduces leaching loss, especially in light textured soils. Placement of N, P and K fertilizers near the zone of root development (about 5 to 10 cm away and below the field crops) improves the fertilizer use efficiency and thus, farmers can get similar yields at reduced fertilizer dosage.

MANAGING NATURAL RESOURCES FOR AGRICULTURAL PRODUCTION (ECOLOGICAL APPROACH)

Ecology is the study of how organisms interact with their abiotic and biotic environment. Abiotic components are non-living, such as space, weather and pesticides. Biotic components include primary producers (for example, rice plants), herbivores (for example, rice insect pests), natural enemies of rice pests (for example, parasitoids, predators, pathogens) and competitors (individuals of the same species). Ecology gives a new context to pest management like "live and let live". It is better not to think of "pest control" simply to reduce crop damage, but to be concerned for the prevention of outbreaks of pests. Pest outbreaks usually occur if the normal equilibrium of populations is disturbed by natural disasters (for example, drought, floods, fire), crop management (for example, removal of natural enemies by insecticides, over-use of nitrogen); or massive pest immigrations. There are some ways to the management of pests namely:

i) Reducing pest levels, for example, using insecticides, cultural practices;

ii) Improving natural enemy levels, for example, establishing refuges; and

iii) Improving resistance of the plant to pest attacks (for example, nutrient management and breeding for host plant resistance to pest).

The concept of ecological management gives equal importance for vigilance on population dynamics of pests as well as their natural enemies. The cultural practices, which reduce the pest population, should not be viewed in isolation from their effects on beneficial macro- and micro-organisms. Conservation of these beneficial organisms is a great step in managing natural resources in pest management programme. Avoidance of chemical spray, unless very essential is conducive for the existence of natural enemies. This is important especially in the month of October, as the populations of natural enemies are observed as maximum.

High quality seed stock with early seedling vigour has the distinct advantage in fighting against weeds, diseases and insect pests. One way of mitigating the problem of blast disease in rice crop is through interplanting of disease resistant high yielding varieties with susceptible high yielding varieties. Similarly, intercropping upland rice with pigeon pea; or sorghum with groundnut, wards off many pest and diseases in addition to complimentary reaction between a legume and cereal and their rooting pattern and spread. In crop rotation, inclusion of deep-rooted crop like alfa-alfa or pigeon pea, not only catch the labile nutrients like nitrogen and potassium escaped to the subsoil, but also loosen the hard pan in subsoil (bio-tillage) and reduce the risk of pest resurgence or disease out-break. Soil borne pathogens like *Fusarium* and *Rhizoctonia* can be effectively controlled by growing non-host crops in crop rotation. Beneficial soil micro-organisms like *Trichoderma* spp. have antagonistic effects on many soil pathogens by releasing toxins, natural antibiotics and other metabolic products. Little study on microbial biodiversity has been accomplished on utilizing this important natural resource in managing insect pests, weeds and pathogens. Some microbes have the potential to improve the resource base for agriculture like increasing the nutrient supplying capacity of soil, improving the quality of agricultural produce etc. For pathogens like blast, ufra, that is, where host plant resistance is available, development and utilization of resistant/tolerant varieties is the need of the hour.

For weed management, critical period begins when the crop yields begin to decline in the infested field and crop yields are no longer negatively impacted even in the presence of weeds (Figure 1). Allowing weeds for initial few weeks will not only help in catching mobile nutrient

