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Enhancing Productivity in Rice-Based Cropping Systems

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Abstract

In India, the rice-based cropping system is a major food production system with rice as the first food crop. The cereal-based cropping system is low-yielding and highly nutrient exhaustive resulting in the declining of soil fertility. Summer/pre *kharif* fallowing leaves on the land fallow for entire season and production of the cropping system is declined. Hence, crops that can improve the fertility status should be included in the cropping system. Development of short duration thermal insensitive rice varieties has encouraged multiple cropping involving a wide range of crops. Diversification of rice-based cropping systems with inclusion of pulses/legumes and oilseeds in summer fallows is one of the options for horizontal expansion, as they are known to improve soil organic matter through biological nitrogen fixation, root exudates, leaf shedding and higher below ground biomass. The strategy for higher yields in the cropping system should be formulated using the combined application of organics, inorganics and biofertilizers coupled with the inclusion of crops in summer fallows for sustainable yields and preservation of soil health.

Keywords: cropping system, legumes, productivity, soil fertility, sustainability

1. Introduction

On 16 December 2002, the United Nations General Assembly declared the International Year of Rice (IYR) as the year 2004. The main theme of IYR, called “Rice is Life”, resulted from the fact that rice-based cropping systems are indispensable to people, directly or indirectly for food security, poverty control and world’s peace. For approximately 70% of world’s population, rice is the second most important food crop, being cultivated in more than 100 countries in 163 million ha with current rice production of 740.9 million tons compared to the global

demand of 765 million tons by 2025. Rice is cultivated two or three times in a year in diverse environments and cropping systems starting with sole cropping systems in rainfed and irrigated conditions (temperate and tropical regions) to predominant mono cropping in irrigated regions (at tropics) [1]. Among the rice growing countries, India ranks second in production (157.2 million tons) next to China. In India, rice is cultivated on 44.14 million ha obtaining a production of 106.65 million tons and yield of 2416 kg ha⁻¹ [2]. Cereals are the most widespread group of crops across the world occupying 20% of the global land or 61% of the total cultivated land. About 2/3 of the world's cropland area is predominantly occupied by wheat, maize, barley, rice and millets. Rice is the second most important crop at global level (around 11% of global cultivated area) and is the most important crop in South and Southeast Asia being also cultivated in the Amazon Basin, the southern United States, and southern Australia [3]. Rice-based cropping systems (RBCS) are the major contributing food production systems with rice as the first food crop, forming an integral part of this system. Rice-rice system is followed in irrigated cropping while rice-pulse system is adopted in rainfed lowlands leaving land fallow during pre *kharif*/summer season. The constraints in rice production are the declining rate of growth during yield formation, shortage of labor, depletion of natural resources and environmental pollution. Hence, improving the productivity of rice-based systems would eradicate the hunger and poverty, and facilitate economic development and food security.

Development of varieties with better yields and response to fertilizers, and the excessive use of chemical fertilizers have increased the yields of both *kharif* rice and *rabi* crops in rice-based cropping systems. Cereal-cereal cropping systems are more exhaustive and resulted in negative nitrogen balances in soil due to its extensive depletion of nutrients from soil resulting in a declining of the system productivity, soil fertility and health, compared to cereal-legume and cereal-oilseed systems [4, 5]. Continuous imbalanced use of chemical fertilizers has resulted in declined soil productivity. Due to the introduction of short and medium duration rice varieties, multiple cropping and the diversification of RBCS were possible with inclusion of pulses, oilseeds and vegetables in summer/pre *kharif* season. This has been found more beneficial, providing enhanced productivity of system and improved soil fertility status than cereal-cereal sequence [6–8]. After the harvest of winter season crops, a short time period (80–90 days) is available until the next rainy season crop having the possibility to include fast growing crops. Inclusions of short duration green manures and grain legumes/pulses in RBCS have been widely investigated and reported [9–11]. Combined application of inorganics and organics along with biofertilizers should be considered for the cropping system within a particular agro-climatic region. The integrated nutrient management system is ideal for RBCS as the rice is predominantly grown under submerged-anaerobic conditions, which offers a wider scope for harnessing various nutrient sources. When biofertilizers and organic manures are applied along with the inorganics, their efficiency is improved and nutrients can be mineralized faster and made available to the plants [12].

