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Department of Agriculture Cooperation and Farmers Welfare
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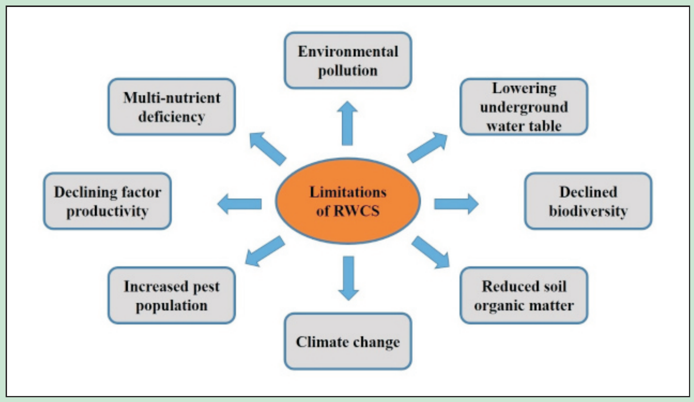
Government of India, New Delhi



H.N. Meena, S.K. Singh, M.S. Meena and Bheem Sen

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Contents

1. Introduction

Farmers in Asia have been following the rice-wheat cropping system (RWCS) for over 1000 years. This cropping system covers 26.00 million hectares area throughout the Indo-Gangetic Plains (IGP) in South Asia and China, making it one of the world's largest agricultural production systems. It is India's major agricultural system, covering around 10.5 million hectares and playing a vital role in its food security. However, the sustainability of RWCS has been adversely affected as rice and wheat yields have remained static or reduced in recent years due to the resurgence of diseases, insects, and weeds. Deteriorating soil health; water depletion; reduction in factor productivity or input-use efficiency; environmental pollution/degradation; increase in cultivation costs and profit reduction.

Crop diversification is a strategy for transitioning from a less profitable and unsustainable crop or cropping system to a more profitable and sustainable one by maximizing resource utilization and changing and modifying the temporal and spatial crop/cropping operations on a farm. Diversification of RWCS may be a realistic strategy for certain circumstances. It can be categorised into horizontal crop diversification and vertical crop diversification.

Horizontal crop Diversification

This relates to multiple cropping or mix of crops instead of cultivating a single crop. Horizontal diversification is beneficial for small farmers who hold a small piece of land. It allows them to earn more by escalating cropping intensity. It entails widening the system's base by simply adding more crops to the existing cropping system, using techniques like multiple cropping and other efficient management approaches.

Vertical crop diversification

It refers to using any crop species that can be refined to make products such as fruits and vegetables canned or processed into juices or syrups. Vertical diversification refers to the incorporation of industrialization and multiple cropping. In this type of diversification, farmers invest in horticulture, agroforestry, livestock, aromatic plant etc.

The country's unique agro-ecological characteristics are ideal for growing a variety of oilseeds, legumes, vegetables, fodder, and medicinal crops. The inclusion of pulses, oilseeds, and fodder crops in the RWCS can help to meet the growing demand. Introduction of Rabi sunflower is a good alternative to wheat in basmati rice-growing areas where the lengthy duration of basmati rice delays the seeding of wheat. Similarly, rice can be replaced with soybean, short duration pigeon pea and urd bean in Punjab and Haryana, where rapidly depleting the groundwater table. Pulses promise agricultural diversification significantly because of their short lifespan and capacity to flourish better than other crops under challenging climates and fragile ecosystems while providing family food and nutritional security. They can be intercropped, relay cropped, or farmed as a catch crop in several different ways. The growing need for pulses to fulfil the needs of the world's growing population has brought non-traditional and underutilized locations into the sharp spotlight.

Furthermore, inclusion of food legumes into the rice production system increases crop area and improves soil's physical, chemical, and biological properties. As a result, the long-term viability of the crop production system and the necessity of increasing pulses production necessitate rapid remedial action in the form of crop diversification. Crop diversification is seen as a key instrument for accelerating agricultural expansion by increasing food and nutritional security, income and employment production, poverty alleviation, the wise use of natural resources, and environmental management.

The rice-wheat farming system in South Asia has contributed significantly to filling the growing number of empty stomachs. However, it has also resulted in many sustainability challenges, such as falling water resources, deteriorating soil health, and environmental degradation, contributing to reduced land and water productivity. As a result, farmers in the Indo-Gangetic Plains should embrace a sustainable diversification and intensification of rice-wheat cropping systems to increase land and water productivity, soil health, and the environment, thereby improving their overall health. On the other hand, diversification and intensification are site-specific and vary based on the farmers' socioeconomic level and agro-climatic circumstances. It implies that farmers must choose from many appropriate options for their socioeconomic level and agro-climatic conditions.

