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Adaptability of Drill Seeding and Broadcast Seeding in Rice-Wheat Rotation Systems

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Abstract This study evaluated the compatibility and effectiveness of drill seeding and broadcast seeding in rice-wheat rotation systems, comparing their impacts on crop yield, resource use efficiency, and environmental sustainability. The results indicated that drill seeding, implemented through mechanized seed drills, significantly enhanced productivity, reduced labor requirements, and improved water and nitrogen use efficiency. In contrast, broadcast seeding, while simpler and requiring lower initial costs, generally demanded higher seeding rates and resulted in uneven seed distribution, leading to lower resource use efficiency. The study also highlighted key challenges such as weed management, residue handling, and socio-economic barriers. Future research should focus on improving mechanized technologies, enhancing environmental adaptability, and addressing socio-economic constraints. This study aims to provide scientific evidence for the long-term sustainable development of rice-wheat rotation systems.

Keywords Rice-wheat rotation system; Drill seeding; Broadcast seeding; Resource use efficiency; Sustainable

1 Introduction

The rice-wheat rotation system is a critical agricultural practice, particularly in South Asia, where it serves as a major food source for billions of people. This system occupies vast areas, such as the Indo-Gangetic Plains, and is essential for food security in the region (Gathala et al., 2011; Jin et al., 2020; Ullah et al., 2021). The middle and lower reaches of the Yangtze River Plain is not only the most economically developed region in China, but also the largest rice wheat rotation system in the world.However, the sustainability of this system is challenged by issues such as stagnant crop yields, high resource consumption, and environmental concerns like greenhouse gas emissions and residue burning (Devkota et al., 2019; Jin et al., 2021; Ullah et al., 2021). Therefore, optimizing crop establishment methods within this rotation is vital for enhancing productivity and sustainability (Singh et al., 2020; Sahu et al., 2023).

Drill seeding and broadcast seeding are two prevalent methods of crop establishment in rice-wheat systems. Drill seeding involves placing seeds in rows using a seed drill, which can improve seed placement accuracy and reduce seed rates, leading to higher yields and lower production costs compared to manual broadcast seeding (Ali et al., 2013; Ott et al., 2016). Broadcast seeding, on the other hand, involves scattering seeds over the soil surface, which is simpler but often less efficient in terms of seed use and yield outcomes (Bautista et al., 2019; Sansen et al., 2019; Koehler-Cole and Elmore, 2020). Studies have shown that mechanized drill seeding can significantly enhance productivity and reduce labor and water requirements, making it a more sustainable option in many contexts (Bautista et al., 2019; Devkota et al., 2019; Sansen et al., 2019). Compared with manual sowing, mechanical drilling of wheat significantly increased the emergence rate, grain number per panicle and actual yield, and the partial productivity of nitrogen fertilizer and agronomic utilization efficiency of nitrogen fertilizer increased by 7.1%~8.2% and 5.0%~5.9%, respectively (Zhao et al., 2019).

This study evaluates the adaptability and effectiveness of drill seeding and broadcast seeding in rice-wheat rotation systems, and assesses the impact of these seeding methods on crop yield, resource use efficiency, and environmental sustainability. By comparing these methods, the study seeks to provide insights into optimizing crop establishment practices to enhance the productivity and sustainability of rice-wheat systems, particularly in regions facing resource constraints and environmental challenges.

2 Current Applications of Drill Seeding and Broadcast Seeding in Rice-Wheat Rotation Systems

2.1 Current status and development of drill and broadcast seeding technologies

Drill seeding and broadcast seeding are two prevalent methods used in rice-wheat rotation systems, each with distinct technological advancements and applications. Drill seeding, particularly with mechanized options, has shown promise in enhancing productivity and reducing labor costs (Tayade, 2017). For instance, in northeastern Thailand, mechanized dry direct-seeding using seed drills has been evaluated for its efficiency and cost-effectiveness, demonstrating a significant increase in grain yield compared to manual broadcast seeding (Sansen et al., 2019). Similarly, in the Philippines, the development of a hand tractor-mounted seed drill has been tested, showing comparable yields to traditional broadcasting methods while offering greater efficiency in terms of area coverage (Figure 1) (Bautista et al., 2019). In contrast, broadcast seeding remains a simpler and more traditional method, often used in regions where mechanization is less accessible (Elsoragaby et al., 2019).