2. Different rice-based cropping systems

The three main characteristics of this type of cropping system are: (1) the biological characteristics of the crop and its response and influence to the physicochemical and ecological

environment, (2) the crop sequences in the system and (3) the management techniques applied in the system including the varieties of crop species [13]. Rice is the major crop in India being cultivated under both rainfed and irrigated conditions. Traditionally, the rice varieties/cultivars are tall, having long duration, being low yielding with a grain to straw ratio of 0.4 and are not well responsive to the applied inputs [14]. Development of short duration photo-insensitive, dwarf and input responsive high yielding rice varieties with a grain to straw ratio of 0.55 has encouraged the multiple cropping involving a wide range of crops. The selection of crops in cropping systems was mainly dependent on agro-climatic and socio-economic conditions of the region with rice as a main crop. The prominent rice-based cropping systems in India are rice-rice, rice-wheat, rice-pulse and rice-potato (**Table 1**). In India, particularly in Indo-Gangetic plains, the rice-wheat zone is a predominant system occupying about 13.5 million ha area accounting for 23 and 40% of total rice and wheat area, respectively [15, 16]. The predominance of rice-wheat system in the whole Indo-Gangetic plains zone is particularly due to compatibility of the two crops mainly during sowing times.

Agro-climatic region	Rainfall (mm)	Soils	Prominent cropping system
Western Himalayan (Himachal Pradesh, Jammu & Kashmir, Uttarakhand)	1650–2000	Hill and Sub-montane	Rice-wheat, Rice-potato-potato
Eastern Himalayan (Assam, North East states, West Bengal)	1840–3528	Red sandy, Laterite, hill, Alluvial	Rice-fallow, Rice-rice, Rice-pulses/oilseeds
Lower Gangetic Plain (West Bengal)	1302–1607	Alluvial, Red and yellow	Rice-rice, Rice-wheat, Rice-potato-jute/vegetables
Middle Gangetic Plain (Bihar, eastern Uttar Pradesh)	1211–1470	Alluvial, Tarai and Calcareous	Rice-wheat Rice-maize, Rice-potato-sunflower
Upper Gangetic Plain (central and western Uttar Pradesh)	721–979	Alluvial, Tarai	Rice-wheat Sugarcane-ratoon-wheat
Trans Gangetic Plain	360–890	Alluvial and Calcareous	Rice-wheat
Eastern plateau and Hills (Chhattisgarh, Jharkhand, Madhya Pradesh, Maharashtra)	1296–1436	Red, Yellow Laterite	Rice-blackgram Rice-niger/linseed Rice-Vegetables
East coast Plain and Hills (Andhra Pradesh, Odisha, Tamil Nadu, Puducherry)	780–1287	Deltaic alluvium, Red, Laterite	Rice-groundnut-greengram, Rice-greengram/blackgram, Rice-rice
West coast Plains and Hills (Goa, Maharashtra, Karnataka, Kerala, Tamil Nadu)	2226–3640	Coastal alluvium, Red, Laterite	Rice-rice
Andaman and Nicobar Island	1600–3000	Red	Rice-fallow

Source: [17].

Table 1. Rice-based cropping systems in different agro-climatic regions of India.

2.1. Effect of cereal-based cropping system on soil properties

The cereal-cereal cropping system is the most predominant in India and the reports have mentioned unsustainability and declining factors for productivity i.e., higher fertilizer dose is needed to obtain the required current yield level [18]. Puddling, which is essential for rice cultivation impoverishes soil physical condition, increases bulk density and reduces the hydraulic conductivity. Furthermore, this practice is energy-consuming, deteriorates the soil health for growing the succeeding crops [19–21]. Repeated cultivation of rice leads to the formation of hard-pan below the plow layer, deteriorates the soil structure, inhibits the root elongation and delays the planting of a succeeding crop [22]. Continuous rice cultivation for longer periods with poor crop management practices has often resulted in loss of soil fertility and in turn leads to multiple nutrient deficiencies [23, 24]. Under puddled conditions, rice undergoes several changes i.e., aerobic to anaerobic environment, resulting in several physical and electrochemical transformations. Puddling operation is water and energy-consuming, breaks the capillary pores, destroys the soil aggregates, disperses the fine clay particles and soil strength is lowered in the puddle-layer. Imbalanced use of N-fertilizer in rice may increase the leaching of nitrates beyond the root zone leading to the ground water pollution in rural areas [25].