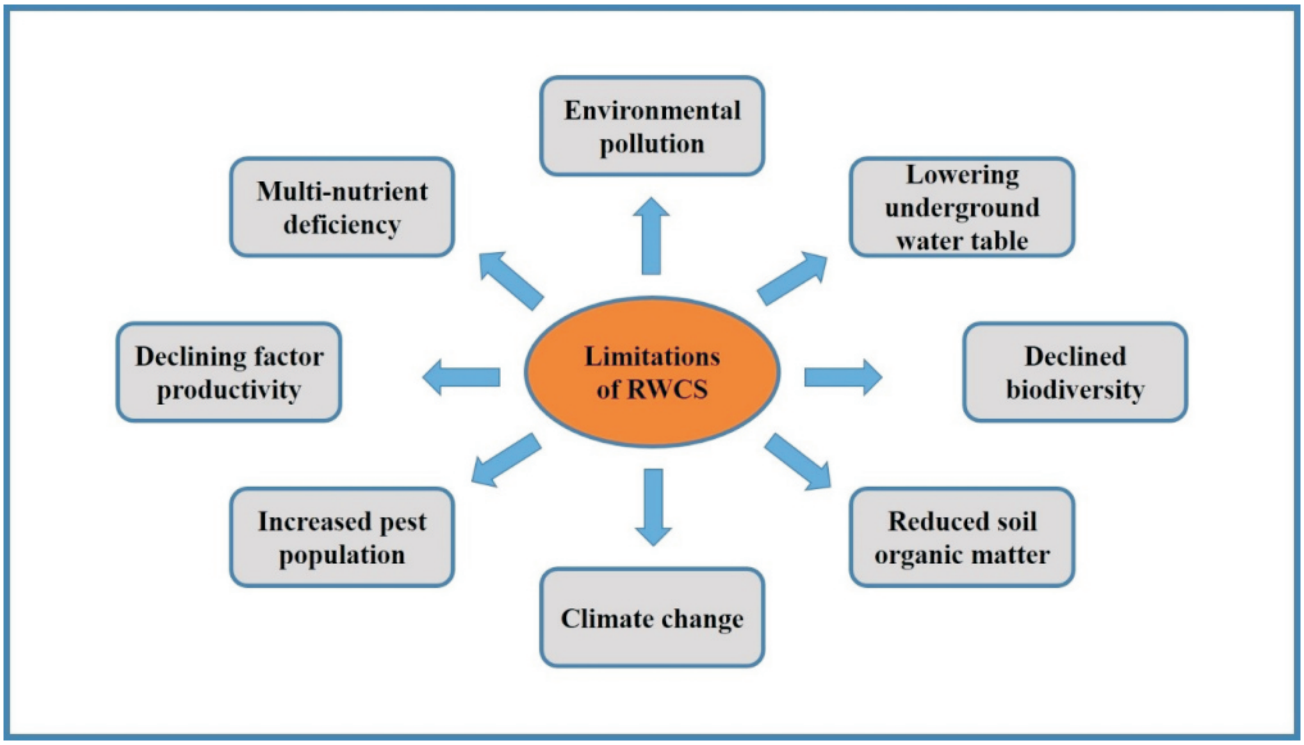
Moreover, in recent years, large-scale burning of rice and wheat residues after harvest raised air quality issues and the consequent impact on human and animal health. By considering all these aspects of RWCS, there seems no other option but to reduce the area under this cropping system in highly vulnerable regions (Northern States of India) and shift to other alternate crops.

2. Limitations of the Rice-Wheat cropping system

Various findings have been emerged with clear-cut evidences that increased input utilization since green revolution technologies has decreased marginal returns. Similarly, it is well known that inefficient use of applied inputs and over-exploitation of natural resources, particularly land and water, is causing several issues, such as a reduction in soil organic matter, emerging multi-nutrient deficiency, decline in productivity, reduction in biodiversity, lowering of groundwater table, and the accumulation of insects, pests and diseases in rice-wheat cropping systems.

2.1 Lowering underground water table

Rice and wheat are water-intensive crops, and their year-round production has resulted in a drop in the water table in Punjab and Haryana. Replacing these water-guzzling crops with low water requiring crops like pulses and oilseeds and growing of cover crops like summer mung bean (Vigna radiata) during



Limitations of Rice-Wheat cropping system

intervening period (period from wheat harvesting to sowing/transplanting of rice) has a tremendous scope and capacity to improve land and water productivity through reduced water use and in-situ soil moisture conservation. The NAAS "GRACE" gravity mapping satellite revealed a rapid reduction in subsurface water (1-foot/year) in northern India over a 440,000 km^2 area, resulting in a loss of 18 km^3 $year^{-1}$. The diminishing water table has three significant negative consequences:

(i) increased underground water pumping costs.

(ii) increased tube well infrastructure costs.

(iii) deteriorating groundwater quality.

which will eventually render the groundwater unusable due to salt upwelling from deeper layers of groundwater and saline groundwater intrusion into fresh groundwater.

2.2 Growing multi-nutrient deficiency

Due to intensive cultivation of high yielding rice and wheat varieties, zinc (Zn) deficiency first, and then iron (Fe) and manganese (Mn) deficiencies in rice and wheat has been emerged as challenges to maintaining high levels of food crop output. Field-scale zinc (Zn) deficiency was initially detected in rice in Tarai soils (Mollisols) in the Himalayan foothills, resulting in the crop's complete failure. Since then, crops produced in around half of the country's soils have been deficient in one or more micronutrients. According to some studies, 49% of Indian soils are potentially deficient in zinc (Zn), 12% in iron (Fe), 5% in manganese (Mn), 3% in copper (Cu), 3% in boron (B), and 11% in molybdenum (Mo). Sulphur (S), zinc (Zn), and boron (B) deficit soils are now widely recognized in India. Other micronutrient deficiencies have been observed irregularly around the country. Under rice-wheat cropping systems, some researchers found that secondary and micronutrients were becoming increasingly important as yield-limiting variables. Zinc deficiency is a major limiting issue for wetland rice on approximately 2 million hectares in Asia.

2.3 Reduced soil organic matter

Carbon is the most important element in determining soil fertility since it mediates the release of various plant nutrients into the soil and controls crop output. Simultaneously, it increases soil resilience by buffering various soil qualities, resulting in a favourable soil environment for plant growth. Soil organic carbon (SOC) sequencing is a critical method for improving soil health and mitigating climate change. However, in the RWCS, conventional rice necessitates puddling for seedbed preparation, requiring additional water and labour; this, in turn, fractures soil aggregates, exposing the soil to organic carbon oxidation. As a result, traditional rice-wheat agriculture depletes SOC at a rate of 0.13 t ha^{-1} yr^{-1} from 0 to 0.6 m deep in the eastern IGP. Crop diversification appears to be one of the most practical solutions to the situation at hand. Incorporating legumes into a cereal-cereal rotation improves soil quality and increases organic carbon levels, which will be helpful in achieving ecological sustainabilty.

