

Evaluating Tillage Practices and Herbicide Applications for Improved Rice Yield and Weed Control

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ABSTRACT

Weed infestation, water scarcity and intensive tillage practices are resulting in contributing low yield of rice crop. Two new and resource-efficient techniques for producing rice are direct seeded rice (DSR) and alternate wetting and drying (AWD). During the 2022 rice growing season, a field experiment was carried out at the Department of Agronomy, Faculty of Agricultural Sciences, University of the Punjab, Lahore, to examine the impact of weed control techniques on weed management in rice under various tillage regimes. Three replications using a two-factorial randomized completely block design (RCBD) were used to conduct the experiment. First factor had four tillage practices [Puddling; Alternate wetting and drying; Direct seeded rice (Drill sowing) and direct seeded rice (Broadcast sowing)] and second factor had four weed control treatments [Control; Pre-emergence weed control (Pendimethalin 33 % EC @ 1000 g a.i. ha⁻¹; post-emergence weed control (Bispyribac sodium (18 % w/w) + Bensulfuron methyl (12 % w/w) @0.15 a.i. Kg ha⁻¹ and combination of pre+ post emergence weed control]. In the experiment, 12 weed species from 7 families were observed as part of the weed flora. Among them 6 were grasses, 1 sedge and 5 broadleaf weeds. Under AWD, a combination of pre- and post-emergence herbicide spraying resulted in the greatest weed species reduction (14.34/m²). Herbicides applied as pre+ post emergence produced the highest grain production (7.60 t ha⁻¹) under puddling and it was statistically similar to grain yield acquired in application of pre-emergence weed control under AWD. In direct seeded rice highest grain yield (6.02 t ha⁻¹) was produced by application of both pre+ post emergence herbicides under broadcast sowing. The potential yield loss was higher in drill sowing when no herbicide was used or only post-emergence herbicide was applied. AWD is found most promising technology with respect to production and resource conservation.

Keywords: Weed control methods, Rice yield, Pre-emergence herbicides, Post-emergence herbicides, Grain Yield, Puddling

INTRODUCTION

Rice is an important crop in Pakistan, making a substantial contribution to both the agricultural sector and the country's GDP. At Punjab's "rice belt," major rice varieties are grown con, particularly at Hafizabad, often known as the "City of Rice." However, pests,

water scarcity, and climate change present difficulties for rice growing. A 10% decrease in the production of rice could result from a 1°C increase over the optimal temperature [1]. Due to its high-water use (27% of the world's freshwater resources), rice cultivation is particularly susceptible to the anticipated water crises brought on by industrialization and population growth [2]. Rice is a staple cereal crop for over half of the world's population and accounts for 20% of global calories [3]. Grown in over 100 countries, primarily from the *Oryza sativa* L. species, China and India are the top producers. Because it contains gamma oryzanol, rice bran oil, which is made from rice husks, is esteemed [4]. Eight Asian nations export 35% of the world's rice production, which accounts for 87% of global production [5]. In South Asia, which is frequently referred to as the "food bowl" of Asia, rice

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accounts for 30% of local caloric demands [6] and more than 40% of harvested land.

The hydrological cycle is predicted to be exacerbated by global warming, increasing the likelihood of floods and droughts [7], particularly in Asia's irrigated rice fields, where up to 22 million hectares could encounter water scarcity. In arid and semi-arid areas, climate change is depleting water resources, resulting in increasingly frequent and severe droughts that have a significant effect on agriculture. Global water shortages would have a significant impact on agriculture, which uses 90% of water in developing countries. China alone would lose 27 million tonnes of grain a year as a result of water constraint. High temperatures and drought reduce rice output by affecting tiller growth, seedling germination, and spikelet fertility [8]. More over to get rid of weeds, farmers frequently flood rice fields, although this practice loses water due to evapotranspiration and seepage [9]. Up to 23% more water will be needed for rice as a result of changing climate conditions. Additionally, by creating hardpans and decreasing soil permeability, excessive tillage, also known as puddling, which accounts for 30% of water use in rice production, degrades soil structure and prevents root development and nutrient extraction [10]. Additionally, by deteriorating the soil's qualities, this approach makes it more difficult to grow later dryland crops [11]. Frequent tillage lowers soil porosity, compacts the soil, and interferes with water infiltration, all of which lower rice-based systems' production.