2.2. Strategies for enhancing productivity in rice-based cropping system

Some of the potential strategies for sustaining the productivity of rice systems are: (i) reduction of the rice monoculture and diversification of the cropping system with pulses/oilseeds and (ii) enhancing of the input use efficiency in existing double and triple rice-based cropping systems through improved technology and management practices. Diversification includes vegetables, grain legumes, oilseeds and green manures, which improves the productivity, reduces the pest incidence and enhances the soil fertility and its physical properties by providing a break in soil submergence [26]. In addition, the balanced fertilizer use, the combined use of organics, the mineral fertilizers and bio-fertilizers and the inclusion of summer/pre *kharif* crops are the possible optimal agro-techniques for sustainable yields, improved fertilizer use efficiency and restoration of soil fertility in cereal-based cropping systems [27, 28].

2.2.1. Chemical fertilizers

Application of higher quantities of fertilizers than recommended rates, more particularly N in Indo-Gangetic plains to rice-wheat cropping system (RWCS) has stagnated/declined the yield levels. Approximately 1/3 of farmers that cultivate rice-wheat apply 180 kg N ha⁻¹ to both rice and wheat compared to the recommended dose of 120 kg N ha⁻¹. Such indiscriminate use of N fertilizers has decreased the yields due to low nitrogen use efficiency (21–31%) and some amount of N were lost through excessive N losses, nitrate leaching and groundwater pollution [25, 29, 30]. Hence, balanced fertilizer use i.e., application of fertilizers in right proportion, right time and appropriate method and in an integrated manner are the promising agro-techniques for a higher use efficiency of applied fertilizers sustaining the productivity of RWCS [31]. Application of nitrogen in excess or the lack fertilizer compared to the optimal amount significantly affect both rice yield and quality, -. Consequently, the balanced crop nutrition is of utmost importance [32].

2.2.2. Organic manures and green manures

In RBCS, the usage of organic sources of nutrients viz. organic manures and green manures area are rapidly declining. Organic manures are traditional sources of nutrients, which help in maintaining the soil fertility. Among the organic manures, farmyard manure (FYM) is the principal source and is commonly available to the local farmers. They are relatively cheap soil amendments, rich in nitrogen, helping in sustaining the soil fertility and protection of the environment. Organic manures contain plant nutrients, though in small quantities in comparison to the chemical fertilizers. The presence of growth hormones and enzymes make them essential for improvement of soil fertility and productivity. In addition to this, the organic manures help in improving the use efficiency of inorganic fertilizers. The supply of essential micronutrients through organic manures has also improved plant metabolic activities especially in the early vigorous growth of plant. Findings of [33, 34] showed that the application of farmyard manure up to 10 t ha⁻¹ has significantly increased the rice growth and yield-contributing traits as well as the grain yield.

Green manure crops can be grown in the rice-based cropping system as they reduce soil pH, improve the soil fertility, water holding capacity and partially diminish the need of nitrogen fertilizer for rice crop. The green manures increase the efficiency of applied mineral fertilizer, help in availability of other plant nutrients and improve the contents of soil organic matter [35]. In rice-based system, the winter crops are usually harvested in the last fortnight of April or early May and rice is transplanted during the last fortnight of July or early August. This fallow period of about 80–90 days is sufficient for the growth of short duration and fast growing green manure crops [36, 37]. The incorporation of animal manure or green manure adds N to rice soils and increase the organic matter in soil. The organic materials viz. green manure, compost or animal manure, have low C-N ratio, supply 20–30% to the current rice crop and 40–60% is stored in the soil [38].