2.4 Decline in biodiversity

Traditional cropping systems provide around 20% of the world's food, but energy-intensive agriculture rapidly degrades these landscapes, resulting in a loss of indigenous agro-biodiversity. The agricultural landscape in India is dominated by rice (*Oryza sativa* L.) and wheat (*Triticum aestivum* L.) based agro-ecosystems (RWAS). Farmers increasingly turn to these crops as new seeds and irrigation infrastructure becomes available. Traditional crops and varieties are gradually vanishing from the farmed landscape. These conventional crop varieties were resistant to insect pests and disease, demanding fewer environmentally harmful pesticides. Only a few rainfed cultivars have spread successfully, raising concerns about agricultural genetic diversity narrowing from favourable to unfavourable conditions. Crop diversification is a vital resilience strategy for agro-ecosystems because it is recognized that biodiversity is essential to maintaining ecosystem function.

2.5 Increased pest population

Weed, pest, and disease problems have become more prevalent as a result of agricultural intensification in general and continuous monoculture of rice-wheat in particular. Wheat and Rice both are grown in a lush environment. Green crops with greater N-fertilizer doses and damp circumstances due to frequent irrigations are breeding grounds for insect pests and diseases. For instance, Rice pink stem borer (*Sesamia inferens*) and shot fly (*Antherigona oryzae*), which are used only to affect rice, can damage both crops and are considered general concerns in India. In the rice-wheat zones of the Indo-Gangetic Plains, soil-borne diseases are becoming an increasingly important issue in limiting crop growth. Soil pathogens such as *Fusarium, Rhizoctonia,* and *Sclerotinium* may accumulate due to the continuous RW system. *Rhizoctonia solani* and *Sclerotinium rolfsii* cause sheath blight and stem rot, respectively, in both crops.

2.6 Declining Factor Productivity

Factor productivity is defined as the ratio of output value to input cost. It is one of the indicators used to estimate the long-term profitability of any system. It could be a Total Factor Productivity (TFP), the ratio of total output value to total input cost, or a Partial Factor Productivity (PFP), which is the ratio of output value to a single input. TFP indices, originally designed to measure production efficiency over a short period, have gotten much attention in recent years as indications of the agricultural system's long-term viability. TFP is used to quantify sustainability; any sustainable production system must have a non-negative trend in TFP over time. Many long-term trials undertaken in India show that, depending on the soil types, rice or wheat production declines after a few years of continuous cropping, even with continuous application of balanced chemical fertilizer (NPK). It could be linked to developing a deficiency in one or more secondary nutrients and micronutrients.

2.7 Climate change

Crop residue burning, common among farmers in the Indo-Gangetic Plains, contributes to GHG emissions. Rice-wheat cropping pattern produce massive left-overs, typically burned onto the field to sow the wheat crop on time. Farm waste burning releases a large amount of greenhouse gases, aerosols, and other hydrocarbons into the atmosphere, altering the atmosphere's composition. When rice straw is burned, 70%, 7%, 0.66% C and 2.09% N were released as CO_2, CO, CH_4, and N_2O, respectively. CH_4 and N_2O, in addition to CO_2, are two very active trace gases in the atmosphere. Puddled transplanted rice in RWCS is a major source of greenhouse gases from the agriculture industry. Rice fields and residue burning are substantial anthropogenic sources of CH_4 in addition to other sources (coal mining, oil and natural gas flaring, domestic ruminants, sewage, etc.). Methane is produced when easily degradable organic matter is stripped of oxygen and other suitable electron acceptors during a process known as methanogenesis. Global climate change, which has resulted in an increase in the frequency of extreme weather events in general and a rise in global temperatures in particular, has harmed the productivity of most food grain crops. Some studies concluded that the expected increase in temperatures due to global warming would reduce crop growth duration and production of both crops (rice and wheat) in the future. It was found that a 2°C increase in mean air temperature can decrease rice productivity by 0.75 t ha^{-1}.

2.8 Environmental pollution

Because the rice-wheat cropping system is a cereal-cereal system, it necessitates more inorganic

Smog in Delhi due to crop residue burning

fertilizers. The combustion of fossil fuels in industries pollutes the environment when substantial fertilizers are produced. An estimated 2.6 kilogram of carbon dioxide (CO_2) is released into the atmosphere for every liter of diesel fuel utilized. In a normal system, a tractor for field preparation and pumping water for irrigation consumes roughly 150 litres of fuel per hectare per year, resulting in CO_2 emissions of about 400 kg/hectare/year. The annual application of a large amount of inorganic fertilizer to the soil causes groundwater contamination, eutrophication of water bodies, and the accumulation of harmful components in the environment. The presence of high nitrate levels in groundwater in intensively planted RWCS has been documented in various research. In north India, farmers harvest the rice crop with combines and burn loose residues to ensure timely wheat seeding. This helps farmers clean the field faster than natural decomposition. Crop residue burning pollutes the air by releasing greenhouse gases, aerosols, and other hydrocarbons, which have negative health consequences by directly creating or exacerbating various health problems and adding to traumatic traffic accidents by reducing visibility. The mortality of beneficial soil fauna and microorganisms is caused by the burning of left-over waste, contributing to poor air quality and human respiratory diseases. Besides carbon, burning results in a loss of up to 80% of N and S, 25% of P, and 21% of K.

3. Diversification options for RWCS

Crop diversification is defined as a method for transitioning from a less profitable and unsustainable crop or cropping system to a more profitable and sustainable crop or cropping system through careful resource management and altering and modifying crop/cropping activities in space and time. Diversification in agriculture refers to shifting from one crop's regional dominance (such as rice) to another crop's regional dominance (such as oilseeds), or from one enterprise (such as crop-based) to another enterprise (such as livestock), or engaging in other complementary activities. In India, one of the most common phenomenon is horizontal diversification. In this strategy, new crops are added to an existing cropping system to increase the total productivity of a farm or region's farming economy or shift from subsistence farming to high-value crops. Similarly, conventional RWCS of northern states of India can also be diversified in many ways, which are as follows:

- Crop-based diversification.
- Diversification into Integrated Farming Systems.
- Agroforestry-based diversification.
- Crop management-based diversification.
- Other potential diversification options

3.1 Crop based diversification

In some years, farmers replace wheat with oilseeds [mustard or rapeseed (*Brassica napus*)], pulses [pea (*Pisum sativum*), chickpea (*Cicer arietinum*), pigeon pea (*Cajanus cajan*), lentil (*Lens culinaris*), maize, and potato to produce a variety of foods, increase income, and avoid risk. Rice-potato-rice, for example, is gaining popularity among Indian farmers. Cotton, maize, sunflower, and soybean may also be substituted for rice in R-W systems, depending on soil type. Pulses, oilseeds, and vegetables have been discovered to be more helpful to the system than cereal-cereal sequence.

