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Crop establishment and nutrient management for production sustainability in rice (*Oryza sativa*)-wheat (*Triticum aestivum*) system in eastern India

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ABSTRACT

In eastern Indo-Gangetic Plains (EIGP), conventional rice (*Oryza sativa* L.)-wheat (*Triticum aestivum* L.) system has led to a decline in total factor productivity, input-use efficiency, and profitability. A three-year (2020–2022) field experiment was conducted at the farmers' fields in Merha village of Katoriya, Banka, Bihar on a sandy clay loam soil to evaluate the impact of crop establishment and nutrient management on production sustainability in rice-wheat cropping system. Experiments were conducted in a split-plot design and replicated thrice. The main-plot treatment had crop establishment methods, viz. (i) Broadcasting: paddy seed broadcasted manually; (ii) Dry seeding: seed drilled on moist soil; (iii) Drum-seeding: dry-seed planted using drum seeder on moist soil and; (iv) Wet-seeding: sprouted seeds broadcasted on puddle soil with variety Sabour Ardhjal in rainy (*kharif)* season and 4-wheat crop establishment method, viz. (i) Broadcasting in CT; (ii) Furrow irrigated raised-bed method; (iii) ZT-drill and; (iv) Seed-cum-ferti-drill machine for wheat variety HD 2967 in winter (*rabi)* season. The sub-plots were allotted four nutrient management treatments, viz. (i) Farmers' practice (130:40:10 kg NPK/ha); (ii) 100% RDF (120: 60:40 kg NPK/ha); (iii) Soil-test-based nutrient management (100% chemical fertilizer-125:75:40 kg NPK/ha) and; (iv) Soil-test based nutrient management (75% chemical fertilizer-94:56:30 kg NPK/ha+25% FYM-6.2 t/ha) in wheat, and (i) Farmers practice (140:30:10 kg NPK/ha); (ii) 100% RDF (120:60:40 kg NPK/ha); (iii) Soil-test based nutrient management (100% chemical fertilizer-150:75:40 kg NPK/ha); (iv) Soil-test based nutrient management (75% chemical fertilizer-115:56:30 kg NPK/ha+25% FYM-7 t/ha) in wheat. Our results revealed that overall system productivity and profitability were higher by 44 and 155.5% in wet seeding paddy-ZT drill wheat system in comparison to broadcasting methods of rice and wheat. System productivity was significantly higher by 28.8% in soil-test based nutrient management production system as compared to the farmers' practices. Thus, to achieve better system productivity and profitability, crops may be grown with wet seeding paddy-ZT drill wheat with soil-test based nutrient management practices under eastern Indo-Gangetic Plains of eastern India.

Keywords: Crop establishment methods, Nutrient management, Rice-wheat system, Sustainable yield index

Rice (*Oryza sativa* L.)-wheat (*Triticum aestivum* L.) cropping system (RWCS) is the largest agricultural production system, extended over nearly 14 mha in Indo-Gangetic Plains (IGP) of South Asia (Mishra *et al.* 2021). Although RWCS is vital for ensuring future food security and livelihood of millions of people in South Asia (Kumar *et al*. 2015), the path to success has been affected by declining soil health (Samal *et al*. 2017) and groundwater resources, monocropping of cereal-cereal production system, increasing climate variabilities, and changing socio-economic dynamics (Mishra *et al.* 2022). The EIGP is an agriculturally important region in South Asia that currently supports millions of human and livestock populations (Kumar *et al.* 2017). Agriculture is one of the important sectors which is more susceptible to climatic variability (Kumar *et al*. 2021). Additionally, socio-economic factors can be considered when determining the benefit:cost (B:C) analysis (Kumar *et al*. 2017) and create a future socio-economic scenario to cropping system models (Kumar *et al.* 2022a). In response to these difficulties, farmers and researchers created a wide array of agricultural strategies that could increase the climate change resilience (Kumar *et al.* 2020). Thus, it is crucial to learn how to accurately evaluate the impact of climate change in agricultural production systems (Kumar *et al.* 2022b). In response to these issues, ICAR launched a nation-wide initiative called National Innovation for Climate Resilient

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Agriculture (NICRA) in collaboration with the ICAR, SAUs and KVK. Over one lakh farming households are a part of this program. The project activities initiated in 2020 at Merha village of Krishi Vigyan Kendra, Banka, Bihar. Natural resource management, crop production, livestock/ fishery management and institutional interventions are implemented in the Technology Demonstration Component (TDC), as they all deal with adaptation of the suitable crop/ cultivars and livestock systems to lessen changing of climate variability. Since its inception, NICRA project has shown and encouraged adoption of a broad range of technology and improved agronomic management methods for mitigating climate change. This has helped the farming community as a whole and its business. These factors were taken into consideration while initiating the experimentation and thus, the present study was planned to be carried out.

