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RESEARCH ARTICLE

Feasibility assessment of rice fallow crops in the machine harvested rice fields for sustaining rice fallow crop production

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Abstract

A field experiment was conducted at the Agricultural College and Research Institute, Madurai, to assess the performance of different rice fallow crops in machine-harvested rice fields. Three crops were selected for the trials: urdbean (*Vigna mungo L. Hepper*), sesame (*Sesamum indicum*) and proso millet (*Panicum miliaceum*). The experiment was laid out in a strip plot design with three replications, with vertical plots assigned to different crops and horizontal plots to varying seed rates and sowing times. The results of the study were particularly noteworthy for the urdbean. When urdbean was sown on the same day as the rice harvest with a 20 % increased seed rate (36 kg ha^{-1}), it significantly outperformed all other treatments. This combination recorded the highest net income among the crops tested, demonstrating its superior economic viability in rice fallow systems. The study highlighted the importance of adjusting seed rates to compensate for potential yield losses. Specifically, increasing the seed rate by 20 % proved to be an effective strategy to mitigate yield reductions caused by the trampling effect of the combined harvester. This approach improved yield and enhanced the profitability of black gram cultivation in rice fallow systems. The research concluded that this strategy of increased seed rate and immediate sowing after rice harvest particularly benefited the urdbean. It offers a practical and viable approach to optimizing production in rice fallow systems, potentially leading to improved agricultural productivity and economic returns for farmers utilizing these cropping patterns.

Keywords

combine harvester; rainfed; rice fallow; seed rate; urdbean

Introduction

Rice fallow crops are extensively cultivated in canal-irrigated areas as relay crops. The residual moisture remaining in the soil during rice harvest is often sufficient to support the growth of short-season crops, particularly pulses (1). Relay crops are characterized by their ability to grow using residual moisture throughout their growth period. Rice fallows gather the scope of many farmers as they obtain income from the fallow crop with less investment (2). Due to the frequent failure of monsoon rains and the irregular rainfall distribution during the cropping period, these crops may be subjected to terminal drought. In

eastern India, the shrinking monsoon period and increased frequency of droughts and torrential rains have reduced rice yields and system productivity (3).

Furthermore, the crops may experience moisture stress during critical stages of their growth period. Early maturity, rapid growth, early ground cover and deep root systems have been proposed as desirable plant characteristics for water-limited rice-fallow conditions (4, 5). Consequently, short-duration crops are selected for rice fallow conditions. Supplemental irrigation, which can be facilitated through the construction of farm ponds and rainwater harvesting, has been reported to significantly enhance the survival rates and productivity of pulse crops in rice fallows (6). Rice fallow crops offer substantial potential in addressing the nutritional security of the growing population. Additionally, they provide supplementary income to farmers with minimal inputs beyond the main crop. Therefore, there exists potential for short-duration crops to be cultivated under rice fallow conditions.

The relay cropping system is significant in rice-growing areas. The increase in human population and rapid urbanization has led to a reduction in cultivable land. Efficient utilization of these fallow lands may increase productivity and enhance the entire systems' sustainability (7). Furthermore, production per unit of land area and proper land utilization must be increased to meet food demand. The inclusion of crops in rice fallows could be a viable option to increase food crop production and improve profitability for farmers. Nowadays, combine harvesters are widely adopted for harvesting rice, which poses a challenge for rice fallow crops. Harvesting rice with heavy combine harvesters has proven disadvantageous for growing rice fallow crops. Heavy machinery with large tyres or belts in moist soil affects young pulse crops sown 7-10 days prior. The primary reason for low productivity in rice fallow crops is poor plant population. Mechanical harvesting further adversely affects the plant population in rice fallow. Consequently, the area under rice fallow crops is declining and farmers hesitate to cultivate them. The present study was conducted to optimize the seed rate, sowing time and selection of economically feasible crops for rice fallow conditions. Urdbean, sesame and proso millet were selected for better adaptation to rice fallows and short-duration crops.