Legume crops fix atmospheric nitrogen, improve soil fertility, and may assist cereal-based cropping systems maintain long-term production. Diversifying the rice-wheat cropping system with a grain/fodder legume or *Sesbania* as a green manure substitute crop reduces soil pH, bulk density, and improves soil organic carbon as well as available nitrogen and phosphorus. The legumes in the rotation fix nitrogen biologically, increase nutrient availability, soil structure, and stimulate mycorrhizal colonization and thereby helpful in achieving ecological sustainability. It was also discovered that including a third crop of legumes in the rice-wheat sequence during the summer increased the sequence's production. So, these traditional crops' regions can be converted to other crops on a rotation basis, which will assist restore soil health and improving farmers' livelihoods.

Sesbania bispinosa (Dhaincha) for green manuring

The Indian Institute of Farming Systems Research (IIFSR) in Modipuram and its sub-centers across the country have identified many cropping systems with higher production while using the same or less water and other resources than the rice-wheat system. For instance, In Punjab, rice equivalent yields from maize-potato-onion and maize-potato-green gram systems were 27.6 and 18.2 t/ha, respectively, compared to 13.7 t/ha from rice-wheat systems. However, stronger governmental assistance in terms of minimum support price (MSP), assured marketing, and trade opportunities will be required to promote such cropping systems. Table 1 lists some of the water-efficient productive cropping systems.

There are numerous choices in India's northern states for replacing rice and wheat crops. On the other hand, Optional crops must be made as profitable as rice crops through increased production and policy support. Table 2 lists some of the alternative crops that can replace rice and wheat crops in major RWCS regions.

Furthermore, in furrow and ridge cultivation geometry, rice and alternate crops such as soybean, maize, and green gram appear to have potential. Only the rice crop cultivated in furrows receives irrigation in this approach; the supplementary crop of maize/soybean/green gram planted on ridges can be effectively raised with the same amount of water.

Table 1. Water-efficient high productive cropping systems

Cropping systems	Rice equivalent yield (t/ha)	Irrigation water use (cm)	Irrigation water productivity (kg/m^3)
Rice-wheat	13.7	205	0.67
Maize-wheat	12.6	84	1.50
Maize-wheat-green gram	15.0	117	1.28
Maize-potato-green gram	18.2	124	1.47
Maize-potato-onion	27.6	127	2.17
Cotton-wheat	10.2	82	1.24
Summer groundnut-potato-pearl millet (Fodder)	16.0	109	1.70

(Source: IIFSR, Modipuram)

Table 2. Suggested alternate crops for RWCS

Crop type	Alternate crop (Rice)	Alternate crop (Wheat)
Cereals	Maize, Sorghum	Oats, Barley, Rabi maize
Pulses	Pigeonpea, Greengram, Blackgram	Pea, Chickpea, Lentil
Oilseed	Soybean, Groundnut	Mustard, Linseed
Vegetables	Okra, Tomato, Brinjal, Cucurbits, Chilli	Cole crops, Carrot, Reddish, Onion
Fodder	Sorghum, Sudan grass, Fodder maize	Barseem, Barley, Oats, Cowpea

Rice + soybean intercropping

Rice + *Tephrosia* sp. (Green manuring crop)

Rice + Groundnut intercropping

3.1.1 Profitability of some alternate cropping systems

Based on field trials, Gangwar and Singh (2011) represented the effectiveness of some substituting cropping systems over RWCS in terms of productivity, water-saving, soil fertility status, micronutrient availability and microbial activity, which is reviewed here:

(A) Productivity and water saving

There are enough opportunities to replace the rice-wheat cropping system with other ones while maintaining or improving economic yields and ecological profitability. The maize-potato-onion, summer groundnut-potato-bajra(f), maize-potato-summer moong, and maize-wheat summer moong systems exhibited 2.1, 1.8, 1.7, and 1.3 times more productivity than the rice-wheat system, demonstrating their superiority over the rice-wheat cycle. These technologies also assisted in the saving of 82-144 cm/ha/year of irrigation water.

The maize-potato-onion system had the maximum yield (278.6 q/ha/year) while using 82 cm less water than the rice-wheat system, which yielded 132.4 q/ha/year. The summer groundnut potato-bajra (fodder) system produced 233.0 q/ha/year with 103 cm irrigation water, resulting in a 109 cm water savings.

With total irrigation water used of 92 cm/ha/year, the maize-potato-summer moong cropping system produced 191.0 q/ha/year productivity, showing a net irrigation water saving of 120 cm/ha/year. The maize-wheat-summer moong system produced 161.8 q/ha/year production while using 68 cm/ha/year irrigation water, 68% less than the rice-wheat system.

The amount of water utilized in the maize-potato-onion, summer groundnut-potato-bajra(fodder), maize-potato-summer moong, and maize-wheat-summer moong systems was 38.7, 51.4, 50.5, and 56.6 percent less than in the rice-wheat system, respectively. The water productivity of the groundnut-potato-pearl millet(F) system was 2.262 kg grain/m^3 irrigation water, followed by maize-potato-onion (2.138 kg grain/m^3 irrigation water). The rice-wheat farming system had the lowest water productivity of 0.625 kg grain/m^3 irrigation water. These alternative crop rotations will save around 135850 ha-m irrigation water if they replace 5% of the rice-wheat land (2.6 million ha).

Table 3. Comparative irrigation water use efficiency of different cropping systems.