Continuous application of organic material for long periods results in an increased output of decomposed organic matter annually [45]. Application of green manures *Sesbania* and *Crotalaria* at 10 t ha⁻¹ to rice has significantly increased the grain yield of rice by 1.6 and 1.1 t ha⁻¹, respectively compared to no green manure application [46]. The soil organic carbon has been improved with the integrated application of NPK and FYM at all locations (**Table 2**). In rice-wheat systems, soil organic carbon was improved from 18 to 62% with organic sources compared to chemical fertilizers [47, 48]. Soil organic carbon and productivity were improved with the combinations of organic and inorganic fertilizers [49–51]. At lower fertility, the green manures showed the maximum response than at higher fertility levels. Groundnut (*Arachis hypogaea*) pod yields were at maximum with 30:26:33 kg NPK ha⁻¹ fertility level plus gypsum combined with the application of green manure to rice [46].

2.2.3. Crop residues

As the cost of chemical fertilizers has increased dramatically in recent years, farmers find difficulties or cannot afford to purchase them. Hence, alternatives to chemical fertilizers such as crop residues might be better options to meet N-fertilizer requirements of successive crops in the cropping system. On an average, 25% of the total nitrogen, 50% of total phosphorus and

Location	Cropping system	Initial	After 20 years (g kg ⁻¹)			References
		(g kg ⁻¹)	Control*	NPK	NPK + FYM	
Bhubaneswar, India	Rice-rice	2.7	4.1	5.9	7.6	[39]
Faizabad, India	Rice-wheat	3.7	1.9	4	5	[39]
Karnal, India	Fallow-rice-wheat	2.3	3	3.2	3.5	[39]
Pantnagar, India	Rice-wheat	14.8	4.9	8.4	14.9	[40]
Pantnagar, India	Rice-wheat-cowpea	14.8	6	9	14.4	[40]
Bhairahawa, Nepal	Rice-wheat	10.3	7.3	8.8	—	[41]
Barrackpore, India	Rice-wheat-jute	7.1	4	4.3	4.5	[42]
Ludhiana, India	Rice-wheat	1.8	2	3.7	—	[43]

*Control: no fertilizer addition. Source: [44].

Table 2. Soil organic carbon after 20 years of alternative fertility treatments in rice-based cropping systems in India and Nepal.

75% of total potassium in the crop harvest are retained in the residues. An estimated 377 million tons of crop residues per year are available in India. With the incorporation of green manure or crop residues, the organic matter has been improved and soil physical conditions has been altered i.e., decrease in bulk density, increase in total pore space, water stable aggregates and hydraulic conductivity [22]. Dhaincha (*Sesbania aculeata*), Sunnhemp (*Crotalaria juncea* Linn.), blackgram (*Vigna mungo* [L.]), cowpea (*Vigna unguiculata* [L.]) and greengram (*Vigna radiata* [L.]) are some of the important legumes used as green manure plants and they are adaptable to different rice-based cropping system. These legumes have the ability to fix atmospheric nitrogen and sustain the productivity and profitability in rice-based cropping systems [52]. Incorporation of Sunnhemp crop residues produced highest seed and haulm yields of rice fallow blackgram (**Table 3**). Yields of rice fallow blackgram with greengram and blackgram residue incorporation were better than with bhendi (*Abelmoschus esculentus*), sesame (*Sesamum indicum* Linn.) and clusterbean (*Cyamopsis tetragonoloba*) residue incorporation [8].

Retention of crop residues is more beneficial than inorganic fertilizers as the residues supply better nutrients through decomposition helping in improving soil organic matter, availability of nutrients and achieving sustainability of the crop production systems. The impact of residue incorporation on succeeding crops depends on the produced quantity of residues and time and method of incorporation [53]. Residue retention in mungbean (*Vigna radiata* [L.])–wheat rotation has increased yields of both crops and nitrogen balances of the crop rotation. Mungbean and lentil (*Lens culinaris*) residues returned to soil have fixed about 112 and 68 kg N ha⁻¹, respectively which has resulted in positive N balances (64 and 27 kg N ha⁻¹, respectively) of the cropping system and hence the fertilizer N requirement could be reduced [54].