Materials and Methods

The field experiment was conducted at the central farm 'A' block, Department of Agronomy, Agricultural College and Research Institute, Tamil Nadu Agricultural University, Madurai, in 2024 in the rice fallow conditions. The experimental site is 9º 54'N latitude, 78º54'E longitude and 147 m above mean sea level. The farm is located in the Southern agro-climatic zone of Tamil Nadu. Soil samples were randomly collected at a depth of 0-30 cm from the experimental site and analysed for their soil physio-chemical properties during the pre and post-harvest stages of the crop. The soil of the experimental field was sandy clay loam in texture, moderately drained, with a pH of 7.6. The soil consists of more clay (29.48 %), followed by fine sand (27.11 %) and coarse sand (24.39 %). The bulk density of the field was 1.35 mg m^{-3} before mechanical harvesting and increased to 1.41 mg m^{-3}. The experiment was laid out in a strip plot design with three replications. The vertical plot consists of three crops *viz*., V_1- Urdbean (ADT 6), V_2- Sesame (VRI 5) and V_3- Prosomillet (ATL 1). Horizontal plot treatment contains various seed rates and time of sowing *viz*., H_1- Recommended seed rate at 7 days before rice harvest (RSR @ 7 DBH), H_2 - Recommended seed rate at a day before rice harvest (RSR @ 1 DBH), H_3- Recommended seed rate at the day of rice harvest (RSR on DRH), H_4 -20 % increased seed rate at 7 days before rice harvest (20 % ISR @ 7 DBH), H_5 - 20 % increased seed rate at a day before harvest (20 % ISR @ 1 DBH) and H_6- 20 % increased seed rate at the day of harvest (20 % ISR on DRH). Due to mechanical rice harvest, the rice fallow seed damage was about 20 %; hence, a 20 % increased seed rate was selected for the study.

Seeds were treated with Rhizobium and Phosphobacteria each @ 30 g kg^{-1} of seed. Treated seeds were sown as per the treatment schedule. The microbial population was observed in the soil before planting and after harvesting rice fallow crops. Pests were controlled by spraying Imidacloprid 17.8 SL @ 120 ml ha^{-1} + neem oil 3 %. Pulse wonder for urdbean was sprayed @ 5 kg ha^{-1} at the peak flowering stage. The crop growth and yield parameters were recorded. Soil moisture was calculated periodically.

The growth and yield parameters were observed: plant height and number of seeds per pod. At physiological maturity, the above-ground portion was harvested manually and dried in direct sunlight for 3-4 days. Subsequently, it was threshed and winnowed manually to separate dust particles and shrunken grains. The grain yield from each plot was weighed and expressed in kg ha^{-1} and the harvest index was calculated. The survival %age of rice fallow crops was observed after a paddy harvested the standing rice crop combine harvester. Economic indices were worked out to find the suitable combination for rice fallow crop sown under machine harvested rice fields.

The data were statistically analyzed based on the procedure described by (8). The critical difference (CD) was calculated at the 5 % probability level (p=0.05). Combinations without significant differences were indicated as 'NS'.

Results and Discussion

The data on the growth and yield contributing characteristics of rice fallow crops revealed that different seed rates and time of sowing significantly influenced the root shoot ratio, root volume, number of seeds $pods^{-1}$, seeds $capsule^{-1}$, seeds $panicles^{-1}$, grain yield (kg ha^{-1}), straw yield (kg ha^{-1}) and moisture % (%).

Survival percentage and soil moisture content of rice fallow crops

Survival percentage was higher in the urdbean because of its capacity to adapt well under rice fallow conditions. In urdbean, a higher survival % of 85.7 was found at sowing with a 20 % increased seed rate on the day of the rice harvest, followed by a 20 % increased seed rate a day before the rice harvest of 83.7 (Fig. 1). The increase in survival % was due to better moisture availability during the critical period. The results indicated pulses have the highest survival rate among the crops due to