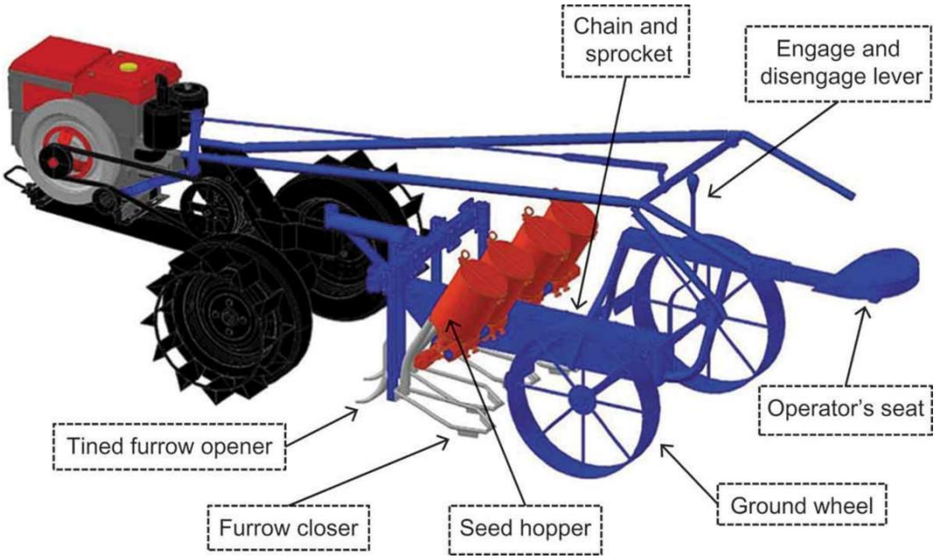

Figure 1 The prototype of a multigrain seed drill designed at the Philippine Rice Research Institute (Adopted from Bautista et al., 2019)

Image caption: The prototype had a ride-on attachment to a two-wheel tractor, a built-in furrow opener and closer, an inclined circulating replaceable seed plate (for seed metering), and seed hopper made of plastic containers. The seed metering was driven by ground wheels through chain and sprocket combination with the provision of engaged and disengaged lever. The furrow opener was positioned in one line. The chain and sprocket drives, which were simplified into a single-stage conversion, were covered with metal plates to protect it from dust during operation and avoid chain damage. The bevel gears were added to rotate the drive shift of seeding plate from the ground wheel (Adopted from Bautista et al., 2019)

2.2 Characteristics and seeding requirements of rice-wheat rotation systems

Rice-wheat rotation systems are characterized by their need for efficient crop establishment methods that can adapt to varying environmental conditions and resource availability (Xing et al., 2017). Drill seeding in these systems often requires precise seed placement and depth control, which can enhance seedling vigor and yield potential. For example, strip tillage combined with drill seeding has been shown to improve seedling growth and nitrogen uptake in wheat, leading to higher grain yields in rice-wheat systems in China (Xu et al., 2022). Broadcast seeding, while less precise, is often favored for its simplicity and lower initial cost, though it may require higher seeding rates to achieve similar plant densities (Phuong et al., 2005). The choice between these methods often depends on factors such as soil type, water availability, and labor resources.