2.2.4. Legumes in cropping systems

Legumes in rotation with cereals not only fix atmospheric N through biological nitrogen fixation but also enrich soil fertility, nutrient recycling from deeper soil layers, minimize soil

Cropping system	Seed yield (kg ha ⁻¹)	Haulm yield (kg ha ⁻¹)
T ₁ : Fallow-rice-rice fallow blackgram	225	462
T ₂ : Sunnhemp-rice-rice fallow blackgram	382	743
T ₃ : Greengram-rice-rice fallow blackgram	342	667
T ₄ : Blackgram-rice-rice fallow blackgram	329	643
T ₅ : Sesame-rice-rice fallow blackgram	278	551
T ₆ : Clusterbean-rice-rice fallow blackgram	263	538
T ₇ : Bhendi-rice-rice fallow blackgram	291	569
SEm	11.92	24.18
CD (p = 0.05)	35	72

Source: [8].

Table 3. Seed and haulm yield (kg ha⁻¹) of *rabi* rice fallow blackgram as influenced by pre *kharif* crops in rice-based cropping system.

compaction, increase in organic matter, reduce pest and disease incidence, promote mycorrhizal colonization and sustain the productivity of cereal-based cropping systems [5, 55]. Intensification of rice-wheat system with short-duration and uniform maturing summer legumes (cowpea and mungbean) has enhanced the productivity and profitability to achieve nutritional security of the system [56]. The legumes/pulses contribute to the sustainability of cropping systems through (1) biological nitrogen fixation, which supplies nitrogen to the system (2) diversification of cropping system, which reduces the disease, pest and weed incidence and (3) provide food and feed that are rich in protein [13]. It is clear that the soil fertility and the physical properties have been enhanced with use of the legumes/green manure crops [57]. The excess application of N-fertilizer has resulted in environmental pollution as large amounts of N were lost as a consequence that fertilizer use efficiencies are very low [58] suggesting that legumes should be used as potential N source for future cropping systems [59].

Rice-legume crop sequences are considered most productive crop sequence in southern part of India as legumes can fix atmospheric nitrogen and scavenge mineral nitrogen. Mineral N may be lost through denitrification or leaching under flooded condition [60]. Grain legumes shed their leaves near maturity and the above ground biomass after harvesting (seeds along with residues and roots) contains nitrogen, improving the soil nitrogen balance and productivity [61, 62]. The legume residues contain about 20–80 kg N ha⁻¹ (about 70% of it is derived from biological nitrogen fixation) depending upon the type of crop and the full N benefits will be realized if all the residues are incorporated after harvesting the seed yield [55, 61]. Legumes can be grown as green manure, as catch crop during summer season [15] and the experiments from various countries showed that legumes have improved the soil fertility and erosion control, the socioeconomic benefits and can be included in the rice-based cropping system [53]. Therefore, the succeeding crop yields in the cropping system are higher when legumes are included [63, 64]. The results from experiments revealed that in each year the yields of rice were significantly ($p < 0.05$) higher in legumes than in the fallow-based rice-wheat system (Table 4).

Treatment	2001/2002			2002/2003			2003/2004			Average (2001/2002–2003/2004)		
	0N	+N	Mean*	0N	+N	Mean	0N	+N	Mean	0N	+N	Mean
Fallow	3642	4107	3875c	3808	4368	4088c	3273	3819	3546b	3574	4098	3836b
Mungbean	4556	5154	4855a	4245	5401	4823ab	3776	4692	4234a	4192	5082	4637a
Cowpea	4559	5008	4784a	4520	5398	4959a	3909	4809	4359a	4329	5072	4701a
Soybean	3784	4496	4140b	4411	4953	4682b	4277	4460	4369a	4157	4636	4397a
Sesbania	4222	5207	4715a	4952	5621	5287a	3803	4349	4076a	4326	5059	4692a
Pigeonpea	4443	5029	4736a	4130	4642	4386bc	3426	4128	3777b	4000	4600	4300a
Guar	4360	4951	4656a	4025	4704	4365bc	3563	4278	3921ab	3983	4644	4314a
Mean	4224B	4850A		4299B	5012A		3718B	4362A		4080B	4742A	

*Means followed by different letter(s) within columns for legumes or within row for fertilizer treatments differ significantly ($p < 0.05$). Source: [65].