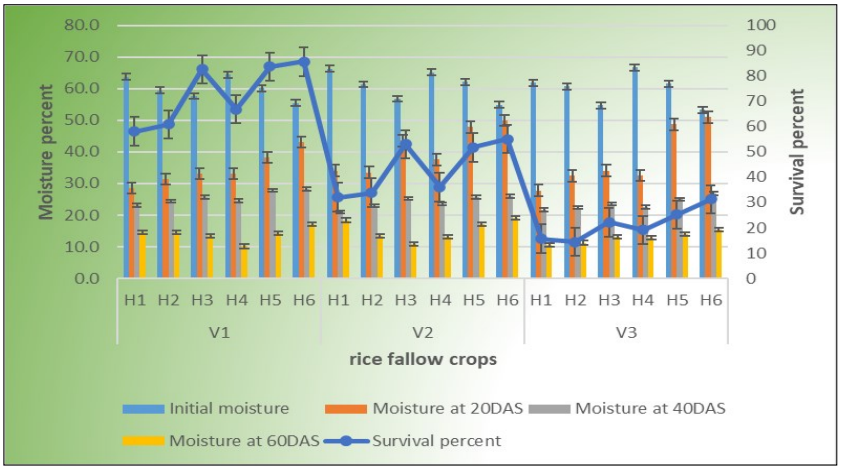

Fig. 1. Effect of soil moisture on survival % of rice fallow crops.

their early germination and adaptability. In sesame, a higher survival % was found at sowing, with a 20 % increased seed rate on the day of rice harvest (55.1), followed by a 20 % increased seed rate a day before (51.8). In prosomillet, a higher survival % was found at sowing, with a 20 % increased seed rate on the day of rice harvest (31.3) followed by a 20 % increased seed rate a day before (25.2). Survival % was found to be poor in the case of prosomillet due to less moisture availability during its growth stages. The ideal plant population decides the yield in the rice fallow conditions. Already, the conditions are not favourable for the germination of crops in the rice fallow conditions. Hence, an increased seed rate is necessary to get more plants regardless of the crops in these conditions.

Growth attributes of rice fallow crops

Seed rate and time of sowing produced significant variation in growth attributes of rice fallow crops. Urdbean sown with a 20 % increased seed rate on the day of rice harvest produced a higher DMP of 830 kg ha^{-1} at 40 DAS, followed by a 20 % increased seed rate a day before rice harvest at 825 kg ha^{-1}. Lower DMP was observed when sowing at the recommended seed rate seven days before harvest. The growth of the blackgram in its early stages likely benefited from the microclimatic conditions created by the standing rice crop, leading to the development of taller plants (9). Root shoot ratio (0.20) and root volume (30.7 cc) were more significant, with sowing at a 20 % increased seed rate on the day of the rice harvest, followed by a 20 % increased seed rate a day before the rice harvest. Optimal root parameters were observed on the day of the rice harvest, which was attributed to the combined harvesters' mechanical dibbling of seeds into the soil. A lower root shoot ratio and root volume were found when sowing at the recommended seed rate seven days before harvest. This was due to root damage caused by the mechanical harvesting of rice, which affects the rice fallow crops at the seedling stage (Table 1). Rice fallow blackgram and finger millet are optimal options for limited irrigations, with reduced management practices, including minimal input cost (10).

Sesame planted with a 20 % higher seed rate on the rice harvest day exhibited the maximum DMP of 733 kg ha^{-1} at 40 DAS, followed closely by those sown with a 20 % increased seed rate one day before rice harvest, 728 kg ha^{-1}. A lower DMP of 690 kg ha^{-1} was observed, with the recommended seed rate applied seven days before harvest. Root shoot ratio (0.55) and root volume (18.5 cc) were higher in plants grown from a 20 % increased seed rate on rice harvest day, which was followed by plants from seeds sown at a 20 % higher rate one day before rice harvest. The Lower root: shoot ratio and root volume were observed in plants grown at the recommended seed rate seven days before harvest. Sesame cultivation is primarily limited to rainfed conditions under suboptimal management practices (11). Hence, sesame may not be suitable in rice fallow conditions where the soil type is heavy clay.