In puddled soil of rice emit huge amount of greenhouse gasses emission i.e. methane (NH₄) and nitrous oxide (N₂O) contribute in global warming. In rice cultivation, puddling delays planting and lowers yields by obstructing following crop growth and causing elevated CH₄ emissions because of low oxygen levels [12]. In uncontrolled areas, weeds can reduce yields by up to 96% due to competition for resources, making them a significant problem in rice production [13]. Because of this rivalry, yield loss in aerobic rice systems can be as high as 50% and water productivity is double [14]. Numerous techniques for growing rice, such as Alternate Wetting and Drying (AWD) and the System of Rice Intensification (SRI), increase production while using less water [15]. SRI can reduce irrigation requirements by 24% and increase output by 71%, while AWD reduces methane emissions, conserves fuel for irrigation, and uses up to 70% less water [16]. As an alternative that uses less water, Direct Seeded Rice (DSR) also saves money on labour and resources. As resources become more limited, techniques like Alternate Wetting and Drying (AWD) and System of Rice Intensification (SRI) provide more environmentally friendly methods of

growing rice by conserving water, lowering greenhouse gas emissions, and coordinating with environmental objectives. Because of its environmental advantages and reduced input requirements, Direct Seeded Rice (DSR) is becoming more and more popular. Because DSR works in an aerobic environment as opposed to traditional transplanted rice (TPR), it uses 35–57% less water, requires less labour, and produces less methane. It is particularly attractive to farmers who are limited by labour and water because of its easier planting procedure and minimum expenses [17].

Additionally, by maintaining structure, avoiding erosion and compaction, and promoting biodiversity, less tillage in DSR improves soil health. This method lowers the costs of labour, fuel, and equipment while increasing production, which is consistent with conservation agriculture [18]. Since DSR doesn't have a water layer to naturally reduce weeds, it has trouble controlling weeds [19], especially in dry weather. Success requires the use of efficient techniques like hand weeding, agronomic procedures, and herbicide application. In DSR systems, both pre-emergence (PRE) and post-emergence (POST) herbicides have been successful [20]; PRE herbicides have been shown to reduce weed density by as much as 82%. DSR is a viable, resource-efficient method for sustainable rice farming since mechanical weeding can also increase crop yield and further reduce weed growth.

MATERIALS AND METHODS

Study Site

Experimental site is geographically located at 31° 29'41.19" N latitude and 74° 17'47.49" E longitude at an altitude of 750 ft. Maximum temperature 41.5 °C recorded during month of June and minimum temperature was 7 °C in December. Maximum rainfall 165.9 mm was recorded in month of July while minimum rainfall was 2.8 mm during November.

Experiment Layout and Preparation

The experiment was set up using a completely randomized block design (RCBD), three replications, and sixteen treatment combinations. Each plot was 1.2 m in width and 4.25 m in length (5 m² area). There was a 0.5-meter-wide bund between each allotment. A 0.5-meter bund separated each replication. After preparing the field for puddled rice with a cultivator and disc harrow, 48 plots were manually created with water channels and bunds for appropriate layout and moisture control. With 750–1000 g of seeds per Marla, a seedbed 5–10 cm high was constructed for a rice nursery grown in dry soil. Soil moisture was maintained through frequent watering and fertilizer application. Ten days prior to transplantation, urea (125 g/Marla) was administered, and two weeks later, zinc sulphate (200 g/Marla) was added. To prevent

illness, paddy seeds were treated with thiophanate-methyl at a dose of 2 g/kg. After being immersed in water for the entire night and treated with the fungicide, the seeds were allowed to dry in the shade before being planted. In order to minimize water and nutrient loss, manage water leaching, eradicate weeds, and soften soil for transplanting, puddling was carried out following initial cultivation.

Treatments

Basmati 515 was the cultivar used in this experiment. The experimental trial included 16 treatments. Factor A included four tillage techniques: 1) Broadcast

Sowing, 2) AWD, 3) Drill Sowing, and 4) Puddling. Factor B included four weed control techniques: 1) No weed control, 2) Pre-emergence weed control, 3) post-emergence weed control, and 4) Combination of pre + post-emergence weed control. Pre-emergence weed control was achieved using pendimethalin, while post-emergence weed control was achieved with bispyribac sodium. Twenty days after sowing (DAS), post-emergence weedicide was applied, whereas pre-emergence weedicide was applied 24–36 hours after sowing.

