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Sustainable Rice Fallow Crop Production Challenges and Opportunities: An Overview

J. DEVI GEETHIKA[1], E. SUBRAMANIAN[2*], A. GURUSAMY[3], P. ARUNACHALAM[4], B. BHAKIYATHU SALIHA[5] and A. SATHISH KUMAR[6]

[1]Department of Agronomy, Agricultural College and Research Institute (AC&RI), Tamil Nadu Agricultural University (TNAU), Madurai, Tamil Nadu, India.
[2]ICAR- Krishi Vigyan Kendra, TNAU, Madurai, Tamil Nadu, India.
[3]Department of Agronomy, AC&RI, TNAU, Madurai, Tamil Nadu, India.
[4]Department of Plant Breeding and Genetics, AC&RI, TNAU, Madurai, Tamil Nadu, India.
[5]Department of Soil Science and Environment, ARS, Thoothukudi, Tamil Nadu, India.
[6]Department of Agronomy, AC&RI, TNAU, Madurai, Tamil Nadu, India.

Abstract

The main objective of this review is to assess the scenario of sustainable production of rice fallow crops. Rice (*Oryza sativa*.L) is a staple foods in Asia, that is extensively grown in various regions. A rice fallow cropping system is an interesting concept for maintaining the sustainability of crop production and better utilization of resources. However, the following are the criteria for crops that are to be grown as fallow crops. The crops grown under rice fallow conditions utilize the moisture retained in the residues of the previous crop. Therefore, the plants are not subjected to moisture stress until there is residual moisture and soil moisture retention. Hence, short duration crops, varieties and drought tolerant crops are mostly preferred for rice fallow situations. Predominantly, pulses, millets, oil seeds and fibre crops such as cotton are preferred under fallow rice conditions, on the basis of the soil texture.

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Introduction

Rice (*Oryza sativa* L.) is one of the major food crops in India, and it is grown in various agroecosystems. The total rice production during 2022-23 was 1,357.55 lakh tones, and the number of pulses across India was 278.10 lakh tonnes during 2023 (Ministry of Agriculture & Farmers Welfare). It is estimated that, 11.695 m. ha in India was left fallow after the paddy was harvested. In the rice fallow pulse cropping system, black and green grams occupied an area of 1.98 lakh ha. Generally, the grain yield ranged from 300 to 500 kg ha^{-1} depending

CONTACT Subramanian esubramanian@tnau.ac.in ICAR- Krishi Vigyan Kendra, TNAU, Madurai, Tamil Nadu, India.

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upon the management practices followed during the cropping period. India is the largest producer of pulses globally, accounting for 27-28% of the world's total production. From 2017-18 to 2021-22, an area of 36.85 lakh ha was covered under rice fallow pulses.

The cereal crop contributes 54% of the agricultural residues (368MT). Compared with other crops, rice and wheat contribute approximately 154 MT and 131 MT of crop residues, respectively, followed by sugarcane (~108 MT) and cotton (~91 MT).[1] In a monocrop-based cropping system, rice-fallow is often uncropped land that is left over after rice is harvested. The initiative have been taken by the farmers in the rice-wheat belt to diversify their cropping systems by including short-duration crops, such as potato, soybean, black gram, green gram cowpea, pea, mustard, and maize, etc., in different combinations.[2] This is a potential avenue for the efficient utilization of resources for sustainable crop intensification and to increase land productivity in predominantly rice-producing countries. The time of sowing and success of a rice fallow crop are determined by the interaction of the harvesting time of the rainy season rice, soil moisture conditions and the temperature during and before the rice harvest.[3] A complete switch to organic fertilizers under rice fallow conditions and an abrupt cessation of chemical fertilizer use would result in significant production gaps in the rice fallow crops across the country. Therefore, nutrient management, which is an integrated alternative to chemical fertilizers is necessary to maintain the health of the soil and provide balanced nutrition to plants.[4] If pulses are grown as rice fallow crops, they supplement soil by implanting nitrogen on the soil and utilize the unused fertilizer left in the soil at the time of crop cultivation.

Compared to manual harvesting,machine harvesting of rice is inevitable, and it is a cost reduction technology that accounts for 58% of the operational cost of harvesting. Mechanical paddy harvesting employs a mini-combine harvester and reaper.[5] Due to their economic feasibility and ability to reduce post harvest losses, farmers prefer mechanical harvesting of rice over manual harvesting. The real fact behind the mechanization of rice production is labor scarcity during critical periods. In the canal irrigated area, owing to labor scarcity, the harvest and plants of succeeding crops were affected by rain. To overcome the labor scarcity, most rice growing areas are now covered by machine planting and harvesting. Owing to the damage caused by the combine paddy harvester at the time of harvesting, farmers are afraid of the need for rice fallow crops via., mechanized harvesting.