MATERIALS AND METHODS

The present study was carried out during 2020–2022 at farmers' field in Merha, Katoriya, Banka, Bihar (86.88 E, 24.76 N, 109.92 m amsl). Experimental field soil was sandy clay loam soil (54% sand, 30% silt;16% clay) with a *p*H of 6.3. Soil was low in organic carbon (0.42%), available N (188.4 kg/ha) and available P (18.7 kg/ha) and medium in available K (173.4 kg/ha). Experiments were carried out in a split-plot design and replicated thrice. Main-plot had crop establishment methods, viz. (i) Broadcasting: paddy seed broadcasted manually; (ii) Dry seeding: seed drilled on moist soil; (iii) Drum-seeding: dry-seed planted using drum seeder on moist soil; (iv) Wet-seeding: sprouted seeds broadcasted on puddle soil with variety Sabour Ardhjal in rainy (*kharif*) season and 4-wheat crop establishment method, viz. (i) Broadcasting in CT; (ii) Furrow irrigated raised-bed method; (iii) ZT-drill; (iv) Seed-cum-ferti-drill machine for wheat variety HD 2967 in winter (*rabi*) season. The sub-plots were allotted four nutrient management treatments, viz. (i) Farmers practice (130:40:10 kg NPK/ha); (ii) 100% RDF (120:60:40 kg NPK/ha); (iii) Soil-test-based nutrient management (100% chemical fertilizer-125:75:40 kg NPK/ha); (iv) Soil-test based nutrient management (75% chemical fertilizer-94:56:30 kg NPK/ha+25% FYM 6.2 t/ha) in wheat, and (i) Farmers practice (140:30:10 kg NPK/ha); (ii) 100% RDF (120:60:40 kg NPK/ha); (iii) Soil-test based nutrient management (100% chemical fertilizer-150:75:40 kg NPK/ha); (iv) Soil-test based nutrient management (75% chemical fertilizer-115:56:30 kg NPK/ha+25% FYM 7 t/ha) in wheat. Fertilizers were applied through urea, di-ammonium phosphate (DAP) and muriate of potash (MOP). At maximum tillering and panicle emergence, 1/3rd recommended dose of N and entire dose P and K was basal applied. In wheat, a recommended dose of of NPK was applied through urea, DAP and MOP. Half of recommended dose of N and whole dose of P and K applied as basal, rest doses of N were applied in two equal splits through urea at maximum tillering and spike emergence stages. Bispyribac-sodium 10 SC @1.5 kg/ha+Pyrazosulfuron-ethyl 10 WP @1.5 kg/ha and ready-mix formulation of sulfosulfuron 75 WP @50 g/ha+metsulfuron-methyl 5 WG @4 g/ha implemented by knap-sack sprayer fitted with flat-fan nozzle using 300 liters of water/ha as 25 days after sowing (DAS) for weed control in rice and wheat, respectively. After harvesting of rice, pre-sowing irrigation was given to ensure ideal soil moisture for wheat sowing. Wheat was directly sown in ZT without primary field preparation, although sowing by seed-cum-ferti-drill-machine, furrow irrigated raised-bed methods, CT all involved cultivators, two harrows followed by planking. Grain and straw yields of each crop in diverse treatments were recorded by crop harvest at maturity from each of 50 m^2 plots. In order to maintain uniformity, crop yields were reported at ~12% moisture content of grains. Rice equivalent yield (REY) of post-rainy crops was computed based on minimum support price (MSP). To compare the productivity of rice-wheat cropping system, grain yields of wheat were converted into rice equivalent yield (REY t/ha) and calculated as sum of rice yield and REYs of wheat for each treatment.