Table 4. Rice grain yield (kg ha^{-1}) as influenced by green manure legumes and fertilizer N in rice-wheat system.

2.2.5. Biofertilizers

Application of biofertilizers in rice fields is gaining attention in recent times. These are alternative sources of nitrogen to chemical fertilizers being eco-friendly, fuel independent and cost effective helping in a better crop nutrient management. The ecological and agricultural importance of these organisms depends upon the ability of certain species to carry out both photosynthetic nitrogen fixation and proliferation in diverse habitats. BGA and *Azospirillum* are capable of growing under rice canopies and have been identified as prospective biofertilizers for wetland rice cultivation. Indeed, biofertilizers bring directly or indirectly certain changes in the physical, chemical and biological properties of the soil in rice fields, which are of agronomic importance. Inoculation of mycorrhizal fungi to upland rice has improved the growth as well as the nutrient acquisition [66, 67]. Rice yields (both grain and straw) are enhanced with the use of effective suitable microorganisms [68]. In rice field, bio-nutrient application containing *Pseudomonas mycostraw*, cyanobacteria and *Azospirillum* has enhanced soil organic carbon by 14–18% [69]. Combined application of bio-inoculants and crop residues retention provides positive C and N balance in soil in rice-legume-rice cropping systems [70]. An integrated nutrient management strategy i.e., organic manures, crop rotations with legumes and application of chemical fertilizers in balanced proportions will improve the soil fertility and sustainability of rice-based cropping systems [44].

2.2.6. Summer/pre kharif crops in rice-based cropping systems

In cereal-based cropping systems, rice is grown during the rainy season (*kharif*) from June to October and *rabi* crops during the winter season from November to March/April leaving the land fallow in-between the harvest of both crops. These cereal-based cropping system yields have stagnated or declined resulting in a serious threat to the sustainability of the

crop rotation [16]. The productions of rice and wheat have to be increased by about 1.1 and 1.7% per annum, respectively for the next four decades to ensure food security in South Asia [71]. Hence, to meet the increasing cereal demand, for sustaining the productivity and improving resource use efficiency there is a need of crop intensification with green manures, legumes/pulses, oil seeds and vegetables in summer season [72]. The crop intensification with legume crops in rice-based cropping system constitutes a viable alternative to traditional practices such as the cultivation of winter wheat or leaving the land fallow [73]. The most important characteristics of green manure legumes are to produce higher biomass with leafy growth, good nodulation activity and considerable amount of nitrogen in short period. These crops produce economic yield, improve the profitability, economic condition of small and marginal farmers and their biomass/residues can be utilized as animal feeds and/or their residues can be used as nitrogen source for the monsoon crop [8]. Research from [37] reported that Sunnhemp green manure has produced higher crop residues/biomass, while bhendi has recorded superior seed yield (**Table 5**). In addition, these leguminous crops/green manures conserve the soil fertility and fix atmospheric nitrogen [74]. Early rains in summer generally start from the beginning of May and a sufficient amount of rainfall occurs during May to August. There is a gap of short period (80–90 days) between harvest of *rabi* crop and planting of *kharif* rice, which is sufficient to take up a short duration crop preceding to rice [37]. The choice of crops and species in RBCS is limited. However, the feasibility of inclusion of these crops in the cropping system is possible, if they are short duration, uniformly maturing, high yielding and disease resistant and improve the long-term productivity and economic viability of the system. Grain legumes are preferred because of their food value and nitrogen fixing abilities that are superior to green manure crops [75]. However, the adoption of pulses/legumes/green manures must consider the growing season, the cost of production, the rainfall and irrigation facilities [27, 75]. Therefore, the selection of crop and variety is mainly specific to the location. Hence, sesbania and Sunnhemp as green manure crops, cowpea, greengram and blackgram as potential grain legumes; clusterbean, bhendi and potato (*Solanum tuberosum* Linn.) as suitable vegetables; groundnut and sesamum as potential oilseeds are suitable in RBCS. In spite of beneficial and positive effects of summer crops in rice-based cropping systems, the adoption by farmers is slow due to the lack of seed availability, escalating production cost and increasing labor wages. Furthermore, previous reports showed that green manure application was not profitable [75]. Diversification of the system with legumes/pulses may enhance profitability, reduce pests and diseases, minimize the risks from fluctuating weather by varying planting and harvesting times. The cropping system yields, profitability and production efficiency of rice-based cropping system were superior when bhendi/blackgram was included during pre *kharif* season rather than leaving land fallow [76]. In recent years, natural resources viz. land, water and energy are reduced and resource use efficiency is an important aspect for considering the suitability of a cropping system [77]. Hence, choice of crop to be grown needs to be optimally planned to harvest the synergism among them for higher productivity of the system and efficient utilization of resource base [78]. Hence, efforts are needed to promote intensification of rice-based cropping system in the country with legumes/pulses, oilseeds and vegetable crops to meet the demand for these crops and for sustaining the productivity [72].