Importance of Rice Fallow Crops

India currently imports more than 3 million tonnes of pulses to suit its demand. Rainfed rice fallow lands (RRFLs) offer a vast potential niche for pulse production, with the goal of increasing the current 15 million tonnes of pulse production to approximately 18 million tonnes.[6] Under rice fallow conditions, The productivity of crops can be increased two or three times since the system utilizes the residual moisture for its growth and development. The resource- poor farmers cannot meet the expenses of fertilizer, irrigation and herbicide requirements of the succeeding crops. Hence, a better option to choose the cropping system that uses minimal resources. In the case of millets, grains can be used as food and the residues can be used as feed for livestock. Rice fallow gathers scope for many farmers as they obtain income from the fallow crop with less investment. Owing to the combined benefits of expanding the crop's growing area and ensuring its sustainability, pulses have to be a crucial component of rice-fallows in order to meet the protein demand for increasing future populations.[7]

The nation's highest production of 6.9 tonnes ha^{-1} was achieved under rice-fallow conditions from 2014-15 in the farmer field. Farmers earn more money in this cropping system especially with respect to rice fallow, moreover, the area under sorghum cultivation is increasing as well.[8] Sorghum is a camel crop that can perform well under fallow conditions by utilizing the available soil moisture and the remaining moisture in the residues. Compared with conventional tillage, sorghum farming with zero tillage offers several advantages in terms of economy and environment, including less labor and fuel requirements, decreased runoff and soil erosion, higher soil organic carbon contents, and enhanced soil biological activity.[9] Millet is frequently planted as a transition crop by the farmers in order to avoid summer fallow while switching back to winter wheat from a full-season summer crop.[10] Hence it is widely known that drought tolerant millets can be cultivated under rice fallow conditions to maintain the nutritional security of the country. All of these difficulties, make India is a developing country that faces the task of providing food security for the world's most populous nation by 2050.[11] To address the increasing demand for food resources especially protein requirements, rice fallow provides a greater opportunity to attain food security of the Nation. Moreover, rice fallow crops are not tapped at their potential.

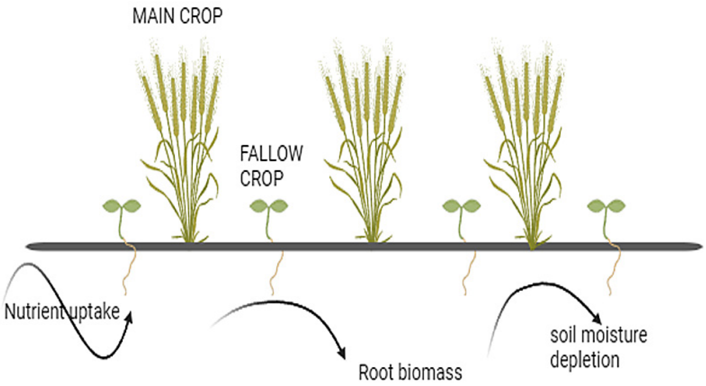

Fig. 1: Illustration of rice fallow crop rotation

Table 1: Comparison of Fallowed Rice Crops

S. No	Parameter	Rice follow crops	Rice fallow crops	Remarks
1	Tillage	Primary tillage, secondary tillage	Zero tillage	
2	Time of sowing	After harvest	Before harvest	Relay cropping
3	Seed rate	Normal seed rate recommended for the crop	Increased seed rate	Due to seed damage
4	Method of sowing	Dibbling	Broadcasting	Due to rice residues its difficult for line sowing
5	Soil type	Any soil type	Clay loam	
6	Moisture condition	Irrigation required	Moisture uptake from soil and crop residues	
7	Soil moisture conservation	No	Yes	
8	Duration of crops	Late maturing	Early maturing	
9	Yield potential	high	low	
10	Per day productivity	less	high	Due to reduction in growth period
11	Cost economics	High	Low	Less input requirement

Concept behind Rice Fallow Crops

This concept is aimed predominantly at zero tillage residual moisture utilization and relay cropping systems. Rice fallow crops are cultivated in standing crop of rice 7-10 days before harvesting as relay cropping is the usual method used in the clay dominated rice fields. This system is designed to conserve the resources and improve the cropping intensity. Conservation tillage is a type of tillage where crop residue is retained and tillage intensity is reduced in order to conserve soil, water and energy resources. Crops are planted, grown and harvested with the minimum disruption to the surface of the soil.[12]

