Review Article

Impact of mechanized crop establishment techniques on growth, yield, and microbial dynamics under rice-wheat cropping system- A review

ABSTRACT

Mechanized crop establishment techniques have revolutionized agriculture, particularly in the rice-wheat cropping system, by significantly influencing growth, yield, and microbial dynamics. The adoption of precision seed drills and mechanized tillage equipment – happy seeder, super seeder, turbo seeder and zero till drill has transformed traditional farming practices, leading to more efficient seed placement, soil preparation, residue incorporation and weed management. This has resulted in improved crop growth dynamics including plant height, dry matter and number of tillers; yield dynamics including grain and straw yield and enhanced root development, nutrient uptake, and overall plant vigor. Furthermore, reduced soil disturbance and less weed pressure associated with mechanized operations have created a conducive environment for beneficial microbial communities to flourish. As a consequence, there has been an observable increase in microbial diversity including the activity of actinomycetes, azotobacter, fungi and soil enzymatic activities like dehydrogenase, urease etc. contributing to enhanced soil health, nutrient cycling, and disease suppression. Overall, the integration of mechanized crop establishment techniques has a positive impact on both crop productivity and sustainability within the rice-wheat cropping system, highlighting its importance in modern agricultural practices.

Keywords: Soil microbial activity; productivity; happy seeder; turbo seeder, dry matter accumulation.

1. INTRODUCTION

In South Asian countries rice-wheat rotation is the primary cropping system in which 57% is located in South Asia [1][2]. Throughout the Indo-Gangetic plains, the rice-wheat cropping system cover around 13.5 million hectares. In India, there are 10 million hectares, while Pakistan has 2.2

million hectares, Bangladesh has 0.8 million hectares, and Nepal has 0.5 million hectares. This cropping system is responsible for 75% of the country's food grain production and is widely practiced in several Indian states, such as Haryana, Punjab, Bihar, Madhya Pradesh, and Uttar Pradesh. But the major issue under those south-Asian countries is the burning of the left-over residue. Around 70% of the fresh rice straw burned mostly in those countries and it also estimated that 44% of all crop waste was burned in China, with India (33.6%), Bangladesh (4.4%), Pakistan (4%), Thailand (3.1%), and the Philippines (3.1%) following closely behind [3, 4]. To coupe up with this problem, using a chopper and spreader is used and the residue retention is done over the fields. Using a zero till drill, super seeder and happy seeder are the modern mechanized technology which allows the sowing of the seeds into directly in the soil covered with residue. For wheat crops, zero tillage is a resource-saving technique that has previously shown to boost crop yield by 5-7% and food production by 0.7% in the Indo-Gangetic region [5]. To avoid primary tillage operations, Happy seeder and super seeder are used in a field of standing crop residue.

Soil health is the interaction of physical, chemical, and biological characteristics that promote the highest possible crop productivity and environmental resilience [6]. Mechanized systems always affect soil compaction, structure, and nutrient cycling, which affects microbial populations that are essential to the activities of soil ecosystems [7]. These technologies provided effective planting techniques and provided notable benefits to soil microbial ecosystems. Compared to conventional tillage techniques, the use of super seeders and happy seeders minimizes soil disturbance, creating an atmosphere that is favorable for the growth of microorganisms such as Actinomycetes, which are necessary for the breakdown of organic matter and the cycling of nutrients, are encouraged to proliferate when organic residues are preserved on the soil's surface [8]. Maintaining paddy straw under mechanized system in wheat improves crop yield and reduces irrigation water usage by preserving soil moisture, regulating temperature, controlling weed growth, and fostering soil health [9,10]. Thus, the mechanization in the rice wheat cropping system helps in the sustainability of agriculture by the residue management and improving the soil health and the providing the suitable environment for the soil microorganisms Which help in the overall growth and development of crops in the field.