$$\text{REY (t/ha)} = \frac{\text{Economic yield of a crop} \times \text{per tonnes price respective crop}}{\text{Price per tonnes of rice}}$$

In a cropping system, since more than one crop is involved, yield assessment of this system becomes important. In these situations, obtaining a maximum sustained level of yield is more desirable. To assess these situations based on sustainable yield is called sustainable yield index (SYI) as described by Gangwar *et al*. (2003).

$$\text{SYI} = \frac{\overline{Y} - \sigma}{Y_{max}} \times 100$$

Where $\overline{Y}$, estimated average yield of a practice over years; σ, estimated standard deviation; Y_{max}, observed maximum yield in experiment. System productivity was calculated by taking total production on rice equivalent yield basis in a sequence divided by 365 and expressed as kg/ha/day. System profitability was calculated by taking the total system net returns in sequence divided by 365 and expressed as ₹/ha/day. Data pertaining to each character of experimental rice crop, rice equivalent yield of winter crop (wheat) as wherever possible various indices and economic parameters for cropping sequences were tabulated, and finally analyzed statistically by applying standard techniques to draw a valid conclusion. Analysis of variance for split-plot design was worked out as per the standard procedure. The significance of treatment differences was judged by F-test as outlined by Cochran and Cox (1957). To evaluate the significance of difference between two treatment means, critical difference (CD) at 5% level was worked out.

RESULTS AND DISCUSSION

Growth indices: Leaf area index (LAI), crop growth rate (CGR) and relative growth rate (RGR) were increased steadily up to 90 DAS, but net assimilation rate (NAR) increased up to 30 DAS and gradually decreased up to 90

Table 1 Effect of crop establishment and nutrient management on physiological attributes in rice and wheat (mean data of 3 years)

Treatments	Leaf area index			Crop growth rate (g/m^2/day)			Relative growth rate (g/g/day)			Net assimilation rate (g/m^2/day)		
	30 DAS	60 DAS	90 DAS	0–30 DAS	30–60 DAS	60–90 DAS	30–60 DAS	60–90 DAS	90 DAS harvest	0–30 DAS	30–60 DAS	60–90 DAS
Rice												
Crop establishment methods												
Broadcasting	0.43	1.45	2.59	0.435	1.594	2.720	0.179	0.638	1.061	0.046	0.033	0.010
Dry seeding	0.67	2.35	2.88	0.679	2.570	4.262	0.278	1.028	1.662	0.054	0.038	0.012
Drum seeding	1.25	3.26	4.07	1.153	3.555	5.844	0.473	1.422	2.279	0.069	0.048	0.015
Wet seeding	0.92	2.88	3.73	0.872	3.193	5.270	0.358	1.277	2.055	0.062	0.044	0.013
CD (P=0.05)	0.10	0.14	0.21	0.088	0.215	0.357	0.058	0.096	0.119	0.003	0.003	0.001
Nutrient management practices												
Farmers' practice (130:40:10 kg NPK/ha)	0.59	1.93	2.83	0.561	2.138	3.655	0.230	0.855	1.425	0.050	0.034	0.009
100% RDF (120:60:40 kg NPK/ha)	0.77	2.37	3.19	0.738	2.602	4.337	0.303	1.041	1.692	0.055	0.037	0.011
Soil test based nutrient management (100% chemical fertilizer)	0.88	2.64	3.51	0.861	2.929	4.856	0.353	1.172	1.894	0.060	0.043	0.013
Soil test based nutrient management (75% chemical fertilizer+25% FYM)	1.04	3.00	3.79	0.980	3.241	5.448	0.422	1.296	2.047	0.066	0.049	0.016
CD (P=0.05)	0.14	0.25	0.27	0.111	0.436	0.514	0.064	0.121	0.151	0.005	0.005	0.003
Wheat												
Crop establishment methods												
Broadcasting	0.39	1.29	2.21	0.392	1.434	2.448	0.157	0.574	0.979	0.042	0.029	0.009
Dry seeding	0.60	2.08	3.46	0.611	2.313	3.836	0.244	0.925	1.534	0.049	0.035	0.011
Drum seeding	0.97	2.88	4.74	1.038	3.200	5.260	0.415	1.280	2.104	0.062	0.044	0.013
Wet seeding	0.79	2.59	4.27	0.785	2.873	4.743	0.314	1.149	1.897	0.055	0.038	0.011
CD (P=0.05)	0.09	0.19	0.40	0.090	0.282	0.460	0.041	0.105	0.202	0.005	0.005	0.001
Nutrient management practices												
Farmers' practice (130:40:10 kg NPK/ha)	0.49	1.73	2.96	0.505	1.925	3.289	0.202	0.770	1.316	0.045	0.031	0.008
100% RDF (120:60:40 kg NPK/ha)	0.65	2.11	3.52	0.665	2.342	3.904	0.266	0.937	1.561	0.049	0.033	0.010
Soil test based nutrient management (100% chemical fertilizer)	0.74	2.38	3.94	0.775	2.636	4.371	0.310	1.055	1.748	0.054	0.039	0.012
Soil test based nutrient management (75% chemical fertilizer+25% FYM)	0.87	2.63	4.25	0.882	2.917	4.723	0.393	1.197	1.889	0.063	0.045	0.014
CD (P=0.05)	0.10	0.24	0.48	0.101	0.327	0.537	0.056	0.131	0.215	0.007	0.005	0.001