Germination Percentage and Establishment of Crops

The main cause of the low yield of chickpea in relay cropping systems is the lack of plant population due to poor germination less than 50%.[13] One of the main causes of the increased yield of lathyrus and lentil crops under the relay cropping system was the higher population of lentil which was observed in relay cropping than in other crops in the study. The plant population per meter square (32 plants) was significantly greater when blackgrams were broadcasted 7-10 days prior to manual paddy harvest, however, the population per meter square (32 plants) was comparable to that when black grams were broadcasted 4–6 days prior to paddy harvest with a combine harvester.[14] Lathyrus and lentil are known for their ability to establish via the surface seeding method.[15,16] The average percentages of black gram for the broadcasting and zero-till seed drill methods were 82.8% and 91.4% respectively.[17]

Advantages of Rice Fallow Crops

The continuous cultivation of rice in the rice growing area disturbs in the ecology of the system. The incorporation of pulses improves the soil quality in terms of nutrient dynamics, soil organic carbon and biological activities increase nutritional security and improve the sustainability of cropping systems. There was no significant difference in the number of irrigations, the number of fallow crops, or the interaction impact between the days to 50% flowering and maturity in fodder maize.[18] Owing to its ability to establish with surface seeds, appropriateness for relay cropping and resilience against soil moisture and temperature stress, pulses are the best crops for planting in the spaces left empty after rice.[19] Pulses thrive on coarse seedbeds with enough aeration, fine seedbeds are not necessary. Before rice is harvested, pulses such as lentils, lathyrus, black grams and green grams can be sown on the surface on rice fallows under conservation tillage conditions via a zero-till ferti-seed drill.[19] Fallow crops also serve as a kind of ground cover and prolong the storage of soil moisture beneath in the soil. In fact, soil moisture storage plays a major role in the growth and development of rice fallow crops. The retention of residue is crucial for soil sealing and crusting in no-till systems, as well as for improving resource management overall.[20] The way crop residues are managed can affect the ability of the soil to absorb, hold and release nutrients and water.[21,22] Rice residues are significant natural resources, but burning them in the major rice growing regions results in nutrient losses and air pollution. A good alternative to current methods for managing wheat crops is the insitu incorporation of rice waste with microbial consortia in rice-wheat cropping systems. This approach reduces the density of *P. minor* and improves soil quality with increased yield, water productivity and profitability.[22] Rice fallow crops grow under zero-tillage conditions, do not require much labor for cultivation compared with conventional method and do not require any specific method of irrigation. Hence, the system provides additional income to the farmers with minimum investment. In northern states of India, rice–lentil is most suitable crop for rice fallow rice. Millets and oilseeds are highly drought tolerant and do not require fine tilth soil for cultivation. Pulses such as chickpea, require approximately one-fifth as much water as cereals do;however, how various pulses respond to different climatic conditions depends on their genetic makeup.[6] Since residues are essential for retaining moisture, they are not burned in fields, although the fact that this practice pollutes the air in many locations. In general, burning has a more negative impact on soil quality at the surface than it does at the subsurface soil layer.[23] Concerns over farmers burning rice residue were reported because there are few practical, affordable and timely options.[24] Research conducted in Latin America has revealed that farmers following short bush fallow rotations may need to employ 74% or more labor to eradicate weeds on their crops.[25] The retention of residue increases the concentrations of total nitrogen and soil organic carbon in the topsoil layers.[26] The best soil mulch is crop residue, which also aids in reducing evapotranspiration. Crop residue affects the ability of rice to absorb micronutrients such as iron and zinc.[27-28] Planting Italian ryegrass (*Lolium multiflorum*) and forage wheat (*Triticum aestivum*), which have relatively high nutritional value, in winter fallow paddy fields may help alleviate food shortages and provide high-quality feed for cattle.[29]

Crops and Varieties Suitable for Fallowing Rice

The root architecture and growth characteristics of crops and varieties suitable for rice fallow must be distinct. The crops sould be short in duration and mature early. These fallow lands can be used for short-term (≤3 months) intensification with low-water-consuming grain legumes (such as chickpea, lentil, black gram, and green gram) and oilseeds (such as safflower and linseed) to increase the earnings of small holding farmers and improve the health of the soil.[7] Most pulses are chosen for this rice fallow, which has a short duration and early maturation. Since the quantity of water in the soil decreases after rice is harvested, pulse crops with quick growth, early maturity and the ability to quickly cover ground in less time with deep root systems are preferred for rice fallows.[30] It is unique over other crops because it fixes atmospheric nitrogen in the soil. On an average a portion of 0 to 400 kg of N is added to the soil, which improves soil micro flora and fauna. After rice is harvested from fields with residual soil moisture, relay cropping of grass pea and lentil is practiced, however, chickpea can also be grown in low- to medium-elevation ecosystems.[31] Rice-green gram, Rice-cowpea, and rice-soybean are the most common rice fallow pulses cropping systems in southern India.