Cropping system	Irrigation water use efficiency (kg grain/m^3 water used)
Maize-Potato-Onion	2.138
Groundnut-Potato-Bajra (Fodder)	2.262
Maize-Potato-Moong	1.819
Maize-Wheat-Moong	1.759
Rice-Wheat	0.625

(B) Soil fertility status

Except in maize-potato-onion and summer groundnut-potato-bajra(F), where it remained the same after seven years, the organic carbon status in soils under different cropping systems was reduced over the baseline status (0.53 percent). The rice-wheat system had the most significant reduction. Groundnut, a leguminous crop, was followed by a potato crop that received farmyard manure and then by pearl millet had the same organic carbon content as the first year of the experiment. The levels of OC were likewise lowered in maize-based cropping systems where FYM was treated at a rate of 10 t/ha, but the severity of the decline was less than in rice-wheat cropping systems.

After seven years of cropping systems, the available N-status improved above the initial value (185.9 kg/ha). The rice-wheat farming scheme has the lowest N-status (218.1 kg/ha). The input demanding high yielding systems maize-potato-mung bean and maize-potato-onion showed significantly improved quantities of accessible nitrogen, although they were still in the low group.

The findings showed that applying farmyard manures to potato and maize crops significantly increased the phosphorus status build-up in the rice-wheat cropping system. The maize-potato-onion cropping system had the highest P level of 48.9 kg/ha, followed by maize-wheat-summer mung bean. The phosphorus status of maize-potato-onion was 48.9 kg/ha, while maize-wheat-summer moong bean was 46.2 kg/ha. The rice-wheat system has the lowest available phosphorus level (32.1 kg/ha). After 7 years, the available K-status followed the same pattern as the available P status. Maize-based agricultural systems had the highest K accumulation (142.6 to 160.8 kg/ha). Rice-wheat system (128.6 kg/ha) had the lowest value, 25.0, 16.6, 10.9, and 6.3 percent lower than maize-potato-summer moong bean, maize-wheat-summer moong bean and groundnut-potato-bajra (Fodder) systems, respectively.

Table 4. Soil fertility status after 7 cropping cycles (0-15 cm upper soil layer)

Cropping system	OC (%)	N (kg/ha)	P (kg/ha)	K (kg/ha)
Rice-Wheat	0.41	218.1	32.1	128.6
Maize-Wheat-Summer mung bean	0.47	232.8	46.2	142.6
Maize-Potato-Summer mung bean	0.51	240.0	45.3	149.9
Maize-Potato-Onion	0.53	252.1	48.9	160.8
Summer groundnut-Potato-Bajra (Fodder)	0.53	229.6	45.8	136.7
Initial status	0.53	185.9	43.7	131.9

(C) Soil micronutrients status

After the rabi crop, the status of micronutrients (zinc, copper, iron, and manganese) in the soil was assessed under various farming techniques. In comparison to the rice-wheat cropping system, maize-based cropping systems, particularly maize-potato-summer mung bean and maize-potato-onion, maintained greater levels of zinc (3.20-6.68 ppm), copper (0.42-0.69 ppm), iron (9.64-10.45 ppm), and manganese (8.49-12.42 ppm). However, all micronutrient values under various cropping strategies were within acceptable limits.

Table 5. Soil micronutrient status after *rabi* season (0-15 cm upper soil layer).

Cropping system	**Soil micronutrient status (ppm)**			
	Zn	**Cu**	**Fe**	**Mn**
Rice-Wheat	2.97	0.52	9.66	8.72
Maize-Wheat-Summer mung bean	3.20	0.42	10.45	8.49
Maize-Potato-Summer mung bean	6.68	0.69	9.64	10.92
Maize-Potato-Onion	6.16	0.66	10.56	12.42
Summer groundnut-Potato-Bajra (Fodder)	2.88	0.71	7.69	10.50