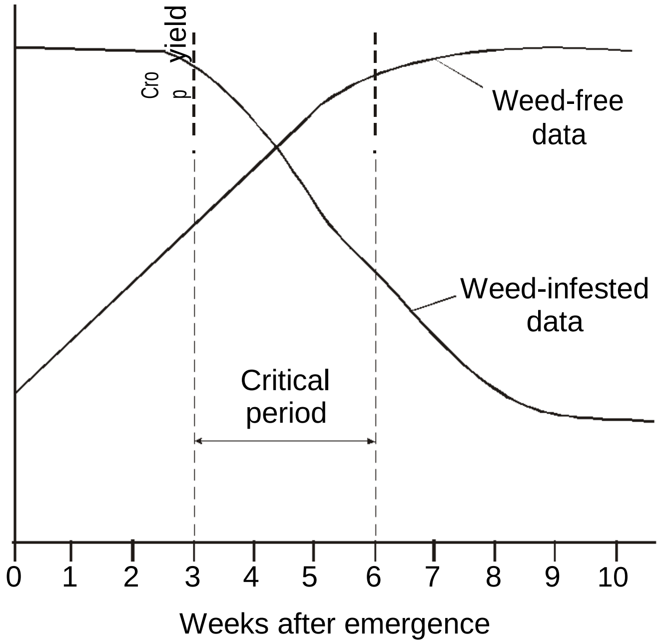

Figure 1. Critical period of weed management begins when crop yields in the weed-infested field begin to decline and ends when crop yields are no longer negatively impacted by the presence of weeds. Source: Ross and Lembi (1999).

Table 1. Rank of world's worst weeds.

Weed specie	Common name
Cyperus rotundus	Purple nutsedge
Cynodon dactylon	Bermudagrass
Echinochloa crus-galli	Barnyardgrass
Echinochloa colona	Jungle grass
Eleusine indica	Goosegrass

Source: Holm et al. (1977).

elements but also encourage an increase in biodiversity.

Allelopathy is one form of interference that occurs when one plant, through its living or decaying tissue, interferes with growth of another plant via a chemical inhibitor. Some plants actively eliminate competition by producing toxins that enter the soil and prevent the normal growth of other plants. Corn cockle and ryegrass seeds fail to germinate in the presence of beet seeds. *Cyperus rotundus*, the world's worst weed (Table 1), can be managed by including *Sesamum indicum* in crop rotation. Allelo chemicals exuded through roots of *Sesamum indicum* hinder the growth of *Cyperus rotundus*.

There are examples of dramatic changes in weed community composition or shifts resulted from changes in crop or weed management practices (Table 2). This crop establishment shift also demonstrated increased abundance of number of weeds in direct seeded rice and a change in abundance from aquatic to more terrestrial species.

Maintenance of plant and animal genetic resources is an important aspect in sustaining agricultural production. Genetic biodiversity of crop plants, fish and animals should be judiciously utilized in overcoming biotic and abiotic stresses, harvesting a quality produce enriched in nutritional components, besides the primary aim of high yields. Utilization of medicinal value of crop plants is less explored and this may be the safest way of overcoming the human ailments. Thus, genetic resources is an important natural resource base for meeting the food demand for human and livestock, and maintaining the quality life as envisaged in the evolution of rice varieties enriched with Vitamin-A (Golden rice), iron and zinc.

Among the abiotic natural resources, management of water has great influence on environment. There is a growing concern for water saving technologies in the context of depletion of ground water. Dry direct seeding saves water for field preparation and labour. Land leveling reduces amount of water needed for flooding and weed control. Alternate wetting and drying, furrow irrigated raised bed system of irrigation and aerobic system of rice cultivation have promise in saving water and improving microbial biodiversity in soil. Among the eco-friendly soil management measures, tillage operation at appropriate soil moisture has great influence in avoiding soil/sub-soil compaction. Minimization of agro-chemicals like pesticides and fertilizers and regular application of safe organic materials, goes a long way in enhancing soil productivity. Important bio-measure for enhancing the soil health is the incorporation of a legume crop in the crop rotation. Weather elements like rainfall, solar radiation, temperature, humidity, evaporation and wind influence crop production directly and indirectly. Period of maximum solar radiation and higher temperature should be associated with the grand growth phase of crop plants. Grain filling stage should coincide with moderately low temperature and low humidity. High temperature at this stage leads to low head rice recovery after milling while high temperature coupled with high humidity activates many pathogens at harvesting stage in almost all crops leading to the loss in quantity and quality.

MANAGING PEOPLE FOR MANAGEMENT OF NATURAL RESOURCES

Awareness must be created among farmers and other stake-holders such as local authorities, extension personnel, non governmental organizations (NGOs), agricultural private sector and policy makers regarding the management of natural resources. Participatory methodologies and tools should be exploited by researchers and extension personnel before undertaking research and extension works on natural resource management. This will activate the involvement of

Table 2. Weed shifts in rice in response to shift from transplanting to direct-seeding of rice in Malaysia.