Table 2 Crops and Varieties Suitable for Fallowing Rice

S. No	Crops	Varieties	State
1.	Black gram	ADT 2, ADT 3, ADT 4, ADT 5, ADT 6, CO 4, TMV 1, LBG 17, LBG 602 and LBG 623	Odisha, Chhattisgarh, Jharkhand, Bihar, Andhra Pradesh, Tamil Nadu and Karnataka.
2.	Green gram	ADT 3, KM 2, CO 4, VBN 1, K 1, CO 6, VBN 2, Pusa 9072, NARM 1-2, and 18	Coastal Andhra Pradesh, Tamil Nadu, Karnataka and Odisha
3.	Cotton	MCU 7, CO 17	Tamil Nadu
4.	Sesame	TMV 7, VRI 4, VRI 5, VRI 1	Tamil Nadu
5.	Ground nut	Kadiri 6, Greeshma, Kadiri Harithandra, TAG 24	Bihar, Odisha, Assam and Andhra Pradesh
6.	Mustard	NRCHB 101, Pusa Agrani , Pusa Mahak , NPJ 112	Eastern Uttar Pradesh, Bihar and Jharkhand
7.	Sorghum	Mahalaxmi 296	Andhra Pradesh

Better tillage and planting techniques can be used to improve the qualities of the soil while growing a second crop during rice fallow. The benefits are greater if the second crop is a legume.[20] By enhancing soil quality parameters and reaping greater benefits while cultivating a second crop in rice fallow through enhanced tillage and planting techniques especially can be used,when the second crop is a legume.[32] Crops planted in rice fallow areas need to be pest and disease--resistant. In Andhra Pradesh, high-yielding chickpea cultivars (ICCV 2 and ICCV 10) were successfully introduced for rice fallow, and chickpea is now replacing the conventional black gram and green gram.[6] The crops grown as rice fallows should not harbor any pests or diseases. It must not act as an alternate host for pests and diseases. Crops help sustain the fertility and productivity of the cultivable land. In terms of yield, cowpea and red gram were found to be perform better than other pulse crops in the rice fallows of northern Kerala. In rain fed rice fallow lands, short-duration, disease-resistant rice and pulse varieties with excellent yields contribute to sustainable intensive cropping systems.[6] Finally, sedentary production systems with short fallow periods are beginning to emerge in some parts of cash crop rotations (mostly centred on cotton and soybeans).[33] The fallow crop must be grow rapidly without much thirst for nutrients. It must be able to withstand moisture stress and be able to take up moisture retained in the residues of preceding crops. The particular benefits of pulse crops include their short growth seasons, resilience and minimal input requirements, which present a better opportunity to utilize leftover soil moisture.[34] Similar results were reported.[35] Similarly, millets are not less valued than pulses are. Compared with pulses, this approach results in high economic returns. They are promisingly highly drought tolerant. Leaf rolling and the waxiness of leaves are some of the moisture stress mitigation strategies used by millets in accordance with fallow condition. Hence, millets are good options for fallowing rice. In rice-fallow situations, selecting early maturing lentil types may help the crop to avoid terminal moisture stress.[36] Owing to higher returns, pulses are replacing *rabi* sorghum in Karnataka and Maharashtra.[37] Safflower and linseed are two oilseeds that can be cultivated under moisture stress.[7,37]