(D) Microbial properties

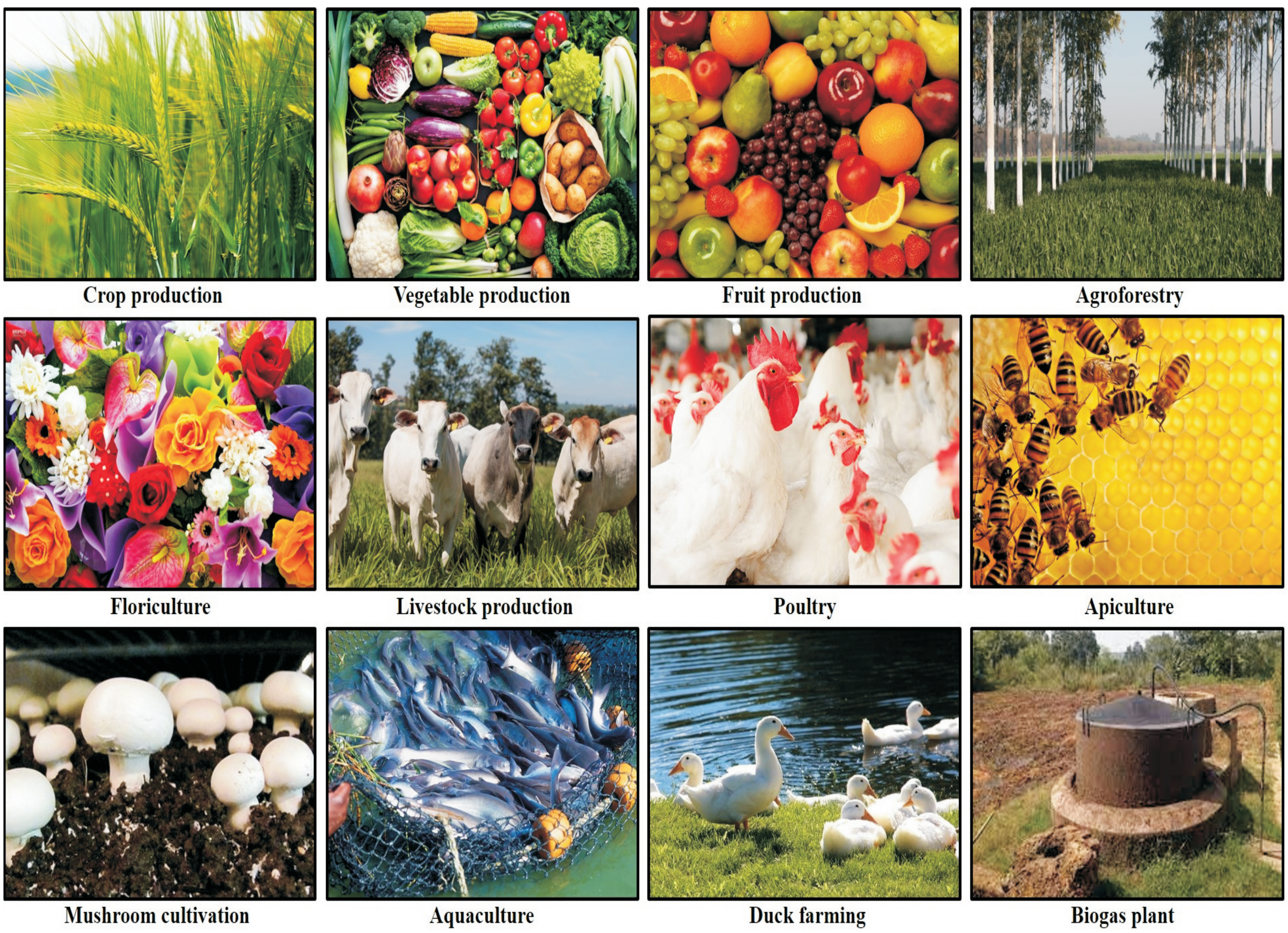
The soil microbial population of diverse cropping systems demonstrated various trends in systems and microorganism types. The bacterial and fungal population was found highest in the wheat crop, while the actinomycetes population was highest in potato crop in the groundnut-potato-bajra (F) cropping system. In the maize-potato-onion system, onion had the highest bacterial and actinomycetes counts of 24.0 x 106 cfu/g (cell forming units/gram soil) and 17.8 x 103 cfu/g, respectively. The wheat crop of the maize-wheat-summer moong bean system had the highest fungal counts of 20.4x103 cfu/g. It can be deduced that elements such as the type of crop, the cropping system, the soil, and the nutrients all have a role in developing microflora in different ways.

Table 6. Soil microbial population under different cropping systems.

Cropping system	**Crop**	**Viable count (cfu/g)**					
		Bacteria ($x10^6$)		**Fungi ($x10^3$)**		**Actinomycetes ($x10^3$)**	
		1st year	**2nd year**	**1st year**	**2nd year**	**1st year**	**2nd year**
Rice-Wheat	Wheat	15.3	19.1	17.8	21.5	29.9	10.8
Maize-Wheat-Summer mung bean	Wheat	18.3	23.7	14.3	20.4	17.7	10.7
Maize-Potato-Summer mung bean	Potato	10.3	15.5	16.2	11.7	8.6	8.4
Maize-Potato-Onion	Onion	13.6	24.0	16.2	16.4	18.0	17.8
Summer groundnut-Potato-Bajra (Fodder)	Potato	7.8	20.2	18.7	16.0	8.4	12.3

3.2 Diversification into Integrated Farming Systems

About half of the farmers have less than one hectare of land in India, and about 80% have less than two hectares. Poverty and hidden hunger affect nearly a third of the country's population. Diversification into a farming system mode in smallholder farming appears to be a potential strategy for ensuring future food, nutritional, and environmental security at the grassroots level. There appears to be a compelling case for rethinking traditional mixed farming approaches and applying new scientific advancements made in specific crops, commodities, and enterprises to small-scale scientific integrated farming. When livestock, fisheries, poultry, piggery, and horticulture were combined with crops, several tests on agricultural system research in the country demonstrated increased nutrient and water usage efficiency and profits. The system guarantees more remarkable recycling of by-products and residues of system components inside the system to reduce reliance on fertilizers. Future nutrient management research should prioritize integrating agricultural system components focusing on synergetic recycling of plant nutrients and in-situ management of greenhouse gases. Multi-enterprise agriculture has demonstrated the ability to reduce cultivation costs through the synergetic recycling of by-products/residues from multiple components within the system and providing a consistent income and employment at the grassroots level.



Components of Integrated Farming Systems

The Integrated Farming System (IFS) is defined as "combination of two or more components employing cardinal principles of minimum competition and maximum complementarity with modern agronomic management techniques aimed at long-term and environmentally friendly development of farm revenue, family nutrition, and ecosystem services." The effectiveness of the farming systems approach is based on the preservation of agrobiodiversity, diversification of cropping/farming systems, and maximized recycling.

ICAR-Indian Institute of Farming Systems Research, Modipuram began research on Integrated Farming Systems at the research farm and the farmers' field. A common approach of area distribution for different components has been developed at all locations, with specific purposes such as meeting family and livestock nutrition, soil health, and income generation. In addition to other benefits, these methods ensure agricultural diversification, increased income, and employment. The output of all of the IFS components was represented as rice equivalent yield and expressed in t/year. Similarly, a sustainability index is presented for chosen models, reflecting the long-term sustainability of net income. These IFS models were mainly created for marginal and small farmers.