Proso millet sown with a 20 % higher seed rate on the same day as rice harvest exhibited a higher root shoot ratio (0.11) and root volume (22.2 cc) at 40 DAS. This was closely followed by sowing, which resulted in a 20 % increase in seed rate one day before rice harvest, which resulted in plants. Lower root shoot ratio and root volume were observed in plants sown at the recommended rate seven days before rice harvest. Implementing soil moisture conservation and water management practices is critical for successful Proso millet cultivation (12). On pursuing the growth parameters, blackgram was found to be an ideal crop under rice fallow conditions when rice was harvested by machine among the

Table 1. Effect of seed rate and time of sowing on growth characteristics of rice fallow crops

Crops/ Parameters	Blackgram			Sesame			Proso millet		
	DMP (kg ha^{-1})	Root volume (cc)	R/S	DMP (kg ha^{-1})	Root volume (cc)	R/S	DMP (kg ha^{-1})	Root volume (cc)	R/S
H_1-RSR @ 7 DBH	796	29.1	0.10	690	15.6	0.50	780	21.4	0.08
H_2-RSR @ 1 DBH	817	29.3	0.13	719	16.6	0.53	790	21.5	0.09
H_3-RSR on DRH	824	29.7	0.14	729	17.6	0.54	794	22.1	0.09
H_4-20 % ISR @ 7 DBH	810	29.4	0.11	710	16.2	0.51	787	21.8	0.08
H_5-20 % ISR @ 1 DBH	825	30.1	0.14	728	17.8	0.54	804	22.1	0.10
H_6- 20 % ISR on DRH	830	30.7	0.20	733	18.5	0.55	818	22.2	0.11
Mean	817	29.7	0.13	718	17.1	0.52	795	21.8	0.08
C.D (p=0.05)	6.8	8.3	0.02	8.7	0.58	0.01	7.6	0.16	0.006
S.Ed	3.4	4.1	0.01	4.35	0.29	0.005	3.8	0.08	0.003

rice fallow crops. The other crops' growth parameters were drastically affected by machine harvesting.

Yield attributes of rice fallow crops

Urdbean planted with a 20 % higher seed rate on the rice harvest day yielded superior results, producing more seeds pod^{-1}, lengthier pods, 592 kg ha^{-1} of grain and 851 kg ha^{-1} of haulm. This was closely followed by sowing with a 20 % increased seed rate one day before rice harvest, which resulted in 577 kg ha^{-1} of grain and 842 kg ha^{-1} of haulm. The lowest yield was observed when utilizing the recommended seed rate seven days before rice harvest, with 368 kg ha^{-1} of grain and 804 kg ha^{-1} of haulm (Fig. 2). This indicates that grain yield sown with 20 % increased seed rate is 37.8 % higher than sowing with recommended seed rate. Hence, an increased seed rate is mandatory for rice fallow crops aimed at machine-harvested rice fields.

Sesame sowing with a 20 % higher seed rate on the rice harvest day also produced the optimal outcomes, with more seeds capsule^{-1}, lengthier capsule, 280 kg ha^{-1} of grain and 418 kg ha^{-1} of haulm (Fig. 3). The subsequent best results were obtained from planting with a 20 % increased seed rate one day before rice harvest, yielding 256 kg ha^{-1} of grain and 405 kg ha^{-1} of haulm. The lowest yields were observed when utilizing the recommended seed rate seven days before rice harvest, producing 195 kg ha^{-1} of grain and 340 kg ha^{-1} of haulm. The data on yield attributes and yield of sesamum and prosomillet (Fig. 4) indicated that these crops are not well suited for rice fallow conditions when a combined harvester harvests rice. Sesame is not well-suited to rice fallow conditions (13).

