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Improving Productivity and Profitability of Rice-Based Cropping Systems in Eastern India

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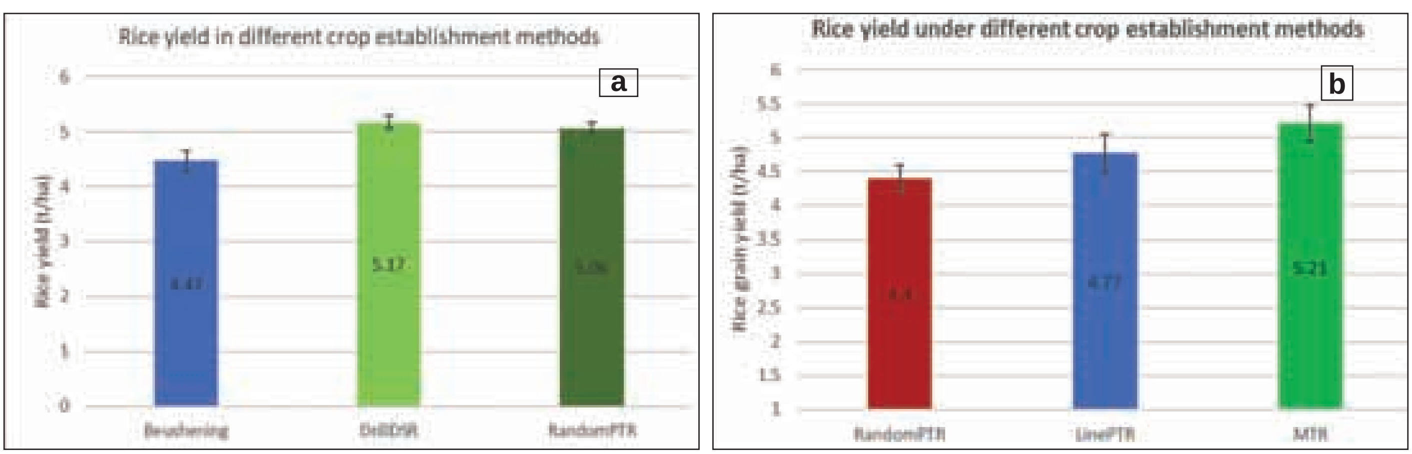
Introduction

Rice is a staple food for 65% of the Indian population and contributes to 43% of food grain production. Rice plays a central role in culture, rituals, diet and employment, and is considered as an instrumental crop that changed India's status from food-deficient to the exporter (Yadhav *et al.,* 2017). Eighty-three percent of rainfed rice in India is from eastern states. The plains of Assam, Bihar, Chhattisgarh, eastern Uttar Pradesh (EUP), Jharkhand, Odisha, and West Bengal are among the states in eastern India which covers a total area of 72 million hectares, representing nearly 22% of the country's area, and supporting about 34% of the country's population. Eastern Indian states have fertile soils and ample water resources but the productivity and profitability of rice farmers in eastern India is low compared to other regions in India. This is mainly because of sub-optimal adoption of improved varieties and technologies in addition to extreme climatic variability including frequent drought and floods. After harvesting the rice, farmers leave their fields fallow rather than planting a second crop in the same year due to physical and socio-economic issues. Utilizing fallow lands effectively can offer enormous possibilities and potentials for raising the system productivity, profitability and sustainability of the rice-based systems. Hence, developing and promoting location-specific sustainable rice production technologies and management practices is of prime importance in rice-based systems. It is highly crucial to improve the rice-based cropping systems (RBCS) by adopting sustainable crop management practices in rice during the *kharif* season which consequently can result in bringing more rice-fallow areas under cultivation through water-efficient and short-duration pulses or oilseeds in the *rabi* season. Altogether, these interventions may enhance the productivity and profitability of RBCS in the region.

Resource-efficient alternative crop establishment methods *in rice*

The crop establishment (CE) method is the most critical for ensuring a good crop stand as well as productivity, particularly under rainfed situations. Rice is commonly established by manual transplanting. A huge amount of water and labor requirements for transplanting reduces profit margins. Since the conventional (manual) puddled transplanting of rice (PTR) is highly input-intensive, precision dry-direct seeded rice (DSR) and mechanical transplanting of rice (MTR) have emerged as alternatives to reduce dependency on farm laborers, reduce cost and input use while increasing the profit (Pannerselvam *et al.,* 2020).