For the states of Haryana, Punjab and Uttar Pradesh, where Rice-wheat rotation is a major conventional cropping system, IFS models (for 1 ha land) recommended by IIFSR are as follows:

3.2.1 Haryana

Crop and orchard based IFS for sustainable farm income:

Enterprises included	Area share %	Income share %
Cropping system	61	51
Horticulture	27	20
Livestock	10	20
Mushroom	2	9

- **Efficient cropping systems:**

Cotton-wheat	Green gram-wheat
Pearl millet-mustard	Sorghum-wheat
Sorghum (Fodder)-berseem	Sorghum (Fodder)-oat
Hybrid napier +cowpea-lucerne+fodder chicory	Bottle gourd-potato-okra
Okra-palak-bottle gourd	

- **Horticulture:** guava, papaya and lemon
- **Livestock:** 2 buffaloes
- **Mushroom:** button mushroom
- **Production:** 17 t/year
- **Employment generated:** 340 man-days

3.2.2 Punjab

Livestock + crop-based IFS:

Enterprises included	Area share %	Income share %
Cropping system	64	25
Multi-tier cropping	10	11
Livestock	20	54
Fish cum poultry	5	8
Mushroom	1	2

- **Efficient cropping systems:**

Maize-wheat-green gram	Maize-berseem-baby corn
Rice-potato-onion	Maize-berseem
Maize + cowpea-wheat-green gram	Maize-brassica (gobhi sarson)-pearl millet
Turmeric-onion	Rice-potato-maize

- **Multi-tier cropping:** guava, intercropping with vegetables
- **Livestock:** 2 cows
- **Fish cum poultry:** composite culture (catla, rohu, mrigal), 50 poultry birds
- **Mushroom:** button mushroom
- **Production:** 50 t/year
- **Employment generated:** 616 man-days
- **Sustainability index:** 0.74

3.2.3 Uttar Pradesh

Dairy-based IFS for improved income and employment:

Enterprises included	Area share %	Income share %
Cropping system	72	22
Horticulture	2	1
Livestock	22	52
Fishery	3	20
Mushroom	1	5

- **Efficient cropping systems:**

Rice-wheat-green gram	Rice-barley-black gram
Rice-mustard-green gram	Bottlegourd-cabbage-sponge gourd
Sorghum (Fodder)-berseem + mustard-sorghum (Fodder)	Pigeon pea + pearl millet-sorghum (Fodder)

- **Horticulture:** papaya, guava, aonla, mango, lemon, orange, banana + vegetables
- **Livestock:** 4 cows, poultry (1200 birds in 6 batches)
- **Fishery:** composite culture (catla, rohu, mrigal)
- **Mushroom:** oyster and button mushroom
- **Production:** 44 t/year
- **Employment generated:** 798 man-days
- **Sustainability index:** 0.91

3.3 Agroforestry based diversification

For several years, the area under forest cover in India has been nearly constant. According to a recent Forest Survey Report, the forest covers 23.8 percent of the land area. To establish ecological stability country must have forest and wooded areas covering at least 1/3 of its total area. Because of the acute need for food and nutritional security, the area under food, fiber, and pasture crops cannot be redirected to increase forest cover. Some of the options for increasing forest and tree cover include (a) integrating multipurpose trees with crops in a unified agroforestry system, (b) rehabilitation of degraded forest areas with faster-growing, more productive tree species, and (c) bringing a significant portion of the estimated 120 million ha of degraded wastelands under trees and grass cover. Incorporating multipurpose trees into agriculture can improve soil, water, and climate resources qualities. Planting trees, grasses, and shrubs on all types of wastelands, such as roadsides, canals, railway tracks, and is likely to play a critical role in increasing forest cover and helping to moderate/mitigate climate change through carbon sequestration, temperature buffering, soil quality improvement through organic matter addition, and halting soil and water erosion.

ICAR research institutes and State Agricultural Universities have developed agroforestry practices/models for various agro-climatic zones of the country. There is a requirement of upscaling such models by including location-specific changes. Many multipurpose, multi-stress-tolerant trees, bushes, and shrubs naturally grow in landscapes in general and wastelands in particular like genus *Prosopis* and *Opuntia* (edible cactus). In dry areas/stressed environments, such species have much potential as a food and feed source. Trees and bush species must be improved for increased productivity, production quality, post-harvest value addition, marketing, and trade potential. Reclamation of wastelands, detoxification of heavy metal-laden soils, use of poor-quality waters, including industrial effluents, lowering of water table in canal command areas, slowing groundwater rise trends, organic carbon build-up in carbon-depleted soils/carbon sequestration, increasing water infiltration rate in impeded/caliche bed soils, and moderating/negating climate change-related risks are all benefits of tree-based land use systems. Table 7 shows positive changes in soil qualities due to planting trees with crops.

Table 7. Changes in topsoil properties (0-30 cm) under different tree-crop combinations in 5 years

Land use system	Organic carbon (%)	Available N (kg/ha)
Crop based	+0.07	+10
Eucalyptus based	+0.12	+21
Acacia based	+0.20	+31
Populous based	+0.17	+25

3.3.1 Poplar based agroforestry in Indo Gangetic plains

Farmers in the Indo-Gangetic alluvial plains have implemented poplar (Populus deltoids) based agroforestry in large numbers. Fast-growing straight bole softwood poplar trees are grown with all crops on field boundaries or combined with crops in a 4x2, 4x4, 6x4 m or even wider row to row and plant to plant distance geometry well as in dense block plantations. Poplar trees are deciduous, which means they lose all of their leaves in the winter and have no effect on the understorey crops.

Winter crops such as wheat, berseem, and turmeric are effectively grown in the inter-spaces. The trees reach saleable age in 6-8 years in ordinary light-textured soil. The leaf litter that falls to the ground throughout the winter functions as a soil mulch and helps to raise the level of organic carbon in the soil.

Poplar based agroforestry system

Almost all farmers who adopted poplar-based agroforestry said that their economic situation improved significantly after combining poplar trees with crops on their farm holdings. In the last 30 years, only one town in Haryana, Yamunanagar, has attracted more than 200 plywood production enterprises that rely on poplar wood as a raw material. Lack of adequate planting material, remunerative price, and price fluctuations have hampered the implementation of poplar-based agroforestry as a diversification option. Poplar wood prices had just plummeted to such low levels that most farmers had uprooted their young plants.

As a result, policy measures are urgently needed to reward farmers who plant and preserve trees on their farmland. The other two requirements for sustaining tree-based diversification are a guaranteed market and MSP.