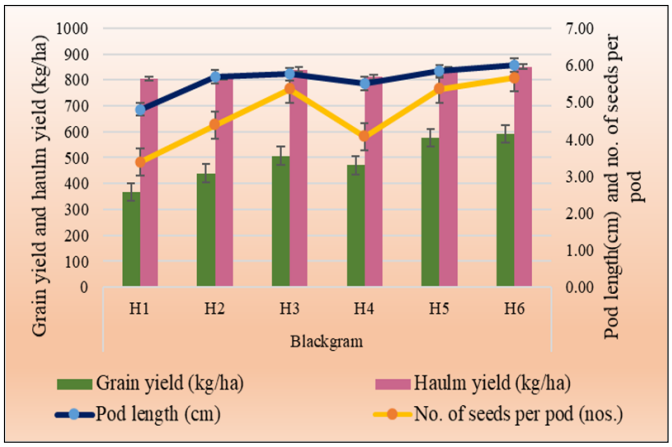

Fig. 2. Effect of various seed rates and time of sowing on yield parameters of rice fallow blackgram.

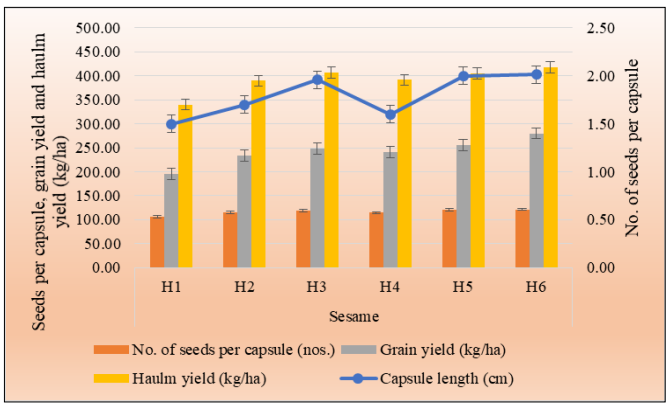

Fig. 3. Effect of various seed rates and time of sowing on yield parameters of rice fallow sesame .

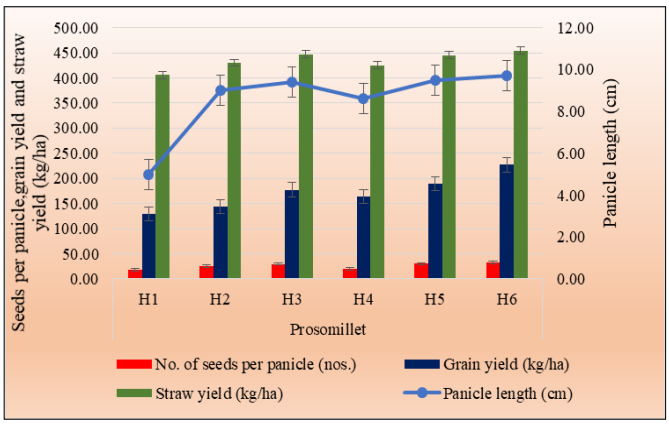

Fig. 4. Effect of various seed rates and time of sowing on yield parameters of rice fallow prosomillet.

A higher plant survival seems to increase grain yield, suggesting that densely planted crops benefit in terms of grain production. The number of seeds per pod/capsule/ panicle directly relates to grain yield. This indicates that plants producing more pods do not affect grain yield, emphasizing the importance of maximizing pod development for better crop yields. The combined relationships suggest that survival %, moisture % and pod/ capsules/ panicle production collectively influence the final grain yield.

