



RESEARCH ARTICLE

Resilient farming systems through crop diversification and integration in lowlands

Bindhu J S^{1*}, John J¹, Meera A V¹, Sudha B², Sajeena A¹ & Amritha Kumari S¹

¹Integrated Farming System Research Station, Kerala Agricultural University, Karamana, Thiruvananthapuram 695 002, Kerala, India

²College of Agriculture, Kerala Agricultural University, Vellayani, Thiruvananthapuram 695 522, Kerala, India

*Correspondence email - bindu.js@kau.in

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Abstract

Climate change and food security are among the most complex issues facing the world today. Diversifying crops to improve farm income stands as a pivotal strategy for fostering sustainable agricultural development. Suitable crop diversification strategies with location-specific crops are inevitable in lowlands for resilience and low emission systems. An experiment was conducted at the Integrated Farming System Research Station of Kerala Agricultural University located in Karamana, Thiruvananthapuram, Kerala during 2021–2022 to 2023–2024. The objective was to evolve different cropping sequences in lowlands suited to integrated farming systems for improvement of soil health, family nutrition, animal nutrition and income enhancement. The study also aimed to assess the weed density over different rice-based cropping sequences and seasons. The experiment was laid out in randomized block design (RBD) with 10 treatments (existing and diversified cropping sequences) replicated thrice. The results showed that the floristic composition of weeds varied with seasons and the weed density was found lower in diversified cropping sequences. The soil health status was assessed through the organic carbon build up in the sequences and all the diversified sequences have a positive build-up of organic carbon. Among the cropping systems evaluated, rice + daincha - rice + daincha - red gram + groundnut, rice - bush cowpea-sweet potato, rice - guinea grass + fodder cowpea - guinea grass + fodder cowpea and rice-sweet potato - culinary melon were identified as the most effective systems for enhancing soil health, family nutrition, livestock nutrition and farm income, respectively. Diversified cropping systems can be recommended for reduced weed density over the seasons.

Keywords: cropping system; diversification; resilience; soil health; weed density

Introduction

Agriculture plays a key role in mitigating climate change by reducing emissions and implementing adaptation measures (1). To adapt the agricultural systems to changing environmental conditions, it has become imperative to shift from traditional farming systems to diversified and integrated systems. Concurrently, population explosion, declining cultivable land and degrading soil quality are placing immense pressure on agricultural sustainability. With a global population of 8 billion in 2022 and 10 billion projected by 2050, sustainable food production should follow a combination of three different approaches, viz., intensification, regenerative or agro-ecological and industrial high-tech approaches (2). The overall goal is to produce enough safe food, ensuring nutrition security while conserving the natural ecosystems and restoring degraded land.

The predominant crop in cropping systems in India was selected based on the agro-climatic and socio-economic situations of the area. Rice-rice, rice-wheat, rice-pulse and rice-potato are the most common rice-based cropping systems in India (3). Rice fallows may be a viable option for enhancing productivity and diversification of rice-based systems. Currently, declining crop

diversity has often been associated with expansion of cultivated area bringing about adverse environmental impacts. Increasing farm income through crop diversification is a crucial strategy for promoting sustainable agricultural growth. Spatial concentration of agriculture could offer environmental benefits by using spatial-based data to evaluate the possible productivity of vegetables through land use cover assessment (4). This approach enables rapid evaluation of the benefits of crop diversification in traditional lowland rice systems and can contribute to mitigating the environmental impacts. Thus, declining crop diversity is associated with increasing cropland areas along with the attendant environmental impacts can be addressed. Employing crop diversification, particularly through intensification and introduction, not only boosts net returns but also enhances overall farm productivity.

In Kerala, rice-rice-fallow is the major rice-based cropping system. During the fallow period, raising of suitable crops is a viable option to increase the income of the farmer and system productivity. Suitable crop diversification strategies, including pulses, oilseeds, millets and other location-specific crops, are being implemented in areas most conducive to their growth (5). By introducing a variety of crop species, cropping systems can be

diversified to preserve soil fertility and productivity while reducing pest attacks, reduce disease prevalence, as well as raise yields (6, 7). Including vegetables, legumes, tubers, fodder crops in the summer and rabi seasons could assist in sustaining the soil health rather than the existing system of leaving the fields fallow (8).

Rice-specific weeds are common in rice-based systems. Thus, it may be possible to reduce the infestation of a specific weed by diversifying the existing rice-based cropping system. The effect of crop rotation had a significant influence on weed population.