A study in Odisha showed that direct sowing of rice with the use of seed drill increased rice grain yield by 0.7 t/ha over beushening systems (broadcasting followed by beushening) (**Figure 1a**). However, the grain yield of DSR was on-par with manual PTR. The *beushening* method consists of broadcasting ungerminated rice seeds using high seed rates (> 100 kg ha^{-1}) in the field before the onset of monsoon rain, followed by cross-ploughing and laddering (leveling using flat wooden plank) at 4–6 weeks after emergence when 10-15 cm of rainwater has accumulated in rice fields. Cross-ploughing and laddering helps to control weeds, thins the crop stand, and distributes rice seedlings more evenly. These operations are labor-intensive, tedious, and are largely carried out by women. The inclusion of drill-DSR can address the challenges associated with the labor scarcity because DSR reduces the labor requirement by 40% (Pandey and Velasco, 2002) and thereby reducing the labor cost (Yadav *et al.,* 2017). A prime reason for higher yields is timely and effective weed control achieved through herbicide-based IWM. In *beushening*, early weed competition is generally higher as weeds are not controlled for the first 30-40 days prior to the *beushening* operation. Another reason for higher yield in drill-DSR is due to more efficient use of applied fertilizer as fertilizers were applied at the recommended time (at sowing, 25-30 DAS, and panicle initiation stage). Net benefit were significantly higher by 166-550 US$/ha in drill-DSR compared to *beushening* due to the combination of increased yield and/or lower variable cost in drill-DSR (Panneerselvam *et al.,* 2020). However, insufficient availability of seed drills poses a major bottleneck to the broad adoption of drill-DSR. Moreover, drill-DSR in very lowland area under rainfed situation is also difficult if there is an excess rainfall.

In another experiment, we tried to compare mechanical PTR with manual PTR (random and line) in Odisha. Our results showed that mecahical PTR increased grain yield by 0.81 and 0.44 t/ha than manual random PTR and manual line PTR, respectively (**Figure 1b**). The higher rice yield in MTR could be attributed to the use of young seedlings (Uphoff, 2002). For instance, under manual transplanting, 25 to 30-day old seedlings were used, whereas for MTR, 15 to18-day old seedlings were transplanted which might have resulted in the early adaptation of the seedlings. Moreover, seedlings in the mat type nursery have less damaged roots resulting in less transplanting shock which is a major problem in the manual-PTR, and consequently leading to higher yield. Additionally, along with the improved yield, the MTR better manages time and reduces the production cost by reducing the labor cost for transplanting. Both drill-DSR and MTR not only produce higher yields, but also address the labor scarcity problems, decrease the input costs, and also reduce GHG emissions such as methane (Pathak *et al.,* 2013). However, there are also major challenges in the adoption of drill-DSR and MTR due to the lack of awareness of the technology, limited availability of the machines, inadequate mat-type nursery, and lack of skilled workers (Yadav et al., 2017).

Integrated weed management for sustainable intensification

Weeds are considered as one of the major constraints to wide-scale adoption of dry-DSR and yield can be reduced from 50 to 90 % if weeds are not properly controlled (Chauhan and Johnson, 2011). When weeds are effectively controlled, DSR yields are similar to that of transplanted rice (Gathala *et al.,* 2013). Manual hand-weeding is becoming difficult and uneconomical due to labor scarcity at the critical time of weeding (Kumar and Ladha, 2011). Hence, effective herbicide based-integrated weed management (IWM) practices are needed to reduce variable costs and labor use/cost. Our results suggest that drill-DSR out-yields *beushening* by an average of 1.5 t ha^{-1} in two out of three districts and increases net benefits by 166 to 550 US$ ha^{-1}. A prime reason for higher yields is timely and effective weed control achieved through herbicide-based IWM. It has been found that the integration of herbicides (PRE or tank-mix application of POST) with one hand weeding can save labor and is more profitable and productive than hand-weeding, herbicide, or mechanical weeding alone. IWM in dry-DSR saved 17-25 labour/ha, saved 28-57 US$/ha and increaded net profit by 68-82 US$/ha over hand weeding alone. Similary, IWM in broadcasing method also saved labour (38-48 labour/ha), saved cost (57-81US$/ha), increased yield (0.4-1.2 t/ha) and profit (114-312 US$/ha). The results of the current research are also in agreement with previous reports of superior weed control in DSR with sequential application of PRE (pendimethalin) followed by POST (bispyribac-sodium) over hand weeding (Walia *et al.,* 2008).