Pre <i>kharif</i> crops	Seed yield (kg ha ⁻¹)	Greengram equivalent yield (kg ha ⁻¹)	Crop residues on fresh weight basis (t ha ⁻¹)
Sunnhemp	—	—	30.11
Greengram	217	217	10.48
Blackgram	385	341	5.94
Sesame	139	205	3.79
Clusterbean	93	54	1.16
Bhendi	1743	915	4.73
SEm	—	27.46	0.85
CD (p = 0.05)	—	85.00	2.55

Source: [37].

Table 5. Seed, greengram equivalent yield (kg ha⁻¹) and crop residues on fresh weight basis (t ha⁻¹) of pre-*kharif* crops in rice-based cropping system.

3. Conclusions

Cereal-based cropping system is the most promising system for about 70% of the global population. The yields have stagnated in recent years with the cereal-cereal system and the land is fallow in the summer/pre *kharif* season. Hence, crop diversification with pulses, oilseeds and vegetables in summer season shows a lot of promises in alleviating the poverty, employment generation, ensuring balanced food supply, and improving productivity and sustainability of the cropping systems. Legume/pulse crops in crop rotation with cereal-based system and their crop residue incorporation in soil sustain the C and N dynamics in soil. The adoption of green manures/pulses/leguminous crops in nutrient exhaustive rice-based cropping system saves the nitrogen fertilizer to successive crops, increases in grain yields and profitability, decreases the soil pH and improves the soil structure. Improved short duration, high yielding varieties and remunerative prices of pulses/oilseeds/vegetables will encourage their adoption in the cropping systems. The adoption of the summer crops in the system will require a lot of adaptive research depending on the soil and environmental conditions of a particular region of cropping. The reduction in the use of chemical fertilizers and balanced supply of nutrients in an integrated manner through inorganics, organics and biofertilizers will enhance the yield and soil fertility. Currently, nutrient supply is mainly focused on the major nutrients i.e., nitrogen, phosphorus and potassium, but RBCS requires also micronutrients since the multi-nutrient deficiencies have been observed. Consequently, they must be considered in the fertilizer schemes.

4. Future research needed

The adoption of any technology in modern agriculture can be acceptable and adoptable by farmers only if it is economically viable. Future research should focus on problems for

non-adoption of these technologies by farmers and find out suitable ways for their adoption. Next, the adoption of summer/pre *kharif* crops instead of leaving land fallow, which could be made possible through best suited cultivars, seed availability, reducing production cost and optimizing production technologies is of high interest. Research must be initiated considering farmers' voluntary participation, identifying the farmer's problems and develop the location-specific technologies by finding ways for easy integration. The new varieties or species of green manure/grain legume crops should be developed that has multiple uses such as fodder, feed, fuel, and other commercial products. The interaction between mineral fertilizers, organics and nitrogen fixing organisms needs further study as a way of achieving better integration of the nutrition systems for different crops.

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