Crop Management Practices

In the case of waxy texture, dibble seeds are recommended if the soil is in waxy condition. However, the plant population is relatively small in relay cropping systems, and a high seed rate is recommended for the optimum plant population.[38] When sown in rice fallow conditions, increasing the seed rate for lentil and lathyrus can greatly increase plant stand and production. Seeds should be sown at a rate that is more than twice as high as usual (30–35 kgha^{-1}).[39] More moisture is present in the soil and seed germination is positively impacted by the planting of wheat before rice is harvested.[40] The results revealed that the soils in this area are fully saturated during the majority of the rice-growing season, and the available water holding capacity of the 1m soil profile of the rice fallow ranges from 150 mm to 200 mm. The remaining soil moisture at the time of rice harvest will be adequate to grow a short-season pulse crops.[6] Seed treatment with *Azospirillum* or *Phospho bacteria*600 gha^{-1} of seed is recommended. In liquid form, 12 ml of *Azospirillum* or *phosphobacteria* ha^{-1} of seed is recommended. Soil microorganisms regulate and control the availability of nutrients and soil enzymes.[41] The use of disease-resistant cultivars and the application of insecticides and fungicides based on the need is beneficial for integrated pest management strategies that treat seeds with fungicides and bio-control agents such as *Trichoderma viride.*[18] With the soil application of 2 kg of *Azospirillum* or *Phosphobacteria* along with 25 kg of FYM and 25 kg of sand with respect to cotton, acid delinting can be performed. With respect to pulses, foliar spraying of NAA 40 mg/l and salicylic acid 100 mg/l once at the time of pre flowering and post flowering stages can be used for better yield or spraying of pulses at the rate of 5 kg/ha or DAP 20g/l can be sprayed during the pre flowering stage and post flowering stage. Improving the quality of fallow vegetation by introducing leguminous cover crops is one of the most well-known alternatives to current cropping practices.[42,43] It is possible for legumes to maintain productivity improvements in systems with increased intensity.[44,45] For increased yield under rice fallow conditions, black gram varieties ADT 3 or LBG 752 seed at 40 kgha^{-1} and then supplemental irrigation at 25 DAS may be advised.[46] Crop management techniques that improve soil moisture availability and storage are expected to increase yield and overall productivity.[47] For better fallow management techniques to be viable and widely adopted, weed control is a necessary.[48]

Yield

The productivity of rice fallow black gram cultivation is consistently much lower than that of regular cultivation.[49] The resulting blackgram grain yield was significantly influenced by the fertilizer application techniques used in the preceding rice crop. The basal application of N and P fertilizer recommended to blackgrams at the rate of 12.5:25 kg ha^{-1} produced the highest grain yield of 891 kg ha $^{-150}$ and the foliar application of two percent DAP and one percent KCl at the flowering and pod filling stages resulted in the highest grain yield of 1007 kgha[1]. Composted paddy straw and paddy straw treated with microbial inoculants combined with 100% inorganic fertilizer (RDF) had an impact on the nutrients available in the soil during the flowering stage (N, P2O5, and K2O), as well as nutrients available after harvest.[51] The lack of adequate moisture in the late scenario causes yield and its contributing characteristics to be different for all cultivars planted in an early and a late situations. In every tillage technique, the moisture content increases with increasing soil depth.[52] The rate of soil moisture depletion increased with Conservation Tillage (0.053 cm day^{-1}) and medium tillage (0.051 cm day^{-1}) compared with no tillage (0.045 cm day^{-1}) from the sowing to the vegetative period.[53]

When grown on rainfed rice-fallow, the yields of lentil and lathyrus were greater than those of mustard, linseed, and chickpea.[54] During the 2008–09 cropping season, the rainy season rice was planted under puddled conditions in the first week of July and harvested in the first two weeks of November. The maize crop sown on November 15 resulted in better yield components and grain yield than those sown on the other dates.[55] After a red gram fallow, rice grain yields are considerably greater.[56] According to reports, less tillage after the wet season (*kharif*) rice yields a higher yield of pulses than does normal tillage.[71] Additionally, under rain fed eastern Indian farmers reported higher yields of pulses with less tillage.[57] Under irrigation, which is the most crucial phase of blooming and pod formation, rice fallow blackgram yields considerably greater yields with two irrigations.[11] The rice yield from a styled fallow can be greater than that from natural fallow[48,58] and styled fallow can reduce weed biomass as shown in northern Laos.[58,59].