2.3 Key issues and limitations in research on drill and broadcast seeding

Research on drill and broadcast seeding in rice-wheat systems faces several challenges and limitations. One major issue is the management of crop residues, particularly in regions like north-west India, where the burning of rice residues is common (Hou et al., 2015). The development of technologies like the Turbo Happy Seeder aims to address this by allowing wheat to be sown directly into rice residues, reducing environmental pollution and improving soil quality (Sidhu et al., 2015). However, adoption of such technologies is hindered by factors like limited operational windows and the need for compatible machinery. Additionally, weed management remains a critical challenge, especially in direct-seeded systems where weed competition can significantly reduce yields. Effective weed control strategies, such as the use of specific herbicides, are essential for the success of drill seeding (Phuong et al., 2005; Saha et al., 2021). Despite these challenges, ongoing research and technological advancements continue to improve the viability and sustainability of both drill and broadcast seeding methods in rice-wheat rotation systems.

3 Agronomic Effects of Drill Seeding and Broadcast Seeding

3.1 Impacts on crop growth and yield

Drill seeding and broadcast seeding have distinct impacts on crop growth and yield in rice-wheat rotation systems. Drill seeding has been shown to enhance crop growth by improving seedling vigor, which is crucial for achieving higher grain yields. For instance, in a study conducted in China, drill seeding following strip tillage improved tiller number, leaf area, and shoot weight, leading to increased grain yield compared to broadcast seeding (Xu et al., 2022). Similarly, in northeastern Thailand, mechanized drill seeding produced 32% higher grain yield than manual broadcast seeding, demonstrating its effectiveness in enhancing productivity (Sansen et al., 2019). In contrast, broadcast seeding often results in uneven seed distribution, which can negatively affect crop growth and yield (Phuong et al., 2005).

3.2 Effects on resource utilization efficiency

Drill seeding is generally more efficient in resource utilization compared to broadcast seeding (El-Hanfy, 2009; Sultan et al., 2023). It allows for precise placement of seeds, which can lead to better nitrogen use efficiency (NUE) and water productivity (Noor et al., 2018). For example, a study in South Asia found that zero-tillage drill seeding improved water productivity by 25% compared to conventional methods (Gathala et al., 2011). Additionally, drill seeding with optimized nitrogen rates has been shown to enhance NUE, reducing the need for excessive fertilizer application (Santiago-Arenas et al., 2021). In contrast, broadcast seeding often requires higher seeding rates and can lead to inefficient use of resources, such as water and nutrients (Phuong et al., 2005; Sansen et al., 2019).

3.3 Impacts on soil structure and health

The choice between drill seeding and broadcast seeding also affects soil structure and health. Drill seeding, particularly when combined with conservation tillage practices like zero-tillage, can improve soil structure by minimizing soil disturbance and promoting better soil health over time (Gathala et al., 2011). This method helps in maintaining soil organic matter and reducing erosion (Nielsen et al., 2018; Rizwan et al., 2021). Conversely, broadcast seeding, especially when coupled with conventional tillage, can lead to soil compaction and degradation due to repeated soil disturbance (Chhokar et al., 2007; Svejcar et al., 2022). Moreover, the use of drill seeding in systems like the Turbo Happy Seeder has been shown to facilitate the retention of crop residues, which can enhance soil quality and reduce environmental pollution from stubble burning (Sidhu et al., 2015).

4 Compatibility Analysis of Drill Seeding and Broadcast Seeding in Rice-Wheat Rotation Systems

4.1 Adaptability under different climatic conditions

Drill seeding and broadcast seeding exhibit varying adaptability under different climatic conditions. In northeastern Thailand, mechanized dry direct-seeding of rice using seed drills has shown to be more productive than manual broadcast seeding, especially in rainfed lowlands, by producing 32% higher grain yield in certain years (Sansen et al., 2019). Similarly, in the Philippines, a hand tractor-mounted seed drill was found to be effective in drought-prone environments, producing rice grain yields comparable to those from broadcast seeding (Bautista et al., 2019). These findings suggest that drill seeding may offer better adaptability in regions with variable rainfall and drought conditions compared to broadcast seeding.