Weed specie by dominance					
Season (crop)					
1979 (2)	**1982 (1)**	**1984 (1)**	**1984 (2)**	**1987 (1)**	**1989 (1)**
Monochoria vaginalis	*Monochoria vaginalis*	*Fimbristylus miliacea*	*Echinochloa crus-galli*	*Echinochloa crus-galli*	*Echinochloa crus-galli*
Ludwigia hyssopifolia	*Ludwigia hyssopifolia*	*Monochoria vaginalis*	*Scirpus grossus*	*Echinochloa colonum*	*Leptochloa chinensis*
Fimbristylus miliacea	*Fimbristylus miliacea*	*Echinochloa crus-galli*	*Ludwigia hyssopifolia*	*Leptochloa chinensis*	*Fimbristylus miliacea*
Cyperus difformis	*Leersia hexandra*	*Scirpus grossus*	*Panicum amplexicaule*	*Scirpus grossus*	*Marsilea crenata*

Source: Ho (1996).

farmers, communities, policy maker, etc. Plan for agricultural production should be knowledge driven looking into the database on conservation and sustainable utilization of the natural resources. This database should be linked to all the stakeholders related to farming through information technology. This will go a long way in managing people and the natural resources.

EXEMPLARY INNOVATIVE FARMING PRACTICES

Three reductions and three gain campaign in Vietnam

Farmers in the Mekong River Delta of Vietnam initially adopted “no early spray” and thereby reduced the use of insecticides. This could be possible due to high recouping capacity of rice plant in early growth stage and the scope for higher number of natural enemies. Latter, the farmers adopted the practice of using low fertilizer dose through site-specific nutrient management. The fields rich in P or K were provided with proportionately low fertilizers without any loss in yield. Thirdly, the encouraged farmers adopted the practice of lower seed rate by using drum seeder. The three reductions in pesticide, fertilizer and seed resulted in three gains viz., increased yield, better grain quality and more profit. The farmers were directly benefited from these gains and simultaneously the practices were eco-friendly.

Seed health campaign in Bangladesh

The proverb “as you sow, so you reap” is directly relevant in selecting a healthy seed lot for use in the next season. Seed stock is to be collected from a disease free field and subsequently, harvest, post harvest and storage operations are to be properly done. These simple practices are useful in getting seedlings with initial early vigour. These seedlings have an edge over other seedlings regarding tolerance against insect pest or pathogen attack or abiotic stresses like drought or submergence.

Interplanting for blast management in Peoples Republic of China

In China, modern high yielding hybrids having blast resistance were interplanted with traditional taller glutinous rice varieties (Leung et al., 2003). This resulted in lower blast incidence in the field because the resistant hybrids did not allow the spread of the disease occurring at few patches. It could be possible to grow these traditional varieties (glutinous) having high socio-cultural and market value without the use of fungicide. This pro-environment intervention can save the use of pesticide and thereby increase the profit margin to farmers.

Utilization of host plant resistance against rice blast in Arab Republic of Egypt

Blast disease of rice is associated with cool temperature and high humidity. Once, blast was a major problem for Egyptian rice growers. Utilization of host plant resistance in to the rice improvement programme has helped in escaping from the menace of this disease. Similar benefits have been reaped in some other countries including Peoples Republic of China and Korea.

System of rice intensification (SRI) in Madagaskar and Sri Lanka

System of rice intensification involves getting higher yield by early planting of younger seedlings (at 2 to 3 week stage) at wider spacing (30 to 40 cm) with more use of organic materials and frequent stirring of soil through intercultural operations. Recycling of organic materials, such as source of plant nutrients, reduce the dependency on chemical fertilizers. Simultaneously, plants grown with organic source of nutrients invite less pest problem and thereby reduce the pesticide application. Farm produce of organic origin fetch higher market price and possess better quality including storability. Adoption of wider spacing in this system helps in reducing cost on seed. However, this system is labour intensive.

Managing water and land resources at the interface between fresh and saline water environments in Vietnam

About 160,000 ha of coastal lands in the Bac Lieu Province in the Mekong River Delta were targeted for complete salinity protection in favour of intensified rice production programme. While the construction of sluice progressed in 1990, brackish water shrimp culture emerged as a highly profitable enterprise. Intensified rice production programme required fresh water while shrimp culture required ingression of saline water from sea. These conflicting interests were managed by sluice operation that allowed carefully controlled entry of saline water for shrimp cultivation during the dry season followed by flushing out of salinity with fresh water at the start of rainy season for rice cultivation.