Types of Machine Harvest

Paddy combine harvesters are becoming increasingly important in the harvesting process.[21] Since the stubble residue is sufficient for the mulch layer after harvesting rice by combing plants on the root, the method of using the nongrain portion of the crop is most significant for rice harvesting via a combine harvester.[60] The crop stage at the time of harvest is a significant determinant of machine performance and has a major influence on loss and the ultimate conditions of grain and straw yield.[61] The highest value of the cutting efficiency of 97.2 % was obtained by increasing the forward speed of the combine harvester from 1.5 to 2.1 to 2.7 kmh^{-1}. Most of the farmers prefer machine harvesting because of labour shortages and cost reductions. The use of paddy combine harvester reduces the time and labor expenses associated with harvesting and threshing operations for rice farming in swamps.[62] Self-propelled track type combine harvesters and tractor mounted wheel type combine harvesters are the two common types of harvesters used for paddy harvesting. Soil compaction is caused by the high traffic intensity and tire ground pressures of tractors combined during harvest, especially when these operations are carried out on wet soil or with high ground pressure tires. If seeds are sown in rice fallows these machines cause heavy losses in the crop stands of fallow crops. compaction can occur on both sandy and clayey soils, particularly when heavy machinery and low starting soil compaction degrees are used.[63] Commercial products include improved sickles, tractor-driven straw combines, a walk-behind self-propelled vertical conveyor reaper harvester,a power tiller-operated vertical conveyer windrower, an animal-drawn reaper, a tractor-mounted rear reaper windrower, a reaper binder and combine harvester.[64]

Changes in the Physical Properties of the Soil

The topsoil layer generally dries at the time of rice harvest and thus, the planting of a postrainy season crop is not feasible. Under such circumstances, the output of legumes might increase, and the productivity of the rainfed rice fallow lands could be sustained by relay cropping of small-seed lentils, particularly in moderately deep soils.[6] After rice is harvested, ploughing the soils produces large clods with greater breaking strength, which lowers the yields of the following crop, possibly as a result of the reduced root growth.[35] Approximately half of the land and approximately 80% of soils used for cultivation are naturally acidic,[33] and strongly acidic soil has also been observed in the rice–fallows of Chhattisgarh and Assam. In terms of seed yield and nutrient uptake, minimal tillage with standing rice straw intact was superior to both regular tillage without straw mulch and minimum tillage without standing straw.[4]

Terminal drought has a negative impact on agricultural yield when postrainy season crops are planted on residual soil moisture under rainfed conditions.[33] In general, pulses are acidity sensitive and have a direct effect on microbial diversity, plant-nutrient accessibility, biological nitrogen fixation (BNF) and toxic effects at the root.[65] Drought reduces net photosynthesis, and translocation from leaves to budding grains and accelerates the aging of leaves. The accumulation of low-quality biomass often cannot support grain development.[3] Temperature anxiety and terminal drought cause strained ripeness which reduces yield by 50 per cent.[82] Deep vertisols in the rice-fallow regions of Central India are generally ploughed by soil cracking and severe compaction which allows quick moisture loss and results in the death of winter crops.[6] Owing to damage to soil aggregates and macropores, puddling causes the soil to become slurried and reduces the bulk density.[66,67] One of the main factors limiting the productivity of relay cropping is the poor establishment of pulses.[54] Wheel traffic at the soil surface and the development of a plough pan in the deeper layers of the soil are the two main causes of compaction.[5] In a field experiment conducted in Tennessee, nonploughed soybeans presented lower nematode counts than conventionally tilled soybeans did.[68] instead of causing soil compaction above the crucial water content machine forces cause profile disruptions and deep ruts.[69,70]

Constraints Faced in the Present Scenario

Biotic Constraints

The pests and diseases that affect preexisting rice crops may cause damage to subsequent fallow crops. In some cases, pests and fungal spores may hibernate during the fallow season and can cause yield loss especially if the crops fallow are cereals. Similar to insect problems, weeds can result in up to 50% of the crop being lost when they invade rice fallows where pulses are grown.[71] In rice-fallow areas, nematodes known as root-knot nematodes are among the most significant in terms of crop damage and spread.[72] The termites are a major problem in rice fallow. The survival of termites favours moisture, harbors the rice residues and makes moisture unavailable for the fallow crops. These biotic agents thrive in rice fallow regions and cause noticeable damage, despite the lack of extensive studies on the dynamics of disease pests in pulses.[73]

Parasitic plants also cause severe infestations to existing plants. In relay cropping systems, weeds are a major problem because crops are grown in uncultivated soil[32] and added that weeds are serious problem under relay cropping, as there is no land preparation.