DAS in case of rice (Table 1). LAI was recorded higher in drum seeding at 30, 60 and 90 DAS and significantly superior with wet seeding, dry-seeding, and broadcasting. In nutrient management practices, soil-test based nutrient management (75% chemical fertilizer+25% FYM) had resulted in a higher LAI and found significantly superior to the soil-test based nutrient management (100% chemical fertilizer), 100% RDF (100:60:40 kg NPK/ha) and farmers practice (130:40:10 kg NPK/ha). The CGR, RGR and NAR were also highest in drum seeding at 0–30, 30–60 and 60–90 DAS in CGR, NAR and 30–60, 60–90 and 90 DAS–harvest in case of RGR. In nutrient management, soil-test based nutrient management (75% chemical fertilizer+25% FYM) resulted in more CGR, RGR, NAR and found significantly superior to soil-test based nutrient management (100% chemical fertilizer), 100% RDF (100:60:40 kg NPK/ha) and farmers practice (130:40:10 kg NPK/ha).

The LAI, CGR and RGR all gradually increased until 90 DAS, but NAR grew up to 30 DAS before declining up to 90 DAS in wheat. This was due to enhanced soil health and micro-environment by implementation of ZT (Kumar *et al.* 2017). In nutrient management, soil-test based nutrient management (75% chemical fertilizer + 25% FYM) resulted in significantly higher LAI superior with soil-test based nutrient management (100% chemical fertilizer),100% RDF (100:60:40 kg NPK/ha) and farmers practice (130:40:10 kg NPK/ha). This might be due to better supply of nutrients and more availability of inorganic form of nutrients by adding FYM, which led to increase the number of leaves per unit area resulting in enlargement in leaf area.

The CGR, RGR and NAR were maximum in ZT-drill at 0–30, 30–60, 60–90 DAS in CGR, NAR and 30–60, 60–90, 90 DAS-harvest in RGR and significantly superior with seed-cum-ferti-drill, furrow irrigated raised bed (FIRB) broadcasting. This was due to increase in organic matter in ZT, which facilitated easy nutrient availability to crop plants and resulted in better plant growth and development as suggested by Jat *et. al.* (2017). In nutrient management practices, soil-test based nutrient management (75% chemical fertilizer+25% FYM) resulted in more CGR, RGR, NAR and found significantly superior with soil-test based nutrient management (100% chemical fertilizer), 100% RDF (100:60:40 kg NPK/ha) and farmer's practice. This might be due to role of nutrients in production and translocation

Table 2 Effect of crop establishment and nutrient management on yield attributes, yield and economics in rice and wheat (mean data of 3 years)

