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Improving Rice-Based Cropping Pattern Through Soil Moisture and Integrated Nutrient Management in Mid-Tropical Plain Zone of Tripura, India

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Abstract: An experiment was conducted in three fallow paddy fields situated on the mid-tropical plain zone of a northeastern Indian state (Tripura) to provide rice fallow management options using leftover soil moisture and nutrients. The three experimental fields were managed by growing rice under the system of rice intensification as the rainy season crop and then groundnut, lentil, rapeseed and potato as the post-rainy season crops. Fertilization under the integrated nutrient management system and lifesaving irrigation at critical stages of each post-rainy season crop were provided. Results showed that the field water use efficiency values were 5.93, 2.39, 2.37 and 59.76 kg/(hm^2·mm) and that the yield of these crops increased by approximately 20%, 34%, 40% and 20% after applying two lifesaving irrigations in groundnut, lentil, rapeseed and potato, respectively. Therefore, fallow paddy field can provide possible profitable crops during the post-rainy season by utilizing the residual moisture and minimum supplemental irrigation under improved nutrient management practices.
Key words: rice; water-use efficiency; post-rainy season crop; integrated nutrient management; yield; net return

Rice (*Oryza sativa* L.) is the most extensively grown crop in South Asia, occupying nearly 5.0 × 10^7 hm^2 of land area. Approximately 1.5 × 10^7 hm^2 of land in South Asia, 2.1 × 10^6 hm^2 in Bangladesh, 3.9 × 10^5 hm^2 in Nepal and 1.2 × 10^7 hm^2 in India remain fallow after the rainy season because of limited soil moisture availability (Subbarao et al, 2001). Rice is grown mainly on the productive lands of South Asia during the rainy season, hence, cropping intensity may be increased by introducing the second crops during the post-rainy season. Nearly 82% of rice fallows are located in states of Bihar, Madhya Pradesh, West Bengal, Orissa, Assam and Tripura in India. Harris et al (1999) found that fallow lands represent diverse soil types and climatic conditions using geographical information system tools. The available soil water-holding capacity of most lands ranges from 150 to 200 mm. Assuming that the soils in these lands are fully saturated during the rice growing season, researchers concluded that the residual moisture left in the soils at the time of harvest is sufficient to raise short-season legume and oilseed crops, such as groundnut, lentil, rapeseed and mustard (Musa et al, 1998; Bourai et al, 2002). Efficient natural resource management using leftover soil moisture and nutrients after the preceding rice crop can convert lowland rice farming into a profitable enterprise (Musa et al, 1998; Maclean et al, 2002). A positive effect has been observed on post-rainy cropping in the rice fallows of India, Nepal and Bangladesh (Kumar et al, 1994; Musa et al, 1998; Harris et al, 1999; Bourai et al, 2002).

In Tripura, a northeastern Indian state, the rice area is approximately 2.5 × 10^5 hm^2, which can be divided into two categories: valley land with deep water table and medium land with shallow water table. The cropping intensity is 176%, which indicates that only 76% of the net cropped area is being cropped more than once within an agricultural year. Approximately 94% of the cultivated area is dominated by rice, and the remaining 6% is planted with other crops, such as groundnut, maize, green gram and sesame. The soils are semi-heavier in texture, acidic in soil reaction, and retain more water and nutrients to support short-duration crops after the harvest of rice. Farmers who use inorganic fertilizers alone achieve low yields and annual return because of nutrient imbalance in soils. During the rainy season, rice is grown with traditional cultivation practices, and rice varieties under cultivation usually require long duration. As a result,

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land is unavailable when residual moisture can still be found in the fields (November). Water becomes scarce for growing the second crops, and approximately 80% of rice area remains fallow. Transforming a rainfed farming system into a sustainable and productive system through the efficient use of existing natural resources is challenging. During the post-rainy season (November to March), rice fallow land can be brought under double cropping through the carry-over of residual moisture. The pre-monsoon shower occurs within 15 to 17 weeks (last week of April or first week of May). Thus, the off-season tillage and preparation of seed beds are followed by transplantation on the 25th week and by harvesting on the 42nd week (last week of October) at a 70% probability of experiencing rainfall. Considering these aspects, the present study aimed to improve rice productivity during the rainy season and to grow the second crops through proper residual moisture and nutrient management in rainfed and lowland rice fallows. Studies on crop water requirements (CWRs) under local conditions were used as bases to improve crop planning and efficient irrigation management in selected crops by establishing a relationship between evapotranspiration and climate (FAO, 2009). This study was carried out from 2010 to 2012 in the farmer's fields of South district of Tripura, India.