Cattles out for grazing cause soil compaction and sometimes may feed on the fallow crops. Because wandering cattle seriously harm fallow crops, farmers prohibit the growth of *rabi* crops in these locations.[54] Another possible danger to pulses in rice-fallow areas is animal grazing. Pulses are severely damaged by wild creatures such as monkeys and Neelgai (blue bull).[6]

In November/December, the rapid loss of soil moisture following rice harvest, the unavailability of suitable winter crop varieties for late planting and socioeconomic issues such as wandering livestock, blue bulls, etc., cause the land to remain fallow after rice harvest.[74]

Abiotic Constraints

The condition deteriorates because of less microbial (Rhizobium) activity, minimum root growth and nutrient shortages, which reduce pulse growth and yield.[75]

In most of the rice fallow crops nutrients are not applied due to the poor socioeconomic status of the farmers and also lack of technical knowledge.

Owing to the short sowing window (10–20 days available for wheat seeding following rice harvest) and personel shortages in some locations, technology was implemented in the form of automated combine harvesters and threshers.[2]

Soil hardiness weakens the hydraulic properties of the soil in puddled rice fields, which impacts the dispersion of soil moisture and the development of tap-rooted pulses.[76] During the post rainy season (November to March), puddled rice soils resulted in drying and cracking which indicates a lack of moisture to support a short-term succeeding crops in terms of residual soil moisture.[77] A deep layer in the rice field causes compaction and a reduction in void space which results in soil crusting and prevents the emergence of seedlings. After rice is harvested, ploughing the soil produces large clods with high breaking power, which reduces the yield of the next crop due to the restricted root growth.[35] Many crops are known to suffer from reduced root growth and yield due to soil compaction whereas, in the Argentine pampas region crops are typically cultivated by direct sowing especially soybeans (*Glycine max* L.) and maize (*Zea mays* L.),which are highly vulnerable.[78] Rice fallow crops are typically sown seven days before the main crop is harvested. Hence, at the time of harvesting of the previous crop, it causes severe damage to the stand of fallow crops occurs. If the rice crop is harvested via a combine harvester then the damage is very heavy such that there is no opportunity for farmers to grow crops during rice fallow. In some areas pulse crops are grown under fallow conditions to increase the nutrient content of the soil which may be utilized by the succeeding crops. In such cases the nutrient availability for the crop is not taken into consideration. Grain and legume productivity under rice fallow conditions is directly impacted by location-specific nutrient deficits (P, Zn, S, B and Mo), unfavourable soil responses (especially soil acidity) and low soil organic carbon (SOC).[6]

In relay cropping systems, the application of basal fertilizer between the rows of standing rice crops does not significantly affect lathyrus yield.[39] Owing to the lack of tillage operations in relay cropping systems, farmers find it challenging to apply fertilizer through top dressing or placement, and as a result, they are not applying fertilizers to the subsequent pulse crops.[79]

The crop was completely dried out twenty to thirty days after planting, making it impossible to collect any data from the rice-chickpea relay intercropping experiment regarding yield or the chickpea yield component for three key reasons: plant architectural issues, restricted plant spacing (mostly row spacing) and abnormally high local temperatures.[80]

Social Constraints

The integrated roles of researchers, extension workers and policy makers are all included in the strategy. The limitations that rice farmers encounter will undoubtedly be mitigated by the efficient execution of designated duties.[22] In regions such as northwestern India where combines are used for harvesting, rice straw is typically burned before the following crop is sown.[81] Nutrient losses from residue burning include 100% C, 90% N, 60% S, and 25% of P and K.[82] In some remote areas owing to a lack of technical knowledge the rice fallow areas are not utilized properly and the burning of residues takes place which can cause air pollution. burning rice straw contributed 0.05% of India's total greenhouse gas emissions. This causes significant losses in biomass or organic carbon and plant nutrients as well as negative effects on the properties of the soil including its flora and fauna.[83] The biggest issue is the inability to obtain high-quality seeds in the required amount at the right time with a fair price.[84] Small farmers do not possess the capacity to purchase the inputs required for rice fallow crops. Therefore, some incentives must be provided for small and marginal farmers to encourage rice fallow and the productivity of crops. After the harvest of rice, farmers often leave their fields untended owing to financial difficulties and limited purchasing power.[85] Indian farm holds are characterized by small and marginal farmlands. Farmers are discouraged from planting a second crop owing to a variety of factors including fragmented land ownership, lack of labor, inputs, restricted access to institutional loans, lack of market and inadequate extension services.[85] Most of the Indian farmers are characterized by small land holdings of less than 2 ha of land area where they prefer for monocropping and stabilized yields. In Assam, the majority of farmers are classified as small and marginal, owning an average of less than two ha of land and relying heavily on monsoon rains for their farming.[86] more than 90 % of farmers believe that a lack of suitable variety is the main cause of the large area that is left fallow during the *rabi* season. They also revealed that people generally believe that the government's procurement of pulses is not as effective as it is for rice and wheat and that farmers are unaware of the minimum support prices set by the government.[6]