Harnessing rice fallows in eastern India

More than 50% of the *kharif* rice area in eastern India is left fallow after rice harvest due to the lack of irrigation facilities/residual soil moisture, lack of knowledge and access to high-yielding varieties of short-duration pulses and oilseeds, animal grazing, and outmigration of labor during *rabi* season. However, most of the rice-fallow areas have suitable climatic conditions to grow short-duration pulses and oilseeds. Pulses are ideal for the rice-fallow system since they require less water for cultivation and have a deep-rooted system to tap the available soil moisture up to 0.4 m of soil depth (Hazra and Bohra, 2020). Our results showed that green gram and black gram can be grown successfully in the rice-fallow areas under rainfed conditions (**Table 1**). Rice equivalent yield (REY) of green gram and black gram was 2.2 t/ha and has potential to grow after rice harvest with residuel soil moisture if timely sowing is done. Toria has less potential compared to green gram due to less yield, less price and low availability of soil nitrogen after the harvest of *kharif* rice. In contrast, pulses are less dependent on nitrogen fertilizers because they fix atmospheric nitrogen and increase soil health (Tonitto *et al.,* 2006).

Table 1. *Rabi* season yield and REY under rainfed situations in rice-fallow areas of Odisha

Cropping system	Yield of pulses/ oilseeds (t/ha)	REY (t/ha)
Rice-Green gram (N=18)	0.65 a	2.27 a
Rice-Black gram (N=20)	0.64 a	2.20 a
Rice-Toria (N=20)	0.43 b	1.17 b

Under the irrigated situations, Rabi rice yield was significantly higher followed by green gram and toria (**Table 2**). Although enhancing productivity is important, protecting the environment and the sustainable use of natural resources is also highly crucial. It has been established that the continuous cultivation of rice can lead to the depletion of soil nutrient and an increase in GHG such as methane and nitrous oxide emissions (Kritee *et al.,* 2018). Our results showed that REY of sunflower was higher after rice. As seen with the rainfed conditions, toria performed poorly under irrigated conditions as well indicating that toria is not a suitable crop for the rice-fallow region in Odisha. Although sunflower yield was higher than green gram, growing pulses in rice-fallow can be beneficial because of short duration 60-65 days to mature whereas sunflower matures in 85-88 days (Mahapatra *et al.,* 2021) and provide nutritional benefits to human in addition to improving soil fertility.

Table 2: Yield and REY under irrigated situations in rice-fallow areas of Odisha

Cropping system	Yield of *rabi* crops (t/ha)	REY (t/ha)
Rice-Rice (N=20)	5.5 a	5.5 a
Rice-Green gram (N=20)	1.0 c	3.3 b
Rice-Sunflower (N=10)	1.8 b	5.1 a
Rice-Toria (N=20)	0.8 c	2.1 c

Conclusions

Bestowed with high rainfall and fertile soils, RBCS in eastern India are challenged with declining factor productivity, input use inefficiencies, and environmental and social insecurities. Efficient use of residual soil moisture by growing resource-efficient diversified crops (pulses, oilseeds,) layered with appropriate sustainable intensification (SI) technologies help in improving cropping intensity, farm income, and nutritional and food security, besides addressing these challenges. Conservation agriculture along with innovative crop establishment methods like direct seeding of rice, mechanical transplanting of rice, etc. can improve water use efficiency, soil health, and system productivity. Converting monocropped areas into double or triple cropped ones through utilization and exploitation of rice fallows, and/or intensification with short-duration rice and climate-resilient varieties of other crops, coupled with improved management practices and scale-appropriate mechanization are the potential strategies to achieve SI in eastern India. Focussed attention also needs to be given to the deployment of alternative crop establishment methods as well as improved agronomic practices in these ecologies.

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