4.2 Adaptability in different soil conditions

The adaptability of seeding methods also varies with soil conditions. In the Indo-Gangetic Plains of South Asia, direct drill-seeding with zero-tillage was found to be less productive for rice compared to conventional methods, but it offered higher wheat yields, indicating a trade-off between the two crops in rice-wheat systems (Gathala et al., 2011). In contrast, in Eastern India, drill seeding was more effective in reducing weed density and increasing profitability compared to broadcast seeding, suggesting better adaptability in managing soil-related challenges such as weed infestation (Table 1) (Saha et al., 2021). These results highlight that drill seeding may be more suitable in soils where weed management is a critical concern.

Table 1 Effect of establishment methods and weed control treatments on weed density (plants m^{-2}) at 30 and 60 days after emergence (DAE) at Cuttack, Odisha (Average of 2015 and 2016) (Adopted from Saha et al., 2021)

Establishment method (T)								
	30DAE				60DAE			
Weed control treatments (W) *	Drill seeding	Manual seeding	Broadcast seeding	Mean *	Drill seeding	Manual seeding	Broadcast seeding	Mean *
Weed density (plants m^{-2})								
BPS	20	26	35	27^{c}	34	43	49	42^{c}
AZM	12	16	21	16^{d}	26	32	36	31^{d}
BSM + Pretl.	26	32	43	34^{b}	41	52	57	50^{b}
Weed free †	-	-	-	-	-	-	-	-
Weedy	49	56	68	57^{a}	71	77	91	80^{a}
Mean **	27^{C}	32 ^{B}	42 ^{A}		43 ^{C}	51 ^{B}	58 ^{A}	
Analysis of variance (ANOVA)								
		p value		LSD		*p* value		LSD
Main plot (T)		<0.0015		3		0.0003		3.0
Sub plot (W)		<0.0001		3.6		<0.0001		4.6
T×W		NS		3.4		0.0494		9.2

Note: BPS- Bispyribac-sodium (30 g a.i. ha^{-1}); AZM- Azimsulfuron (35 g a.i. ha^{-1}); BSM + Pretl.- Bensulfuron-methyl + Pretilachlor (70 + 700 g a.i. ha^{-1}); NS: not significant difference; † Weed free-Weed density was not recorded since weed was removed manually at 15, 30, 45 and 60 DAE; § Means are separated by least significant difference (LSD).* Within each timing, means with the same lower case letter in a column are not significantly different using $LSD_{0.05}$.; ** Within each timing, means with same upper case letter in a row are not significantly different using $LSD_{0.05}$. Data in bold are mean values of main plot and sub plot treatments (Adopted from Saha et al., 2021)

4.3 Techno-economic analysis

From a techno-economic perspective, drill seeding often results in lower production costs and higher profitability compared to broadcast seeding (Hassann et al., 2009). In northeastern Thailand, mechanized seeding reduced production costs significantly by lowering the seeding rate by 50%-61% compared to manual methods (Sansen et al., 2019). Similarly, in Eastern India, drill seeding was found to be more profitable, with a net income increase of US $685 ha^{-1} over broadcast seeding, primarily due to higher yields and reduced energy consumption (Saha et al., 2021). These findings suggest that drill seeding can be a more economically viable option in rice-wheat rotation systems, especially when considering long-term sustainability and cost efficiency.

5 Case Studies

5.1 Successful cases: rational applications of drill and broadcast seeding

In northeastern Thailand, mechanized dry direct-seeding of rice using seed drills has shown significant success. This method produced 32% higher grain yield compared to manual broadcast seeding, and reduced production costs by enabling a 50% reduction in seeding rates (Sansen et al., 2019). Similarly, in the Philippines, a hand tractor-mounted seed drill demonstrated promising results, achieving rice grain yields comparable to those from broadcast seeding while offering a high operational capacity of over 2 hectares per day (Bautista et al., 2019). In Eastern India, drill seeding in dry direct-seeded rice systems was found to be more profitable than broadcast seeding, primarily due to higher yields and effective weed control, resulting in a net income increase of US $685 per hectare (Saha et al., 2021). Additionally, the Turbo Happy Seeder in NW India allowed for wheat sowing into rice residues without burning, maintaining or increasing yields while reducing fuel consumption and establishment costs (Figure 2) (Sidhu et al., 2015). Lastly, in the Indo-Gangetic Plains, zero-tillage with direct drill-seeding of rice on flat beds showed potential for sustainability, offering higher net returns in the rice-wheat system (Gathala et al., 2011).