Soil microbial population of rice fallow crops

The microbial population was higher in blackgram combinations when compared to sesame and prosomillet. The results indicated that the symbiotic relationship between legumes and nitrogen-fixing bacteria enriches the soil, leading to a higher bacterial population post-harvest period. Sesame and prosomillet soils, while exhibiting a lower microbial population than blackgram, still supported a healthy level of bacteria, fungi and actinomycetes. Rice fallow crops sown with 20 % increased seed rate on the day of rice harvest registered the maximum microbial population of 12.1 ×10^4 CFU/g of soil (fungi), 41.2 ×10^{6}CFU/g of soil (bacteria) and 37.3×10^{3}CFU/g of soil (actinomycetes), in blackgram (Table 2) and sesame produced the maximum population of 7.59 ×10^4 CFU/g of soil (fungi), 36.4 ×10^{6}cfu/g of soil (bacteria) and 11.2 × 10^{3}CFU/g (actinomycetes) of soil whereas, prosomillet registered the maximum population of 6.30 × 10^4 CFU/g of soil (fungi), 26.4 ×10^6 CFU/g of soil (bacteria) and 8.69 ×10^3 CFU/g (actinomycetes) of soil, respectively. A higher cost of cultivation is obtained with a 20 % higher seed rate at various days of sowing of about ₹21719, 16889 and 17609 ha^{-1} in urdbean, sesame and proso millet, respectively. Due to increased microbial activity, the pulses grown in the dry/post-rainy season after rice harvesting improved soil enzymes by around 10–25 % (14). This suggests that cultivating blackgram as a rotational crop could enhance the microbial balance and soil nutrient levels for future crop cycles. Fallow pulses meet up to 80 % of their nitrogen fixation from air, leaving substantial residual nitrogen and organic matter for subsequent crops (15). The higher bacterial count in blackgram soil indicates its potential use as a green manure crop to boost soil health. The results from the study showed that urdbean sown at a 20 % increased seed rate (36 kg ha^{-1}) on the day of rice harvest could be the suitable crop under rice fallows in a machine-harvested rice field.

Table 2. Effect of seed rate and time of sowing on soil microbial population in rice fallow crop field

Crops/ Parameters	Black gram			Sesame			Prosomillet		
	Fungal load post-harvest soil ($\times10^4$) CFU/g of soil	Bacterial load post-harvest soil ($\times10^6$) CFU/g of soil	Actinomycetes load post-harvest soil ($\times10^3$) CFU/g of soil	Fungal load post-harvest soil ($\times10^4$) CFU/ g of soil	Bacterial load post-harvest soil ($\times10^6$) CFU/g of soil	Actinomycetes load post-harvest soil ($\times10^3$) CFU/g of soil	Fungal load post-harvest soil ($\times10^4$) CFU/g of soil	Bacterial load post-harvest soil ($\times10^6$) CFU/g of soil	Actinomycetes load post-harvest soil ($\times10^3$) CFU/g of soil
H_1-RSR @ 7 DBH	10.0	40.1	36.2	7.10	35.03	10.2	5.01	25.2	7.70
H_2-RSR @ 1 DBH	11.4	40.2	36.5	7.10	35.1	10.3	5.09	25.5	7.90
H_3-RSR on DRH	11.5	40.7	36.9	7.50	35.8	10.9	5.70	25.9	8.20
H_4-20 % ISR @ 7 DBH	11.1	40.5	36.7	7.20	35.6	10.7	5.19	25.7	7.99
H_5-20 % ISR @ 1 DBH	11.2	40.9	37.1	7.50	35.9	11.1	5.69	26.0	8.49
H_6-20 % ISR on DRH	12.1	41.2	37.3	7.59	36.4	11.2	6.30	26.4	8.69
Mean	11.2	40.6	36.7	7.33	35.6	10.7	5.49	25.7	8.16
C.D (p=0.05)	0.42	0.22	0.34	0.09	2.27	0.23	0.25	0.24	0.19
S.Ed	0.21	0.11	0.17	0.04	1.13	0.11	0.12	0.11	0.09

Conclusion

The experimental results indicated that rice fallow cultivation is an optimal practice in the delta region, where high yield and income can be achieved under farming conditions. The findings demonstrated that in machine-harvested rice fields, fallow crops, particularly black gram, can be successfully cultivated by sowing with a 20 % increased seed rate on the day of the mechanical rice harvest. This increased seed rate mitigates the potential damage caused by the harvesters' mechanical trampling, increasing yield and enhancing farmers' net income. Thus, black gram sown with a 20 % increased seed rate on the day of rice harvest by combine harvester proves to be the most effective combination and suitable practice for sustaining cereal-based relay cropping systems.

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Authors' contributions

DG helped in the execution of field research and in manuscript preparation. ES formulated the research proposal and reviewed the manuscript edition. AG guided on agronomic aspects to conduct the research. PA helped in preparing the outline for research article and in reviewing. BS guided on picture representation and KJ guided on checking.

Compliance with ethical standards

Conflict of interest: Authors do not have any conflict of interests to declare.

Ethical issues: None

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