Rice based farming system approach in South-East Asian countries

Growing of a single crop in large patches over seasons led to erosion in biodiversity and the risk of pest outbreak. Farming system involves growing of several crops and other enterprises like dairy, poultry, piggery, fishery, apiary etc in a complementary manner so that available farm resources are utilized optimally and most efficiently. The choice of farm enterprises is also dependent on the socio-cultural value and the needs of the locality. Rice-fish based farming system in South-East Asian countries is a glaring example based on the plenty availability of rain water for cultivation of rice and fish. Recycling of animal wastes into the fishponds and utilization of crop residue as livestock feed is based on the principle of complementary use of resources so that there is no waste product in the system. Co-existence of complementary enterprises may help in maintaining wide biodiversity and it is close to nature.

Field experiment was conducted at Regional Rainfed Lowland Rice Research Station (RRLRRS), Gerua on occupying 60% of the total area followed by horticulture and agro-forestry components on dykes (23%). The pond refuge (30 x 12 x 2 m) was constructed at the lower end (down slope) of the field occupying 7.2% area. The two trenches of 2.5 m width occupying 10% of the total area were constructed adjacent to the dykes along the longitudinal side of the field and those connected to the pond refuge at one end. The trench bottom had a gentle slope of 0.75% towards the pond refuge. The dug-out soil from the pond refuge and side trenches, were used for construction of wide dykes all around with bottom and top width of 4 and 2 m, respectively. The average height of the dykes was 1 m, which was 0.4 m higher than the usual maximum water level in the field. 6 platforms of 4 x 3.5 m size were hanged over the trenches for planting the creeper vegetables.

The results from this experiment revealed that integrated rice fish based farming system is economic, eco-friendly and a low risk enterprise. The gross return from the different components of the rice-fish system for the first year (2002-2003) was Rs. 44,382 (Table 3). The total expenditure including cost for farm construction was Rs. 33,156. Thus, a net profit of Rs. 11,226 was obtained besides generating employment of around 350 man-days. Compared to this, the income from the same field through traditional rice farming (only one crop) was Rs. 4,000. The return increased in the subsequent years from the produce of fruit plants (viz., plantain, papaya, lemon and guava) and it is expected to increase from coconut, areca nut and teak in subsequent years. The income could further increase through incorporation of some other components like duckery, poultry and piggery as reported by Sinhababu and Singh (2001) in rainfed lowlands in Eastern India. Besides the favourable economics and employment generation potential of the system, the other advantages include: (a) Low requirement of pesticide (b) water harvesting for off-season use (c) soil conservation (d) enhanced biodiversity due to differential soil condition (from upland to lowland), different plant species and no pesticide use

(e) availability of fresh proteins from farm animals and also the fruits and vegetables for good health of farm families.

Agricultural development in the uplands of Yunan

Poor ethnic populations of Western Yunnan Province of China were adopting extensive cultivation of low yielding upland rice varieties. High yielding upland rice varieties introduced by Yunnan Academy of Agricultural Science, substantially improved yield status with some additional fertilizers and further with the increased availability water under terraced condition. This increment in yield could be achieved from less land that was enabled to meet the rice requirements. Farmers were encouraged to discontinue rice cultivation on slopes exceeding 25°. Sloping lands released from upland rice cultivation were rehabilitated with forest plantations. Crop and livestock diversification around, a pond refuge connected to two side trenches (micro-watershed-cum-fish refuge) and one guarded outlet (Figure 2). Rice was the major component low-lying rice field (125 x 40 m) holding 20 to 60 cm water in *sali* season. Field design included wide dykes all programme were introduced in the next phase for improving the natural resource base.

RAINFED RICE-POTATO CULTIVATION WITH THE USE OF MULCHES

Field experiment conducted at Regional Rainfed Lowland Rice Research Station, Gerua, India revealed the

Table 3. Return on expenditure from different components in first year (2002-2003) from rice-fish system at RRLRRS, Gerua.