Treatments	Yield attributes			Grain yield (t/ha)	Economics		
	Panicle or ear length (cm)	Grains/ panicle or spike (no.)	1000-grain weight (g)		Gross returns (₹/ha)	Net returns (₹/ha)	B:C ratio
			Rice				
Crop establishment methods							
Broadcasting	17.6	167.5	22.6	2.40	50615	18415	1.27
Dry seeding	20.3	178.6	23.5	2.87	60603	27978	1.50
Drum seeding	23.0	195.9	25.5	3.46	72982	45882	2.17
Wet seeding	22.2	188.4	24.0	3.10	65436	32211	1.59
CD (P=0.05)	0.86	8.40	NS	0.16	4310	18415	0.13
Nutrient management practices							
Farmers' practice (130:40:10 kg NPK/ha)	18.8	157.6	22.7	2.58	54530	24680	1.50
100% RDF (120:60:40 kg NPK/ha)	20.4	180.8	23.6	2.82	59575	28875	1.59
Soil-test based nutrient management (100% chemical fertilizer)	21.3	190.7	24.0	3.10	65483	34233	1.73
Soil-test based nutrient management (75% chemical fertilizer+25% FYM)	22.5	201.3	25.1	3.32	70047	36697	1.72
CD (P=0.05)	1.07	11.66	1.37	0.19	4062	1488	0.11
			Wheat				
Crop establishment methods							
Broadcasting	6.5	34.8	41.1	2.76	50615	16915	1.50
Dry seeding	6.8	36.1	42.6	3.30	60603	26478	1.77
Drum seeding	7.4	41.1	43.7	3.98	72982	44382	2.55
Wet seeding	7.1	36.7	42.2	3.57	65436	30711	1.88
CD (P=0.05)	0.57	2.46	NS	0.18	4310	899	0.13
Nutrient management practices							
Farmers' practice (130:40:10 kg NPK/ha)	6.6	35.3	42.2	2.97	54530	23180	1.76
100% RDF (120:60:40 kg NPK/ha)	6.8	36.4	42.4	3.25	59575	27375	1.87
Soil-test based nutrient management (100% chemical fertilizer)	7.2	39.2	42.3	3.57	65483	32733	2.03
Soil-test based nutrient management (75% chemical fertilizer+25% FYM)	7.3	37.8	42.6	3.82	70047	35197	2.03
CD (P=0.05)	0.55	1.94	NS	0.22	4062	1904	0.13

of cytokinin from root to shoots resulting in an increase in the cell division (Kumar *et al.* 2015).

Yields attributes and economics: Grains/panicle (no.) was more in drum seeding (195.9) followed by wet seeding (188.4), dry seeding (178.7) and farmers practices (167.5) and statistically at par with wet seeding (Table 2). In nutrient management, soil-test based nutrient management (75% chemical fertilizer+25% FYM) resulted in more grain (3.33 t/ha) and was significantly superior to soil-test based nutrient management (100% chemical fertilizer), 100% RDF (100:60:40 kg NPK/ha) and farmers practice (130:40:10 kg NPK/ha). Panicle length (cm) and grains/panicle were maximum with soil-test based nutrient management (75% chemical fertilizer+25% FYM), which was significantly superior to the soil-test based nutrient management (100% chemical fertilizer), 100% RDF (100:60:40 kg NPK/ha) and farmers practice (130:40:10 kg NPK/ha). This could be attributed due to efficient nutrient management treatment in drum-seeding produced better growth, thus increased accumulation of photosynthates in reproductive part, which ultimately brought marked improvement in crop yields. Drum seedling gave the highest B:C ratio and net income, thus it proved more economically viable. This was ascribed due to higher crop yield and minimum cost of cultivation. Maximum net income was recorded with soil-test based nutrient management practices (75% chemical fertilizer+ 25% FYM) but maximum B:C ratio was noted with soil-test based nutrient management (100% chemical fertilizer).

The ZT-drill sowing of wheat had higher grain yield (3.98 t/ha), which was higher than seed-cum-ferti-drill (3.57 t/ha), FIRB (3.31 t/ha) and broadcasting (2.76 t/ha). Higher grain yield in ZT-drill might be due to improved yield attributes and earlier planting (Bohra and Kumar 2015; Pratap *et al*. 2022). For wheat, ZT-drill treatment had the highest grain yield ~10–12% as reported by Samal *et al.* (2017). The ZT-drill recorded more grains/spike (41.1) and was significantly superior to seed-cum-ferti-drill and FIRB. More effective tillers/m row length (112.6) and ear length (7.4), but statistically at par with seed-cum-ferti drill and noted significantly superior with FIRB. Soil-test based nutrient management (75% chemical fertilizer+25% FYM) had more grain yield (3.82 t/ha) and significantly superior with soil-test nutrient management practices (100% chemical fertilizer), 100% RDF (100:60:40 kg NPK/ha). Grains/spike, and ear length were more in soil-test based nutrient management practices. The ZT-drill proved to be more profitable owing to its highest advantage, which had a B:C ratio of 2.55 and net income of ₹44,382/ha (Table 2). This was attributed to a better crop yield and having low cost of cultivation. Maximum net income (₹35,197/ha) was noted in soil-test based nutrient but maximum B:C ratio (2.03) was under soil-test based nutrient management practices (75% chemical fertilizer+25% FYM) and soil-test based nutrient management (100% fertilizer).