MATERIALS AND METHODS

Study area

The study was conducted in Hrishyamukh, Garjee and Dudhpuskarini villages in South district of Tripura, India. According to the National Agricultural Research Project classification (NARP, 1979) of Agriculture Climatic Zone (India), the study area belongs to the Mid-Tropical Plain Zone (NEH-6) of Tripura and lies between the north latitudes 22°57′ N to 23°45′ N and the east longitudes 91°19′ E to 91°53′ E. From 2010 to 2012, the study area had a mean monthly maximum temperature ranging from 32.2 °C in May to 25.5 °C in January and a mean minimum temperature ranging from 25.4 °C in September to 12.8 °C in January. In addition, the area had a mean total rainfall of 2 001 mm, 80% of which occurred during the southwest monsoon period (June to September). The crop evapotranspiration of the district varied from 4.88 mm in May to 2.78 mm in December.

Soil characteristics

Soil samples were collected from the study area and analyzed before each crop season from 2010 to 2012. The general chemical and physical properties of the soil samples are presented in Table 1. The surface soil was strongly acidic with pH ranging from 4.5 to 5.4. The soil samples contained moderate levels of organic carbon (6.0 to 15.0 g/kg) and available nitrogen (186 to 480 kg/hm^2). Soil fertility was low to moderate with available P (Bray's P), K, Zn and Fe ranging from 21.0 to 54.4 kg/hm^2, 116 to 340 kg/hm^2, 0.1 to 1.1 mg/kg and 42 to 145 mg/kg. The soil samples were classified as sandy loam to sandy clay loam. The water requirements of different important crops from the study area were computed using the CROPWAT8.0 model (Ghosh and Jha, 2002). The irrigation requirements of the crops were determined by subtracting the water requirements from effective rainfall, which was calculated using the United States Department of Agriculture Soil Conservation Services method.

Management practices adopted for rice

The rice variety Gomati/TRC 2005-1 with 125 d duration was grown during the rainy season under both improved system of rice intensification (SRI) and farmer's management practices (conventional rice culture, CRC). Nursery beds for growing rice seedlings under SRI were prepared following standard methods. The agronomic practices used for growing rice under both systems are given in Table 2. A top dressing of nitrogen fertilizer was applied during the maximum tillering stage. Micronutrient (Zn at a rate of 2.5 kg/hm^2) fertilizer and biofertilizer (Azotobacter) were also applied in the improved SRI cultivation. Need-based weeding and plant protection measures were taken.

Management practices adopted for post-rainy season crops

Four post-rainy season crops, namely, groundnut (GG7), rapeseed (RAU-TS-17), lentil (WBL58) and potato (Kufri Jyoti), were grown under limited irrigation from harvested rainwater ponds and carry-

Table 1. Important soil properties of lowland (rice soil) in South Tripura, India.

Parameter	Location of study area (village)		
	Hrishyamukh	Garjee	Dudhpuskarini
Texture	Sandy clay loam	Sandy loam	Clay loam
pH	5.1–5.4	5.1–5.3	4.5–5.0
Organic carbon (g/kg)	6.0–9.6	6.9–7.5	7.5–15.0
Available N (kg/hm^2)	186–345	196–271	340–480
Available P (kg/hm^2)	30.0–54.4	21.0–24.8	25.0–45.0
Available K (kg/hm^2)	116–335	119–335	150–340
Available Zn (mg/kg)	0.5–1.1	0.1–0.9	0.5–1.0
Available Fe (mg/kg)	112–145	42–89	110–121

Table 2. Agronomic practices for growing rice during rainy season.