Overcoming Constraints on Rice Fallowing

No-till (NT) with minimal soil disturbance including crop residue management is an efficient conservation management method that can improve soil attributes by lowering soil water evaporation, soil sealing, and crusting.[87,88] Before seeds are broadcasted in rice fallow areas, only a small disturbance to the land can enhance the establishment of plants. under field conditions, the treatment injected with Rhizobium resulted in a savings of 42.6 to 48.4 kg N ha in pulse seed yield (lentil, gram, and lathyrus). They also concluded that, the best way to manage nitrogen (N) for crop productivity and improved soil fertility was to apply inorganic and organic N at a 75:25 ratio together.[89] To reduce yield greater seed rate and nutrient management according to its requirements can be used. Improved seed treatment and seed hardening techniques can overcome major constraints. In a field study conducted during the *kharif* season in Indore, (1994) reported that the application of 5 t FYM ha^{-1}, inoculation of Rhizobium and the use of cycocel in combination with soybean produced the highest seed yield (22.86 q ha^{-1}) compared with the control yield (19.80 q ha^{-1}).[56] When lentils were inoculated with Rhizobium, the results were consistently greater than those of the inoculated seeds in terms of plant height, number of nodules, dry weight $plant^{-1}$, nitrogenase activity, pods plant^{-1}, and grain yield.[90] In 1999, Namdeo and Gupta carried out a field study at Schor, Madhya Pradesh to investigate the effectiveness of biofertilizers on red grams. They reported that when *Phospho bacteria* were added to seeds, the resulting grain yield increased by 9.9% compared with that of untreated seeds.[74] Appropriate farm implements, machineries and equipment should be designed especially for rice production in order to overcome the limitations of farm machinery for tasks such as transplanting, weeding, and harvesting. Rice machinery development should be flexible enough to accommodate various rice scenarios.[1] The use of machinery with a little soil contact pressure is always advised. This can be accomplished by employing lighter machinery, lowering tire pressure, adding more tires, and using larger tire sizes.[91]

SWOT Analysis of Fallowed Crops

Strengths

1. Making use of the resources and infrastructure already in place for rice farming.
2. The potential for crop rotation to increase soil fertility and health.
3. Farmers should diversify their sources of revenue.
4. Crop rotation reduces pest, disease, and weed pressures.
5. Additional income with less input cost.

Weaknesses

1. The possibility of a lower yield as a result of insufficient soil moisture.
2. Limited options for crops and a market price for specific fallow crops.
3. Maintaining an optimum plant population is very difficult.
4. Shorter sowing period
5. It is difficult to control weeds, pests and diseases.
6. Compared with continuous cropping, more inputs and management techniques are needed.

Opportunities

1. Support and incentives from the government for crop diversification and sustainable agriculture.
2. The consumer interest in sustainable, healthier food options is growing.
3. The possibility of producing value-added goods such as oilseeds and pulses, from fallow crops exists.
4. Wider area of rice cultivation.
5. Availability of high-yield specific varieties.

Threats

1. The effects of climate change result in erratic weather and water supplies.
2. Variability in the market and fallow crop prices.
3. Competition from urbanization and other agricultural methods for land utilization.
4. This analysis can assist in identifying tactics to overcome the drawbacks of rice fallow cropping while optimizing its advantages.
5. Difficulty in controlling pest and diseases.
6. Self sown rice and its associated weeds.

Conclusion

Long-term studies can be conducted to assess the sustainability and economic viability of the zero-till system with limited irrigation in rice fallows. Studies on various suitable crops can be performed according to the moisture availability of a particular area. Studies on farm machineries which are less in weight and cause less wheel trafficking can be conducted. Development will be performed on a combine harvester attached to a seed drill. Comparitive studies must be performed on zero tillage and reduced tillage operations. Studies must be carried out to increase the productivity and profitability by using reduced-cost operations.

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This research did not involve human participants, animal subjects, or any material that requires ethical approval.

Authors' Contribution

- J.Devi Geethika: Execution of field research, manuscript preparation, Review writing, data collection.
- E.Subramanian – Formulated research proposal, reviewed and manuscript edition.
- A. Gurusamy – Guided on agronomic aspects to conduct the research.
- P. Arunachalam –outiline for review article,reviewing.
- B. Bhakiyathu Saliha – Guided on picture representation.
- A.Sathishkumar- Guided on Checking, Review.

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