2. ROLE OF MECHANIZATION IN RICE WHEAT CROPPING SYSTEM

The role of mechanization in the rice-wheat cropping system is pivotal for enhancing agricultural productivity, sustainability, and farmer livelihoods. The mechanization helps in the timely conductance of the different operation in the field like tillage practices, land preparation, sowing etc. These are carried out with help of tractors, spreaders and cultivators in the field. (Fig 1)

Mechanized planting methods like sed drill, happy seeder, turbo seeder, super seeder, and spatial drill which helps in the management of residue in the field and helps in precise and uniform planting of the seeds at the certain depth in the soil also helps in better growth and development of the plant. Mechanization improves the crop management practices like weed management-weed suppression, herbicide spraying, precession amount of fertilizer application, timely irrigation hence water saving. Mechanization in agriculture leads to the sustainable way of agriculture which improves the soil health, soil structure with the minimal disturbance of soil structure leading to more suitable environment for growth of microorganism. The use combined harvester and threshers at the time of harvesting has made it easy to harvest crops which save time and labor energy. By using the machinery in the rice wheat cropping system it leads to the profitability, sustainability, energy saving, less labor intensive, reducing environmental impact and resilience in the rice wheat cropping system.

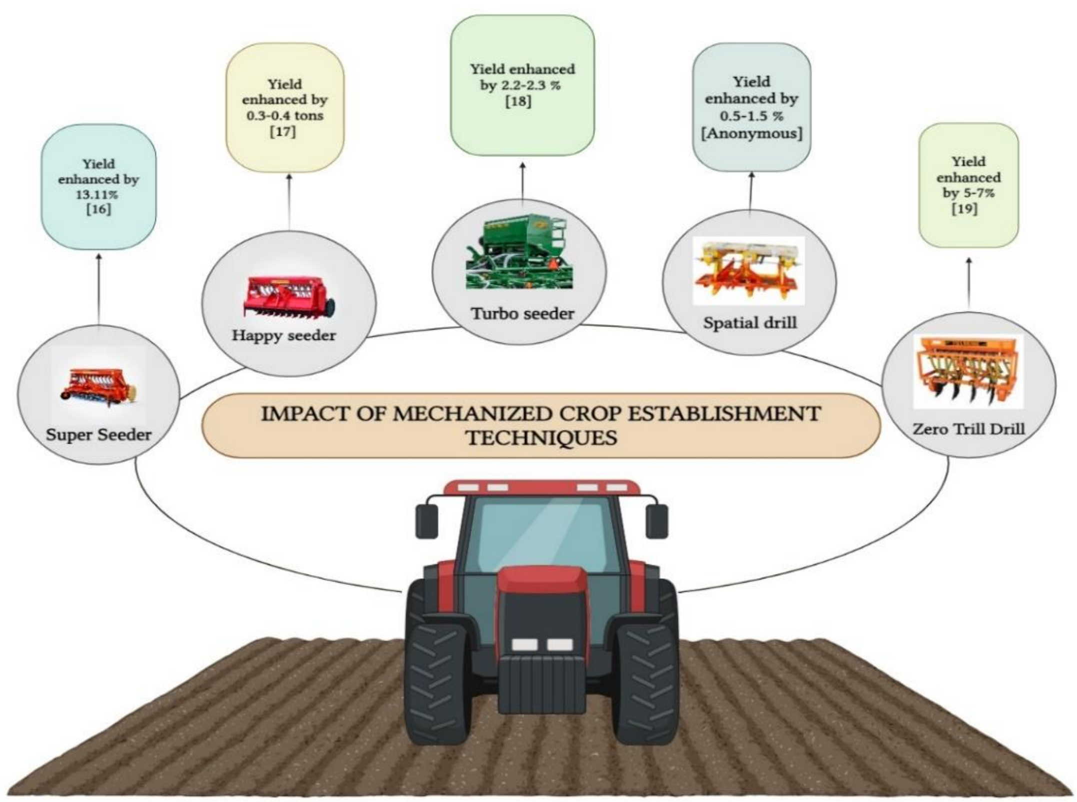

Fig 1. Impact of Mechanized crop establishment techniques

3. LITERATURE REVIEW

3.1. IMPACT OF MECHANIZED CROP ESTABLISHMENT TECHNIQUES ON CROP GROWTH AND DEVELOPMENT

In a comprehensive review of studies examining the influence of tillage practices on wheat by Kaur et al. [11] observed that plant height varied notably, with the highest heights recorded in conventional tillage with mulch (108.4 cm), followed by zero tillage with mulch (101.8 cm), and the lowest heights in conventional tillage without mulch (95.5 cm). These findings underscore the importance of soil physical conditions and moisture conservation in shaping plant growth dynamics, in line with previous research by Qamar et al. [12]. Expanding on this theme, Goswami et al. [13] delved into the effects of irrigation and tillage on plant height, revealing that conventional tillage resulted in the greatest plant height at 120 days after sowing, which was 11 times greater than minimum tillage, attributed to improved soil structure conducive to root establishment and moisture retention. Furthermore, Kahlon and Dhingra [14] provided insights into the impact of tillage depth on plant height, highlighting variations between deep tillage before wheat and conventional tillage. deep tillage before wheat recorded the highest plant height (104.0 cm) followed by deep tillage before rice (102.3 cm) and least in conventional tillage in both rice and wheat (100.1 cm). Nevertheless, the crop establishment methods showed the highest wheat mean plant height in no-tillage with residue (103.2 cm) and the lowest in conventional tillage (100.7 cm).