Cultivation method	FYM:N:P:K (kg/hm^2)	Date of transplantation	Seedling per hill	Spacing
System of rice intensification (SRI)	5000:20:10:10	10 d after sowing (15th July)	1	25 cm × 25 cm
Conventional rice culture (CRC)	1000:80:20:20	30 d after sowing (5th August)	3	20 cm × 15 cm

FYM, Farm yard manure.

over residual moisture after the harvest of rice. Two lifesaving irrigations (50 mm of water) were provided at two critical stages of each post-rainy season crop (Table 3). The agronomic practice for growing post-rainy season crops in rice fallow is presented in Table 4. Lime (10% of lime requirement) and seed treatments with biofertilizers (except potato) were also applied to all post-rainy season crops. The overall water use efficiency (WUE) was determined by dividing the grain yield by the water used (sum of soil water at planting + soil water at harvest + irrigation water + effective rainfall) and expressed as $kg/(hm^2 \cdot mm)$.

RESULTS

Productivity of rice with different combinations of nutrient sources

The grain yield of rice was significantly influenced after 100% of the recommended dose of fertilizer (NPK_{100}) was applied alone and in combination with farm yard manure (FYM), biofertilizer (seedling treatments) and micronutrient ($ZnSO_4$) under the improved SRI and CRC systems (Table 5). The maximum grain yield was obtained when 50% of the recommended dose of fertilizer (NPK_{50}) was applied in combination with FYM, biofertilizer, and $ZnSO_4$ under both SRI and CRC systems. The maximum rice yield (5 200 kg/hm^2) was recorded under SRI with integrated nutrient management (INM) practices (NPK_{50} + FYM + biofertilizer + $ZnSO_4$). No significant variation in rice grain yield was recorded under NPK_{100} + FYM + $ZnSO_4$ and NPK_{50} + FYM + biofertilizer + $ZnSO_4$ across both SRI and CRC systems. However, the cost of cultivation was lower under NPK_{50} than under NPK_{100}. SRI produced 24% higher rice yield than CRC under the INM practices.

Table 3. Irrigation scheduling at two critical growth stages of post-rainy season crops.

Irrigation schedule	Crop			
	Groundnut	Lentil	Rapeseed	Potato
Irrigation-I	Peg initiation	50 % flowering	50 % flowering	Stolonization
Irrigation-II	Grain filling	Grain filling	Siliqua development	Tuberization

Productivity and field WUE of post-rainy season crops in rice fallow

After rice being harvested, groundnut, rapeseed, lentil and potato were grown during the post-rainy season on the same land with three replications to visualize the effects of NPK fertilizer and organic matter management on the succeeding crops under two lifesaving irrigations at the critical stages. Reasonable yields of all the four crops were obtained even under rainfed conditions, with average values of 1 500, 600 and 500 kg/hm^2 for groundnut, rapeseed and lentil, respectively (Table 6), which can be attributed to the moderate available water capacity. In addition, the yields of groundnut (1 800 kg/hm^2), rapeseed (800 kg/hm^2) and lentil (700 kg/hm^2) increased by approximately 20%, 34% and 40%, respectively, when two lifesaving irrigations at two critical stages were applied with integrated nutrient application (NPK_{100} + FYM + biofertilizer).

The highest actual water used by crops (Table 7) during the post-rainy season was observed in potato (401.6 mm), followed by rapeseed (337.2 mm), groundnut (303.2 mm) and lentil (291.9 mm). The moisture deficit at harvest was the lowest in potato

Table 4. Agronomic practices for growing post-rainy season crops during winter season.

Crop	Variety	Crop duration (d)	Spacing	FYM:N:P:K (kg/hm^2)	Date of sowing
Groundnut	GG7	110	50 cm × 15 cm	5000:20:60:40	20 November
Lentil	WBL58	100	30 cm × 10 cm	5000:20:40:20	15 November
Rapeseed	RAU-TS-17	115	30 cm × 10 cm	5000:60:40:40	15 November
Potato	Kufri Jyoti	110	50 cm × 20 cm	5000:120:60:40	24 December

FYM, Farm yard manure.