Item/crop	Operational cost Including labour (Rs.)	Gross return (Rs.)	Net profit (Rs.)
Farm construction	6000 (10% of the cost of construction + interest on total cost is taken as the depreciation cost)		-
Rice (3 crops)	17106	25387	8281
Fish	8650	17180	8530
Vegetables and flowers	1400	1825	425
Total	33156	44382	11226

Source: Rautaray et al. (2005).

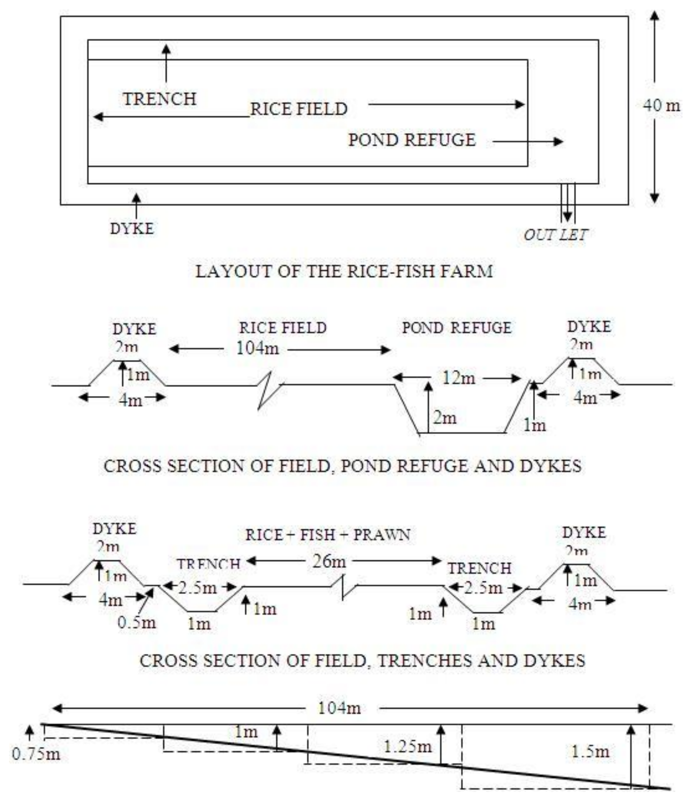

Figure 2. Design of the rainfed lowland rice-fish based integrated farming system at RRLRRs, Gerua (0.5 ha).

feasibility of rainfed rice-potato cropping system by using mulches for potato crop in medium lands of Assam.

Mulch of dried water hyacinth or paddy straw could retain soil moisture and improved the soil temperature facilitating fast sprouting and subsequently better plant growth. Mulching avoided the need for irrigation, weeding and earthing up of potato crop. The incidence and severity of bacterial wilt and late blight disease were lesser in mulched plots as compared to the no mulch control. Avoidance of irrigation, earthing up, low or no pesticide use with mulching was conducive to natural conservation of resources in terms of undisturbed ground water, less soil erosion and reduced load of pesticides. Mulching with dried water hyacinth reduced the disease

Table 4. Yield of potato varieties under mulching with dried water hyacinth.

Variety	Yield (q/ha)		
	Without mulching	With mulching	Mean
K. Giriraj	2.1	7.6	4.9
K. Jyoti	4.5	16.4	10.5
K. Megha	8.3	70.0	39.2
Naintal	4.4	8.5	6.5
K. Kanchan	4.7	19.1	11.9
Kufri Chandramukhi	6.0	16.5	11.3
Mean	23.0	5.0	

CD (P = 0.05); Variety (V) = 4.7; Mulch (M) = 2.2; V x M = NS.
Source: CRRI annual Report 2005-06. Central Rice Research Institute, Indian Council of Agricultural Research, Cuttack (Orissa), India.

incidence and improved tuber yield from 5 to 23 q ha^{-1}. (Table 4). Significantly high tuber yield was recorded from Kufri Mrgha (39.2 q ha^{-1}) due to better tolerance to wilt and blight (CRRI Annual Report, 2005-06).

CONCLUSION

Some successes have been achieved in natural resource management in agriculture. However, a lot need to be achieved through research results followed by their adoption. With the advancement in science, further development in knowledge and understanding of natural resource is expected if a special insight is given towards this neglected aspect. Data base on conserving and sustaining the natural resource base for agricultural production and its link to all the stakeholders through information technology will go a long way. “It is not difficult to manage our natural resources for us and our posterity”.

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