Rajanna et al. [15] elucidated the role of conservation practices such as FIRBS (Furrow Irrigated Raised Bed System) and zero tillage in enhancing tiller numbers. They attributed this increase to the improvement in growth conditions throughout all growth stages, facilitated by factors such as increased light interception, higher moisture availability, and improved nutrient supply compared to conventional tillage methods. Additionally, earlier emergence rates, improved plant vigor, and enhanced root development resulting from these practices further contributed to the observed increase in tiller numbers, as noted by Kumar et al. [16]. Furthermore, localized deposition of fertile topsoil over the beds, reducing soil compaction, may have played a role in promoting tiller development, as suggested by Naresh et al. [17]. Building upon this understanding, Gupta et al. [18] conducted experiments on wheat cultivation with varying residue management approaches. Their findings revealed that tiller density was significantly higher in treatments involving zero till sown wheat with Happy Seeder and rice straw as mulch, compared to conventional tillage methods or zero tillage without residue incorporation. Specifically, zero till sown wheat with Happy Seeder and rice straw mulch exhibited the highest tiller density at 378 m^-2, highlighting the importance of residue retention and conservation tillage practices in optimizing wheat growth parameters.

In an extensive examination of tillage practices and their impact on wheat dry matter accumulation, Kaur et al. [11] highlighted notable variations among different tillage treatments. Their findings revealed that conventional tillage with mulch recorded the highest dry matter accumulation at 896.7 g/m^2, followed closely by zero tillage with mulch at 833.3 g/m^2. This increase in dry matter accumulation could be attributed to improved weed control and enhanced water retention associated with these treatments, creating optimal conditions for plant growth. Conversely, traditional tillage experiments exhibited the lowest dry matter yield, possibly due to subsurface soil compaction hindering plant growth and reducing dry matter production. These results were consistent with similar research by Akter et al. [19], further emphasizing the importance of tillage practices in influencing dry matter accumulation. Building upon these findings, Alam et al. [20] underscored the significance of dry matter accumulation as a key determinant of photosynthetic efficiency and plant growth. Their study observed the highest dry matter accumulation in wheat sown using the Furrow Irrigated Raised Bed (FIRB) method, comparable to reduced tillage with conventional tool line sowing. Conversely, traditional tillage methods resulted in the lowest dry matter yield, consistent with findings by Atikullah et al. [21] and Idnani and Kumar [22]. These collective insights underscore the critical role of tillage practices in shaping dry matter accumulation and, consequently, overall crop productivity and sustainability.

3.2. IMPACT OF MECHANIZED CROP ESTABLISHMENT TECHNIQUES ON WHEAT PRODUCTIVITY

Mechanized crop establishment techniques have significantly enhanced wheat productivity by streamlining planting operations, optimizing input management, and improving overall field conditions. Precision seed drills ensure uniform seed placement, promoting consistent emergence and stand establishment, which directly contributes to higher wheat yields. Leharwan et al. [23] highlighted the superiority of the combine harvester, Happy Seeder with Mulcher system in terms of grain yield (highest (56.8 q ha), demonstrating a significant increase of 30.27% compared to conventional tillage practices. Additionally, the study revealed notable increases in grain yield for other conservation practices, such as zero tillage (21.33%) and manual harvesting (18.11%) with Happy Seeder, further emphasizing the benefits of conservation agriculture in enhancing production levels. The enhanced production observed in systems utilizing crop residues can be attributed to their efficient moisture retention properties, which alleviate moisture stress in plants, ultimately leading to improved yields. Similarly, findings from Thind et al. [24]