Table 5. Effects of different fertilizers on rice yields under system of rice intensification (SRI) and conventional rice culture (CRC) system.

Replication-Village	Rice yield (kg/hm^2)					
	NPK_{100}		NPK_{100} + FYM + $ZnSO_4$		NPK_{50} + FYM + biofertiliser + $ZnSO_4$	
	CRC	SRI	CRC	SRI	CRC	SRI
R_1-Hrishyamukh	3 900	4 500	4 100	4 600	4 400	5 010
R_2-Garjee	4 000	4 650	3 900	4 700	4 100	5 000
R_3-Dudhpushkarini	4 200	4 700	3 600	4 750	4 300	5 200
Mean	4 003	4 620	3 870	4 680	4 270	5 070

SRI = 12; CRC = 35. NPK_{100}, 100% of the recommended dose of fertilizer; NPK_{50}, 50% of the recommended dose of fertilizer; FYM, Farm yard manure.

Table 6. Effects of integrated nutrient management (INM) on yields of post-rainy season crops.

Crop	*SD* (*P* = 0.05)	Yield (kg/hm^2)							
		NPK_{100}				NPK_{100} + FYM + biofertilizer			
		R_1	R_2	R_3	Mean	R_1	R_2	R_3	Mean
Groundnut	58.91	1 505	1 470	1 525	1 500	1 810	1 800	1 790	1 800
Rapeseed	29.42	608	590	602	600	804	808	788	800
Lentil	26.95	500	510	490	500	685	710	705	700
Potato [a]	186.73	20 960	21 000	20 980	20 980	24 040	23 900	24 060	24 000

[a], No biofertilizer application. R_1, R_2 and R_3 are three replications.
NPK_{100}, 100% of the recommended dose of fertilizer; NPK_{50}, 50% of the recommended dose of fertilizer; FYM, Farm yard manure.

Table 7. Computed water and irrigation requirements of crops under study.

Crop	Season	Effective rainfall (mm)	Actual water requirement (mm)	Actual water used by crop (mm)	Moisture deficit at harvest (%)	Grain yield (kg/hm^2)	Water use efficiency [kg/(hm^2·mm)]
Rice	Wet (rainy)	1 317.1	841.3	475.8	0.0	4 800	10.08
Groundnut	Dry (winter)	53.1	250.1	303.2	61.0	1 800	5.93
Rapeseed	Dry (winter)	76.9	260.3	337.2	86.8	800	2.37
Lentil	Dry (winter)	51.0	240.9	291.9	84.4	700	2.39
Potato	Dry (winter)	81.3	320.3	401.6	30.7	24 000	59.76

(30.7%) and the highest in rapeseed (86.8%) and lentil (84.4%). This result may be attributed to the fact that one or two irrigations of 50 mm at the critical stages were sufficient to meet the total CWRs of all post-rainy season crops. The crops were sown on the third week of November when a sufficient amount of carry-over residual moisture was available in the fields. Previous research also reported that productivity and cropping intensity increase when lifesaving irrigation is provided to post-rainy season crops, such as wheat, barley, rajmash and sunflower, in rainfed paddy fallow areas (Prasad et al, 2000; Sarker et al, 2000; Singh et al, 2000).

Net returns from different crop combination

The economics of the rice-based cropping system under improved management practices in rainfed rice ecosystem are presented in Table 8. The highest net return was achieved in rice-potato (US$ 3 462), followed by rice-groundnut, rice-lentil and rice-rapeseed crop combination. However, rainfed sole crop produced only US$ 462 and US$ 245 of the net return under improved and farmer's management practices, respectively. Under this situation, improved crop and nutrient management can pay more dividends with potato and groundnut compared with lentil and rapeseed, which can be grown under input-limited conditions.

DISCUSSION

Different combinations of nutrient sources and stand establishment techniques significantly influence rice productivity. Rice grain yields were approximately 18.7% to 20.9% higher in SRI than in CRC during the same period under the INM (NPK_{50} + FYM + biofertilizer + $ZnSO_4$) fertilizer treatment. The INM

Table 8. Net returns from different crop combinations in lowland area of South Tripura, India.