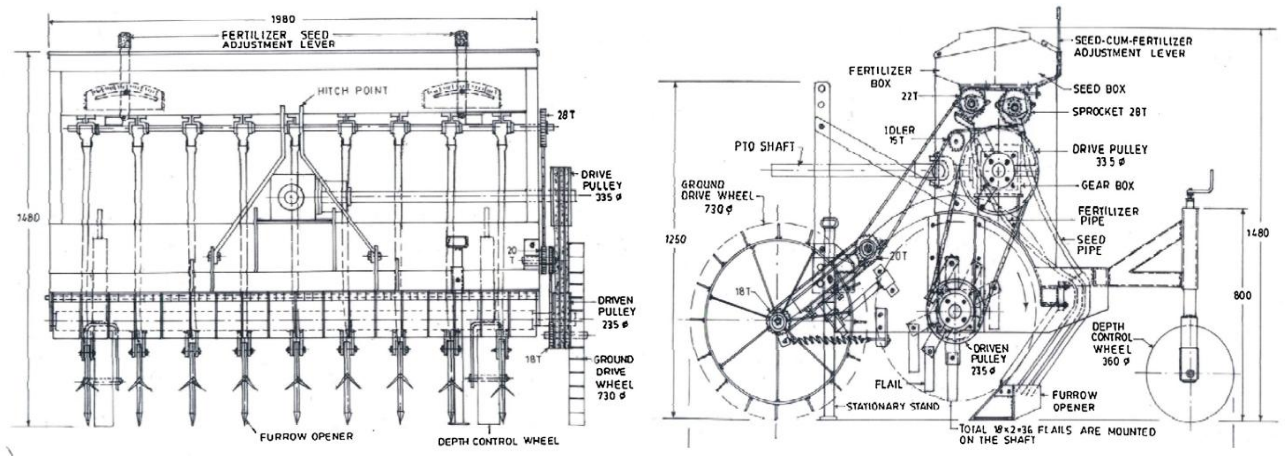

Figure 2 Line diagram of front (top) and side (bottom) view of the 9-row Turbo Happy Seeder (v.2) showing the straw management unit. All the dimensions are in mm (Adopted from Sidhu et al., 2015)

5.2 Failed cases: impacts of inappropriate technology choices

Despite the successes, there have been instances where inappropriate technology choices led to suboptimal outcomes. In the Philippines, while the hand tractor-mounted seed drill showed promise, its adoption was limited by the need for specific biophysical conditions and the initial cost of the technology (Bautista et al., 2019). In NW India, the Turbo Happy Seeder faced low adoption rates due to constraints such as a limited operational window, low machine capacity compared to conventional drills, and challenges in operating in wet straw conditions (Sidhu et al., 2015). In the Indo-Gangetic Plains, direct drill-seeding with zero-tillage on raised beds resulted in significantly lower rice yields, decreasing over time, which highlights the importance of selecting suitable tillage and seeding methods for specific environmental conditions (Gathala et al., 2011).

5.3 Summary and lessons learned

The case studies illustrate that the adaptability of drill and broadcast seeding technologies in rice-wheat rotation systems is highly context-dependent. Successful applications often involve mechanization and integration with effective management practices, such as nutrient management and weed control, which enhance productivity and profitability. However, the failure cases underscore the importance of considering local environmental conditions, operational constraints, and economic factors when choosing seeding technologies. Lessons learned include the need for tailored solutions that address specific challenges, such as labor scarcity, water management, and weed control, to optimize the benefits of these seeding methods.