Hence the present study was undertaken to evolve and evaluate different cropping sequences suited to integrated farming systems for improving soil health, family and animal nutrition and farm income. The study also aimed to assess the weed density over different rice-based cropping sequences and seasons.

Materials and Methods

The study was conducted at the Integrated Farming System Research Station (IFSRS) of Kerala Agricultural University located at Karamana, Thiruvananthapuram, Kerala during kharif, rabi and summer seasons of 2021–2022 to 2023–2024. The experimental site is located in 8° 28' 25" latitude and 76° 57'32" E longitude and at 5 m above mean sea level. The mean rainfall of the site ranged from 1276–2075 mm. The soil of the experimental site is an isohyperthermic typic tropofluent sandy loam (9). The experiment was laid out in randomized block design (RBD) with 10 treatments replicated thrice (Table 1). The treatment sequences were T₁: Rice - fallow-fallow; T₂: Rice-rice-fallow; T₃: Rice-bush cowpea-groundnut; T₄: Rice + dhaincha-rice + dhaincha-red gram + groundnut; T₅: Rice-cassava + groundnut-ragi + bush cowpea; T₆: Rice-bush cowpea-sweet potato; T₇: Rice-Guinea grass + fodder cowpea - guinea grass + fodder cowpea, T₈: Rice - fodder cowpea - fodder maize + fodder cowpea; T₉: Rice-sweet potato-culinary melon; T₁₀: Rice-okra-amaranthus. The cropping sequences were selected as per criteria given in Table 1. The details of variety, duration and market price are given in Table 2.

The gross plot size was 6 × 6 m. The recommended agronomic package of practices of the Kerala was followed for raising diversified crops (10). In T₄, daincha was sown one week after transplanting of rice and was incorporated at 50 % flowering. After each crop season, surface soil samples (0–15 cm) were analysed for organic carbon (11).

Table 1. Criteria for selection of diversified system

Treatment No.	Treatment details	Criteria for diversification
T ₁	Rice-fallow-fallow	Existing farmers' practice in lowlands
T ₂	Rice-rice-fallow	
T ₃	Rice-bush cowpea- groundnut-daincha	Improve soil health
T ₄	Rice+daincha-rice+daincha-redgram + groundnut	
T ₅	Rice-cassava+ groundnut-ragi+ bush cowpea	Improve family nutrition
T ₆	Rice- bush cowpea-sweet potato	
T ₇	Rice-guinea+ fodder cowpea-guinea cuts of earlier planting+ fodder cowpea	Livestock nutrition
T ₈	Rice-fodder cowpea- fodder maize + fodder cowpea	
T ₉	Rice-sweet potato-culinary melon	Income enhancement
T ₁₀	Rice-okra-amaranthus	

Table 2. Details of variety and duration of crops

Crop	Variety	Average duration (days)	Market price (₹ kg ⁻¹)
Rice	Uma	129–135	30
Bush cowpea	Anaswara	85–90	65–80
Cassava	Vellayani Hraswa	130	20–30
Ground nut	Co7	106–110	30–35
Guinea grass	Harithasree	115	3
Fodder cowpea	Co8	80	4
Sweet potato	Sree Arun	95–100	30
Okra	Salkeerthi	90	40
Ragi	VR 847	101–105	30
Red gram	PRG 176	105–110	112
Fodder maize	African Tall	87–95	3
Amaranthus	Arun	55	40
Culinary melon	KAU Vishal	103	30

The productivity of the system was assessed through equivalent basis as below (12):

$$REY = \frac{\sum Y_i P_i}{P(p)}$$

Where, REY denotes rice equivalent yield;

Y_i = yield of different crops;

P_i = price of respective crops and P(p) = price of rice.

The benefit: cost ratio was calculated as the ratio of gross income to cost of cultivation.

Experimental data were statistically analysed using ANOVA following a RBD, as suggested by previous researchers (13). The significance was tested using F- test (14) and critical differences were calculated for comparison, wherever treatments were found to be significant.

Results and Discussion

System productivity

Rice-based cropping system, which alternates crops with vegetables, fodder crops, pulses and oilseeds, is the main cropping system practiced in India. The management of nutrients during different seasons has a major impact on a system's productivity (15). Crop intensification in a rice-based cropping system yields two to four times more rice equivalent (16). The type of crop, the number of crops involved and the ecology in which the crop is grown which all affect the rate of increase of REY. The analysed data pooled over 3 years (Table 3) clearly indicated that the diversified sequence with rice- sweet potato-culinary melon (T₉) produced 279 % more equivalent yield (29111 kg ha⁻¹) than the predominant rice-rice-fallow system (7681 kg ha⁻¹).