System productivity, profitability, sustainable yield, and value index (SYI and SVI): System productivity and net incomes were significantly higher in wet seeding paddy-ZT-drill sowing wheat, and it was superior to drum seeding paddy-seed-cum-ferti-drill-wheat, dry seeding paddy-FIRB planting wheat and broadcasting of rice and wheat (Table 3). System productivity was significantly higher by 28.8% in soil-test based nutrient management production system as compared to the farmers' practices. System productivity and profitability was higher under soil-test based nutrient management (75% chemical fertilizer+25% FYM) and it was significantly superior over soil-test based nutrient management (100% chemical), 100% RDF and farmers practice of rice and wheat. Sustainable yield index and sustainable value index (SYI and SVI) was determined based on total productivity and net return of the entire rice-wheat

Table 3 System rice equivalent yield (SREY), productivity, sustainable yield index and sustainable value index (SYI and SVI) of rice-wheat system under different tillage-cum-crop establishment methods (mean data of 3 years)

Treatments	SREY (t/ha/yr)	System productivity (kg/ha/day)	System net returns (₹/ha/yr)	System profitability (₹/ha/day)	SYI	SVI
Crop establishment methods						
Broadcasting methods of rice and wheat	5.27	21.6	35330	145	0.57	0.14
Dry seeding paddy-FIRB sowing of wheat	6.30	26.0	54456	225	0.70	0.35
Wet seeding paddy-ZT drill sowing wheat	7.59	30.6	90264	364	0.87	0.75
Drum seeding paddy-Seed-cum-ferti-drill wheat	6.81	27.9	62922	257	0.77	0.44
CD (P=0.05)	0.28	1.93	2549	25	-	-
Nutrient management practices						
Farmers practice (130:40:10 kg NPK/ ha)	5.66	23.9	47860	202	0.73	0.52
100% RDF (100:60:40 kg NPK/ha)	6.20	25.9	56250	235	0.81	0.63
Soil-test based nutrient management (100% chemical fertilizer)	6.81	27.3	66966	269	0.90	0.78
Soil-test based nutrient management (75% chemical fertilizer +25% FYM)	7.29	29.1	71894	287	0.97	0.85
CD (P=0.05)	1.40	2.38	1815	19.2	-	-

system for 3 years under each treatment. Higher values of SYI and SVI were recorded in drum seeding paddy-seed-cum-ferti-drill wheat (0.87 and 0.75) followed by wet seeding paddy-ZT drill sowing wheat (0.77 and 0.44). Among the nutrient management practices, maximum SYI and SVI were noted in soil-test-based nutrient management (75% chemical fertilizer+25% FYM) (0.97 and 0.85). As a result, wet seeding paddy-ZT drill sowing wheat yields were more reliable for increasing system productivity and profitability of rice-wheat cropping system. Thus, yield in wet seeding was proved to be more sustainable for higher productivity and profitability of rice-wheat system than growing of rice by direct seeding either by zero till and drum seeder. These findings are in close conformity with Bohra and Kumar (2015).

Thus, from the above study it may be concluded that wet seeding paddy-ZT drill-sowing wheat along with soil-test based nutrient management practices (75% chemical fertilizer+25% FYM), which achieved better system productivity and profitability of rice-wheat cropping system may be promoted for wider adaptability at the farmers' fields of eastern Indo-Gangetic Plains (EIGP) of eastern India. The results also indicate that these alternative practices have potential to conserve soil moisture, improve soil health and biodiversity, and tolerance to terminal heat stress. However, to scale out these profitable, but capital-intensive options for smallholders, there is a need to strengthen service providers in EIGP. More long-term data under varying agro-ecologies would be beneficial to increase the impact and large-scale adoption of these technologies in EIGP.

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