underscored the positive impact of residue retention on wheat yields, with significantly higher yields observed in no-till wheat systems with 100% surface retention of rice residue compared to conventional tillage without residue retention. 15% less wheat yield was produced from zero till wheat (no residue), compared to no till wheat with residue retention. Crop yields were maximum in no till wheat with rice residue retention, which was 5% higher than the practice of conventional till no residue. Moreover, these systems exhibited significant increases in soil macro-nutrient availability, particularly potassium, further contributing to enhanced crop productivity. Complementing these findings, Hossain et al. [25] reported the highest mean grain yield (4.39 t/ha) from raised beds with 30% residue retention systems, highlighting the importance of residue management in optimizing wheat yields. Conversely, conventional tillage practices resulted in lower yields (4.28 t/ha), attributed to reduced yield components.

In an extensive review of agricultural systems and their impact on straw yield, Leharwan et al. [23] highlighted the significant advantages of the combine harvester, Happy Seeder with Mulcher (MHS) system, which exhibited the highest straw yield (62.2 q ha) among the systems tested. Notably, conservation practices such as MHS (27.98%), zero tillage (ZT) (21.19%), and manual harvesting with Happy Seeder (HS) (15.84%) demonstrated higher straw yields compared to conventional tillage (CT) techniques, underscoring the benefits of conservation agriculture in enhancing straw production. The superior performance of the MHS system can be attributed to the water retention capabilities of crop residues, which mitigate water stress in plants and contribute to overall production levels. Similarly, findings from Alam et al. [20] emphasized the influence of moisture retention and tillage techniques on straw yield, with wheat grown on Furrow Irrigated Raised Beds (FIRB) exhibiting notably higher straw production (63.6 & 65.8 q ha-1) compared to other treatments. Furthermore, the effects of conservation tillage practices on straw yield varied significantly, with moisture retention and bed arrangement positively influencing straw yield. Meanwhile, Singh et al. [26] highlighted the straw yield (66.6, 66.2 q ha-1) were recorded significantly higher with tillage crop establishment treatment (FIRB) as compared to all other treatments except (ZT) (64.8, 65.9 qha-1) during the study. The previous two years of the study showed 7.0, 7.3% yield increase with tillage treatment compared to conventional planting for the first and second years, respectively. The treatment reduced tillage and rotavator tillage showed similar results during the year of study. Nevertheless, the CT one had been the lowest yield of grain among all the experiments recorded.

In a comprehensive analysis of sowing techniques and their impact on grain weight, Alam et al. [20] highlighted the effectiveness of sowing under Furrow Irrigated Raised Beds (FIRB) treatment, which yielded statistically comparable results to reduced tillage with conventional line sowing. Their findings revealed a significant 21.3% increase in grain weight in raised beds compared to conventional tillage methods, emphasizing the potential of FIRB in enhancing grain yield. Moreover, conventional tillage with line sowing treatments demonstrated higher grain weights compared to conventional tillage with broadcasting and reduced tillage with rotavator line sowing. These results corroborate findings by Sepat et al. [27] and Mollah et al. [28], underscoring the benefits of raised bed cultivation techniques in optimizing grain weight. Similarly, Singh et al. [26] observed improvements in yield parameters, particularly test weight, with FIRB treatments, which were comparable to zero tillage methods. Notably, reduced tillage treatments exhibited positive impacts on yield attributes compared to rotavator and conventional tillage methods. Additionally, Rajanna et al. [29] reported higher grain yields per thousand weights under FIRBS treatments compared to conventional tillage and minimum tillage, with results consistent across multiple seasons, further highlighting the efficacy of conservation tillage practices, particularly FIRB, in optimizing grain weight and overall crop productivity. These collective findings underscore the importance of adopting innovative sowing techniques and conservation tillage practices to enhance grain weight and ensure sustainable agricultural production.