The recommended dietary guidelines, which include proposed food groups for a balanced diet to meet the daily nutritional requirement and upscaling for the annual requirement depending on the number and category of family members, can be used to calculate the family's nutrition requirement (12). Among the diversified system for family nutrition, rice-bush cowpea-sweet potato can be recommended for meeting the annual requirement based on the system yield (Table 3). Inclusion of bush cowpea in rabi provided the required protein source for family. In addition, inclusion of pulses can restore the soil health

also. Similarly for animal nutrition, rice-guinea + fodder cowpea, guinea + fodder cowpea was recommended for lowland rice based diversified system based on the system productivity (Table 3). The dry and green fodder requirement was calculated based on the number and type of livestock. The requirement can be enumerated using yield data of the system.

Table 3. Pooled mean of system yield (kg ha⁻¹)

Treatment No.	Pooled mean equivalent yield kharif	Pooled mean equivalent yield rabi	Pooled mean equivalent yield summer	System yield
T ₁	3671	0	0	3671
T ₂	3747	3935	0	7681
T ₃	3878	1528	2094	7501
T ₄	3962	4206	3515	11683
T ₅	3777	9007	4272	17056
T ₆	3684	1424	15264	20372
T ₇	3590	2821	3613	10024
T ₈	3596	1845	5615	11056
T ₉	3690	16496	8925	29111
T ₁₀	3753	10214	9178	23145
CD ($p = 0.05$)	NS	2617.5	4532.3	5259.78

NS: not-significant.

Weed population

The predominant weed flora during kharif were grasses and in rabi sedges and grasses whereas in summer broad-leaf weeds were dominated (Table 4). The findings of many studies have showed that the species composition and weed density varied with crop rotation and method of land preparation. The weed flora was significantly influenced by the cropping systems (17).

The weed density was significantly influenced by cropping sequences and seasons (Table 5). The lowest weed density in kharif was observed in T₄. This may be due to the inclusion of daincha in the system, which occupied the interspaces effectively. This was on par with the treatments T₉, T₈, T₆ and T₇. The inclusion of legumes causes lower weed population in treatments T₈, T₆ and T₇. During Rabi the lower weed density was observed in T₈ and it was on par with all treatments except T₁ and T₁₀. The weed density was lower in T₃ (68.7 m⁻²) and was on par with all treatments except the predominant cropping sequences (T₁ and T₂) and cropping sequences with vegetables in summer (T₉ and T₁₀).

Table 4. Floristic composition of weeds in the experimental site

Season	Predominant weed flora	Predominant weed species
Kharif	Grasses	<i>Isachne miliacea</i> and <i>Echinochloa colona</i> .
Rabi	Sedges and grasses	<i>Cyperus rotundus</i> and <i>Echinochloa colona</i>
Summer	Broad-leaf weeds	<i>Marsilea quadrifolia</i> and <i>Lindernia grandiflora</i>

Table 5. Pooled mean of total weed density of different treatments over three seasons

Treatments No.	Kharif (No./m ²) at 25 DAT	Rabi (No./m ²) at 25 DAT/DAS	Summer (No./m ²) at 25 DAT/DAS
T ₁	86.0	94.0	102.1
T ₂	81.7	71.9	96.8
T ₃	81.0	65.1	68.7
T ₄	64.6	66.6	71.9
T ₅	79.8	73.3	80.7
T ₆	72.4	59.9	82.1
T ₇	70.0	74.3	78.9
T ₈	66.9	57.0	77.4
T ₉	65.6	60.3	88.9
T ₁₀	84.3	77.0	83.6
CD ($p = 0.05$)	13.93	19.20	14.16

Soil health

Depending on the availability of resources, adding legumes and other crops to cropping systems could increase soil fertility, productivity and profitability (18). The soil health status was assessed through the organic carbon build up in the sequences and all the sequences have a positive build-up of organic carbon. Incorporation of a pulse crop in a cropping sequence is essential in terms of crop diversification, soil health enhancement, nitrogen economy and carry-over effects (19).

The results indicated that all diversified systems recorded a positive build-up of organic carbon at the end of summer season. The treatment T₄ recorded the highest value in first year and during subsequent years it was on par with T₃. At the end of summer 2023–2024, T₄ registered 6 % increase over the organic carbon at the beginning of the experiment (Table 6). Pulses for diversification will continue to play a major role in cropping systems in the future due to the shifting landscape of diminishing natural resources, climate change, the pursuit of sustainable agriculture and nutritional security.