3.4 Crop management based diversification

Diversifying the traditional rice-wheat cropping system (RWCS) has enormous potential for improving the system's production and long-term sustainability. In the management-based diversification approach, the crops of the system are not replaced. However, their different management practices such as field preparation, sowing, irrigation, etc. are changed economically and ecologically sound. For intensive planting, conventional rice transplantation can be replaced with direct-seeded rice (DSR), or aerobic rice; similarly, wheat sowing after multiple tillage practises can be replaced with zero till wheat or furrow irrigated raised bed sowing. Adoption of these all alternatives depends on resources and suitability to local conditions.

Table 8. Diversification based on crop management

Conventional practice	Potential alternative systems
Transplanted rice	System of rice intensification (SRI)
	Direct seeded rice (DSR)
	Aerobic rice
Wheat grown with multiple tillage practices	System of wheat intensification (SWI)
	Zero till wheat
	Sowing on furrow irrigated raised bed (FIRB)

Direct seeded rice (DSR)

Aerobic rice

Zero till wheat sowing by happy seeder

Wheat sowing on furrow irrigated raised bed (FIRB)

3.5 Other potential diversification options

Many crop species are under-exploited but have a high potential to accomplish humans' food, forage, and medicinal demands. Along with the above diversification strategies, these plants can also be used for crop diversification. Several types of Cactus, also known as Naghphani, can grow wild in the country's dry and wet areas. These thorny plants are commonly used as biofences on field boundaries to safeguard crops by farmers. Cactus species such as *Opuntia ficus* indica have been used as human food, forage, medicinal, and energy crop in nations such as Mexico, the United States, Brazil, South Africa, Israel, Italy, Morocco and so on. Mexico is the world's largest exporter of cactus fruit, also known as *tuna*.

In rangelands in the United States, Mexico, Brazil, and other countries, both Prosopis and Cactus are part of a sustainable agroforestry system. Both species have a better water use efficiency per unit dry matter production, hence they should be used for rangeland/wasteland rehabilitation in India to generate alternative food and fodder resources and a drought-proofing option in drought-prone areas. There is a need for collaborative research and development programs with international organizations to promote these agroforestry practices in wastelands.

4. Efficient crop zone concept for crop diversification

The National Institution for Transforming India (NITI Ayog)/Planning Commission has divided the country into 15 agro-climatic zones. Crops and cropping systems that are productive, efficient, and environmentally friendly have been created and documented for each zone. However, diversification based on the concept of an effective crop zone is not taking place. For instance, rice is usually a crop of marshy and shallow groundwater with considerable rainfall. However, it is grown in Punjab, Haryana, and Uttar Pradesh, where the aforementioned crop growth conditions do not exist. Its shows that other variables have a significant influence on crop diversification. Some ideas for promoting agriculture diversification based on an effective crop zone concept are as follows:

- In non-efficient agriculture zones, discourage infrastructure development for post-harvest value addition, marketing, and trade prospects.
- Ascertain that the selected cropping strategy is more profitable for the farmer than any other option. It should be appropriately managed during the determination of crop MSPs so that farmers can continue cultivating efficient and environmentally friendly crops in a given zone.
- Establish post-harvest value addition and secure marketing and trade facilities for productive crops in a central zone.
- In-built incentive system to encourage diversification based on an efficient crop zone idea.
- Develop crop varieties that produce the same or higher yields with 20-30% less water. Promote water-saving techniques like the ridge-furrow method, direct-seeded rice, SRI (rice intensification), drip/sprinkler irrigation, and conservation agriculture.
- Develop integrated farming system models that allow small landowners to make multiple finite resources for food, livelihood, and environmental security.
- Wastelands encourage the large-scale growth of multipurpose forest, grasses, and fodder crops as unified Silvi-pastoral/agroforestry systems. Carbon sequestration will help in reducing the adverse effects of climate change.
- Protected production of high-value, low-volume commercial commodities in unfavourable conditions, with a focus on small and marginal farmers.

5. Constrains against diversification of the rice-wheat system

- Lack of proper foundation for agro-based industry.
- Poor research & extension.
- Seeds of improved varieties are in short supply.
- Basic infrastructure is poor, such as rural roads, power, transportation, and communication.
- Inadequate infrastructure and post-harvest technology
- Around $2/3^{rd}$ of the country's cropped area is mainly dependent on rain.
- Lack of trained workers and farmers.

6. Conclusion

- For both irrigated and rainfed environments, diversification strategies have been developed. The majority of these choices were limited to on-farm testing and demonstrations. Adoption of diversification appears to be governed by many factors other than research and extension.
- Market-driven crop diversification has overlooked ecological principles/efficient crop zone concepts recently. In the past, such diversification was necessary to ensure that the country was self-sufficient in food grains. However, this resulted in the degradation of natural resources and the threat of agricultural sustainability in the near future.
- In Punjab and Haryana, it is seen necessary to transfer some land from rice to other crops such as horticulture and agroforestry. However, this is not the case. To replace rice with maize and soybean the private sector must be involved. Alternatively, optimum management strategies for rice should be developed, such as direct seeding, short-duration low-water-demanding varieties, delay in transplanting, intercropping, and so on, to reduce the adverse effects of rice on groundwater and the environment.
- Multi-enterprise agriculture, which ensures diverse resource uses, has a lot of capacity for adoption to sustain livelihood and improve natural resources. There appears to be a compelling justification for developing integrated agricultural systems for land holdings of one and two hectares.
- Agroforestry systems that are farmer-friendly, such as poplar, eucalyptus, melia, and acacia, require legislative assistance for proper marketing, MSP, and trade.

- For the rehabilitation and exploitation of wastelands, agroforestry appears to be a promising diversification alternative. This type of land usage will aid in carbon sequestration, which will assist in mitigating global warming, as well as providing a new source of food, fiber, lumber, and firewood.
- Diversification based on industrial, medicinal, and bio-diesel crops will require reliable processing, marketing, storage, and trade facilities.

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