3.3. IMPACT OF MECHANIZED CROP ESTABLISHMENT TECHNIQUES ON SOIL MICROBIAL DYNAMICS

(Table 1.) different crop establishment techniques increase soil health by residue incorporation which helps in the increase of microbial population in the soil. In a comprehensive assessment of soil biological activity, Korav et al. [30] highlighted the positive influence of zero tillage (ZTW) treatments on soil microbial populations, particularly when combined with Happy Seeder (HS) and residue management practices. Their findings revealed that ZTW seeded with HS, following the use of a chopper and spreader, significantly increased soil microbial count (94.9× 10^7 and 99.8× 10^7 cfu/g) ZTW sowed with Happy Seeder following the use of a chopper and spreader increased the soil microbial count over residue burning and residue removal plots by 23.7–38.3% and 47.9–60.4%, respectively, actinomycetes count (68.9× 10^5 and 64.1× 10^5 cfu/g) It matched ZTW seeded with Happy Seeder in full residue load statistically, But when ZTW was sown with Happy Seeder after employing a chopper and spreader, the diazotrophic count increased over residue burning and residue removal plots by 37.0–39.2% and 47.3–54.2%, respectively, compared to conventional tillage (CT) methods. Specifically, ZTW with HS and full residue load demonstrated the highest microbial counts, indicating enhanced soil biological activity. Additionally, residue retention on the soil surface was found to increase alkaline phosphatase activity, The highest alkaline phosphatase activity was obtained at 75 DAS for ZTW seeded with Happy Seeder after utilizing a chopper and spreader with full residual load (95.3 μg TPF g^{-1} soil 24 h^{-1} in 2018–2019; 98.6 μg TPF g^{-1} soil 24 h^{-1} in 2019–2020). further enhancing soil microbial functions. Chandra et al. [31] further supported these findings, demonstrating significantly higher microbial biomass carbon (MBC) levels (130.3 to 288.8 mg·kg^{-1} (0–15 cm) and 107.9 to 235.3 mg·kg^{-1} (15–30 cm) in soil layers treated with residue integration compared to conventional tillage methods. Specifically, ZTW with residue integration exhibited the highest MBC levels, indicating superior soil biological activity and nutrient cycling. the addition of residue raised MBC in both soil layers by 26 and 25%, respectively. MBC was 48 and 45% higher ZT in both soil depths when compared to CT practice Collectively, these studies underscore the importance of conservation tillage practices, residue management, and zero tillage techniques in promoting soil biological activity and overall soil health in agricultural systems. Similarly supporting by the Dhaliwal et al. [32] All soil enzyme activity (DHA, URSE, ACP, and ALP) were considerably greater under ZT than under CT when averaged across residue treatments. ZT had 13% more DHA activity than CT. Activities related to URSE, ACP, and ALP increased by 5%, 24.8%, and 15.6%, respectively. Relatively to residue retention, there were increases in the DHA, URSE, ACP, and ALP activity of 24.6%,9.7%,31.8%, and 24.4%, respectively. More findings supporting to it. Kar et al. [33] found that the best results were found in ZT, where there were 10 and 14% more actinomycetes and fungi, respectively, than in CT. The evaluation also revealed that the variation in the actinomycetes population resulting from modifications in tillage methods under the rice-wheat-green gram system was larger than the variation in the population resulting from tillage adjustments under other cropping systems.

TABLE 1. EFFECT OF MECHANIZED CROP ESTABLISHMENT TECHNIQUES ON RICE - WHEAT CROPPING SYSTEM

Implements	Impact on yield	Impact on soil health	References
Zero till drill with anchored stubbles	(6.1 t/ha)	58.0 (10^5 cfu/g soil) Actinomycetes count	[34]
Rotary tillage	(7151 kg/ha)	Soil microbial biomass (33.5 mg $100g^{-1}$)	[35]
CTW with full residue	(5.7 t/ha)	Diazotrophic count (10^4 cfu/g soil) 64.8±1.44c	[34]

Zero till with rice residue	(7.34 t/ha)	Dehydrogenase activity, 86.00 (µg TPF* /g soil/h)	[36]
CTW broad cast sown with rotavator after using chopper and spreader	(5.8 t/ha)	Soil microbial count (10^{7} cfu/g soil) 92.8±1.44cd	[34]
CTW with spatial drill	(5.68 t/ha)	soil microbial count (107 cfu/g soil) 92.1±1.44cd	[34]
Minimum tillage	(6.00 t/ha)	Urease activity (44.4 µg)	[37]
Happy seeder with full residue	(5.9t/ha)	alkaline phosphatase activity (95.3 µg TPF g^{-1} soil 24 h−1)	[34]

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