Table 6. The organic carbon content of soil at the end of cropping sequence (g kg⁻¹)

Treatments No.	Summer 2021–2022	Summer 2022–2023	Summer 2023–2024
Initial value	13.51		
T ₁	13.13	13.00	12.20
T ₂	12.97	13.13	12.77
T ₃	13.67	13.70	13.90
T ₄	13.97	14.13	14.37
T ₅	13.50	13.47	13.50
T ₆	13.47	13.63	13.33
T ₇	13.23	13.22	12.37
T ₈	13.53	13.17	12.47
T ₉	13.37	13.57	13.60
T ₁₀	13.43	13.67	13.27
CD ($p = 0.05$)	0.261	0.317	0.551

System profitability

The analysed data (Table 7) clearly indicated that the profitability of the system varied with the treatments. Among the different cropping sequences, rice-sweet potato-culinary melon sequence was the most profitable with the highest gross returns (Rs. 921585 ha⁻¹) followed by rice-okra-amaranthus (Rs. 704787 ha⁻¹) which was found to be on par with rice-bush cowpea-sweet potato (Rs. 692481 ha⁻¹). The B:C ratio was the highest (2.77) for rice-sweet potato-culinary melon sequence, followed by rice-okra-amaranthus (2.12) which was on par with rice - bush cowpea - sweet potato (2.09) and rice - cassava + ground nut - ragi+ bush cowpea (2.0), respectively. The highest net returns were recorded in (Rs. 591555 ha⁻¹) in rice-sweet potato-culinary melon sequence which was followed by rice-okra-amaranthus and rice-bush cowpea-sweet potato which were on par.

The results clearly indicated that inclusion of resilient crops like sweet potato and cassava will enhance the profitability of system. The high value crops like vegetables (culinary melon, okra and amaranthus) can be a good choice for diversification in rabi and summer. Economically significant systems are those that yield the highest net returns and profitability. The B:C ratio and net return were significantly higher in the rice-okra-culinary melon. Vegetable-based cropping sequences demonstrated higher productivity with higher gross and net returns compared to other cropping sequences (20).

Table 7. Pooled mean on economics of the different rice-based sequences (2021–2022 to 2023–2024)

Treatment No.	Kharif	Rabi	Summer	Gross return (₹ ha ⁻¹)	Net return (₹ ha ⁻¹)	B:C ratio
T ₁	Rice	Fallow	Fallow	144683	45783	1.47
T ₂	Rice	Rice	Fallow	291694	99161	1.51
T ₃	Rice	Bush cowpea	Groundnut-daincha	269575	-37192	0.88
T ₄	Rice + daincha	Rice + daincha	Red gram+ groundnut	400931	114585	1.39
T ₅	Rice	Cassava + ground nut	Ragi+ bush cowpea	503579	254646	2.00
T ₆	Rice	Bush cowpea	Sweet potato	692481	363515	2.09
T ₇	Rice	Guinea+ fodder cowpea	Guinea+ fodder cowpea	295220	104586	1.53
T ₈	Rice	Fodder cowpea	Fodder maize+ fodder cowpea	269740	67207	1.32
T ₉	Rice	Sweet potato	Culinary melon	921585	591555	2.77
T ₁₀	Rice	Okra	Amaranthus	704787	369901	2.12
CD (p = 0.05)				135523	60115	0.44

Conclusion

Diversified cropping systems significantly improved system performance by enhancing soil health, nutritional security, livestock fodder availability and farm income. The cropping sequences, rice + daincha - rice + daincha, redgram + groundnut, rice - bush cowpea - sweet potato, rice - guinea + fodder cowpea - guinea + fodder cowpea and rice-sweet potato - culinary melon were identified as the best system for soil health, family nutrition, livestock nutrition and income enhancement, respectively. Overall, the adoption of diversified cropping sequences is recommended as an effective strategy for reducing weed density across seasons while enhancing system sustainability.

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Authors' contributions

BJS conducted the field-level experimentation and drafted the manuscript. The concept was visualised and framed by JJ. Field experimentation and laboratory analysis were carried out by MAV. SB and SA also contributed to parts of the field experimentation. AKS handled the plant protection aspects and assisted in drafting the manuscript. All authors read and approved the final manuscript.

Compliance with ethical standards

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

Ethical issues: None

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