6 Optimization Strategies for Drill Seeding and Broadcast Seeding in Rice-Wheat Rotation Systems

6.1 Integrated technical optimization strategies

To optimize drill seeding and broadcast seeding in rice-wheat rotation systems, several technical strategies can be employed. Strip tillage has shown promise in improving grain yield and nitrogen efficiency in wheat, which can be adapted for rice-wheat systems. This method enhances seedling growth vigor by increasing tiller number, leaf area, and shoot weight, thereby boosting grain yield and nitrogen uptake (Xu et al., 2022). Additionally, mechanized dry direct-seeding technology, such as the use of seed drills, has been effective in increasing grain yield and reducing production costs compared to manual broadcast seeding (Sansen et al., 2019). The development of specialized equipment like the Turbo Happy Seeder allows for sowing wheat into heavy rice residues, reducing fuel consumption and enabling timely sowing (Sidhu et al., 2015).

6.2 Farmer training and technology promotion plans

Farmer training and technology promotion are crucial for the successful adoption of optimized seeding methods (Uzonna and Gao, 2013). Participatory evaluation and demonstration trials have proven effective in promoting mechanized seeding technologies, as seen in northeastern Thailand, where farmers achieved higher yields and reduced costs with seed drills (Sansen et al., 2019). Training programs should focus on the benefits of mechanized seeding, such as reduced labor and water usage, and the importance of site-specific nutrient management to maximize productivity (Bautista et al., 2019; Sansen et al., 2019). Additionally, educating farmers on effective weed control practices, such as the use of azimsulfuron in drill-seeded systems, can further enhance profitability and yield (Saha et al., 2021).

6.3 Policy support and supply chain integration

Policy support and supply chain integration are essential to facilitate the adoption of optimized seeding methods. Policies that provide subsidies for mechanized equipment, such as the Turbo Happy Seeder, can encourage farmers to transition from traditional methods. Removing subsidies for diesel and electricity, along with enforcing bans on straw burning, can further promote environmentally sustainable practices (Sidhu et al., 2015). Integrating supply chains to ensure the availability of necessary equipment and inputs, such as herbicides for weed control, will support farmers in adopting these optimized practices (Gathala et al., 2011; Saha et al., 2021).

7 Concluding Remarks

The adaptability of drill seeding and broadcast seeding in rice-wheat rotation systems has been extensively studied, revealing several key insights. Drill seeding has shown to be more effective in promoting seedling growth and yield compared to broadcast seeding. For instance, strip tillage combined with drill seeding significantly improved tiller number, leaf area, and shoot weight, leading to increased grain yield and nitrogen uptake in wheat. Similarly, mechanized dry direct-seeding of rice using seed drills resulted in higher grain yields and reduced production costs compared to manual broadcast seeding in Thailand. In the Philippines, a hand tractor-mounted seed drill demonstrated comparable rice yields to broadcast seeding while offering greater efficiency. Furthermore, drill seeding has been found to effectively suppress weed growth, which is a major constraint in direct-seeded rice systems.

To optimize the use of drill seeding technology, it is recommended to focus on improving the design and functionality of seed drills. Enhancements such as incorporating site-specific nutrient management and ensuring compatibility with various soil conditions can further increase productivity and reduce costs. Additionally, integrating effective weed management strategies, such as the use of specific herbicides like azimsulfuron, can enhance the profitability and sustainability of drill-seeded systems. Encouraging the adoption of technologies like the Turbo Happy Seeder, which allows for direct drilling into rice residues, can also reduce environmental impacts and improve soil health.

Future research should aim to address the challenges and limitations identified in current practices. This includes exploring the long-term sustainability of zero-tillage and direct-seeding methods, particularly in terms of soil health and water productivity. Investigating the socio-economic factors influencing the adoption of mechanized seeding technologies, such as the availability of subsidies and farmer education, can provide insights into improving adoption rates. Additionally, further studies on the interaction between seeding methods and weed control practices can help refine strategies for maximizing yield and minimizing resource use.

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Conflict of Interest Disclosure

The authors affirm that this research was conducted without any commercial or financial relationships that could be construed as a potential conflict of interest.

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