Crop combination	Net return (US$/hm^2)		
	The first crop	The second crop	Total
Rice-groundnut	462	762	1 224
Rice-rapeseed	462	294	757
Rice-lentil	462	400	862
Rice-potato	462	3 000	3 462
Monocropped rice	245	-	245

practice promoted crop growth (Kar et al, 2006), produced a crop yield equivalent to NPK_{100}, and reduced cultivation cost. SRI reduced fertilizer and water requirements and promoted harvest time by 15 d. Hence, this method increased the availability of residual moisture to post-rainy season crops.

When post-rainy crops were grown after rice in the same fields, the yields of groundnut (20%), rapeseed (34%), lentil (40%) and potato (15%) were higher under the INM fertilizer treatment than under the 100% inorganic fertilizer application. Previous research also indicated that inorganic fertilizer sources are better utilized when applied in combination with organic fertilizers than when used alone (Saravaran et al, 1987; Budhar et al, 1991). Puste et al (1999) found that applying 75% of the recommended dose of fertilizer along with FYM or crop residues produces the highest grain yield of rice during the rainy season and subsequently the highest seed yield of some oilseed crops, such as linseed, safflower and niger, during the post-rainy season.

WUE refers to the yield of harvested crop product achieved from the water available through rainfall, irrigation and soil water storage. The WUE values of lentil, groundnut and rapeseed are higher than those of legume and oilseed crops. The computed values of all the post-rainy season crops revealed that WUE values of 5.93, 2.39, 2.37 and 59.76 kg/(hm^2·mm) were achieved when two irrigations were applied to groundnut, lentil, rapeseed and potato, respectively (Table 7). WUE decreased as the amount of available residual moisture increased. Crops with lower residual moisture had higher WUE. The results indicated that timely sown (first week of November) lentil and rapeseed crops can be grown with available residual soil moisture in fallow paddy fields (Doorenbos and Pruitt, 1975). When rain water was scarce, only a single irrigation was found sufficient for the lentil and rapeseed crops, particularly during the pod formation stage. By contrast, groundnut and potato required a minimum of two irrigations to obtain optimum yield. Field crops demonstrate high WUE when irrigation matches the crop evapotranspiration at the critical growth stages during the post-rainy season (Hunsaker et al, 1996; Norwood and Dumler, 2002).

The maximum water productivity often does not coincide with farmers' interest, which is the maximum land productivity and economic profitability (Zwart and Bastiaanssen, 2004). Hence, a shift from 'maximum irrigation and maximum yield' strategies to 'less irrigation and maximum crop water productivity' policies is required. The total amount of irrigation water applied and the timing of irrigation are also important. Water stress during different growth stages affects water productivity but rapidly increases when minimal irrigation is applied during the critical stages of crops. An evaluation of the production cost showed that rice-potato and rice-groundnut cropping sequences require more investment than rice-lentil and rice-rapeseed cropping sequences. Nevertheless, the high yield increase with the rice-potato and rice-groundnut systems can provide many dividends under this rice ecosystem.

CONCLUSIONS

Adopting improved practices (SRI) to high-yielding varieties of rice enhanced the average grain yield from 2 600 to 5 200 kg/hm^2 in lowland during the rainy season. Inorganic fertilizer sources, when applied in combination with organics (FYM and biofertilizer) produced the highest grain yield of rice during the rainy season and subsequently the highest yields of potato, groundnut, lentil and rapeseed during the post-rainy season. Among the different field crops grown with limited irrigation, rice-potato was the most profitable cropping system followed by rice-groundnut. The productivity and WUE of the second crops in lowland rice area can be improved by practicing timely sowing of post-rainy season crops and providing one or two lifesaving irrigations during the critical stages of the crops. The study demonstrated the potential for growing at least two crops in rainfed lowland rice ecosystem by utilizing residual moisture, practicing improved nutrient management, and applying limited irrigation from harvested rainwater.

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