Table 1: Description of treatments for experiment

Sr. No	Treatment Symbol	Treatment Combinations
1	T1	Puddling+ Control
2	T2	Puddling+ Pre-emergence
3	T3	Puddling+ post-emergence
4	T4	Puddling+ Pre+Post-emergence
5	T5	AWD+ Control
6	T6	AWD+ Pre-emergence
7	T7	AWD+ post-emergence
8	T8	AWD+ Pre+Post-emergence
9	T9	DSR(Drill)+ Control
10	T10	DSR(Drill)+ Pre-emergence
11	T11	DSR(Drill)+ post-emergence
12	T12	DSR(Drill)+Pre+Post-emergence
13	T13	DSR(Broadcast)+ Control
14	T14	DSR(Broadcast)+Pre-emergence
15	T15	DSR(Broadcast)+post-emergence
16	T16	DSR(Broadcast)+Pre+Post-emergence

Sowing of Direct Seeded Rice

DSR was sown through drill and broadcast. Sowing was done in dry soil with immediate irrigation. Seed rate @ 10-12 kg/acre was used. In drill sowing row spacing was 9 inches. The puddled and alternate soaking and drying approach was used to transplant 35-day-old rice seedlings that had been cultivated in nurseries. On each hill, two seedlings were planted, with a 25 cm × 25 cm gap between each plant. Farmers used Alternate Wetting and Drying (AWD), a water-saving technique, two weeks after transplanting rice to reduce irrigation water use without affecting yield. A 30 cm long, 15 cm diameter perforated plastic tube was installed 15 cm into the soil to monitor water levels. After water fell to about 5 cm below the soil surface, irrigation was applied to re-flood the field. The field was kept at a water depth of 5 cm during the week before and after flowering.

For direct-seeded rice, fertilizers were applied at 100:75:50 NPK kg/acre and ZnSO₄ at 6 kg/acre. For

puddled and AWD rice, the rate was 125:87.5:62.5 NPK kg/acre. Half of the nitrogen was applied before sowing (DSR) or puddling (AWD/conventional), with the remainder split between the panicle initiation and tillering stages. Phosphorus, potash, and zinc were applied fully as a base dose, using urea, DAP, SOP, and ZnSO₄. Insect damage at the heading and milking stages was managed with Lambda Cyhalothrin, and Nativo 75 WG was applied to protect against diseases.

Application of Irrigation in DSR

A key factor in direct-seeded rice (DSR) is early irrigation. After the first irrigation the day after sowing, a pre-emergence weedicide was used, and the soil was kept moist for the first 12 days to guarantee complete germination. Twenty days prior to harvest, the last irrigation was given, and subsequent irrigations were determined by the WATTAR (soil moisture) conditions. Continuous ponding was maintained in puddled rice, with the water level being lowered while weedicide and pesticide were being

applied. Thirty days prior to harvest, irrigation was halted. After the ponded water disappeared after four

days, the tube's highlighted location was used for the future irrigation.



Figure 1. Pictorial presentation of experiment activities

RESULTS

Weed density (number/ meter square)

Diversity of weeds were found in the rice field in which the grass type weeds i.e. *Dactyloctenium Aegyptium*, *Echinochloa colona*, *Cynodon dactylon*, *Sorghum halepense*, *Leptochloa chinensis*, *Digitaria adscendens*, were the most common weeds in the rice fields while roadleaf weeds include *Amaranthus viridis*, *Convolvulus arvensis*, *Eclipta prostrate*, *Cucumis melo*, and *Solanum nigrum*, whereas sedges include *Cyperus rotundus*.The weed flora density were determined at different time interval (20, 40 and

60 DAS) presented in table 2. The result of weed density after 20DAS showed that maximum broadleaf (75.34), grasses (459.3) and sedges (236.81) were found in the T10, T9 and T11 respectively while other all treatments showed minimum weed density (Table 2). Maximum weed density of broadleaf, grasses and sedges were 161.46, 326.51 and 64.58 were recorded in the treatments T10, T9 and T10 respectively at 40 DAS. At 60 DAS, treatments T10, T11 and T6 showed maximum weed density i.e. 35.88, 434.15 and 53.82 respectively while all other treatments showed least number of weed density (Table 2).

Table 2. Total weed density (number m⁻²) under different tillage and herbicide application treatments.

Treatments	Total Weed Density (Number m ⁻²)								
	20 DAS			40 DAS			60 DAS		
	Broadle af	Gras ses	Sedges	Broadle af	Grasses	Sedge s	Broadlea f	Grasse s	Sedge s
T1	7.17cd±1.2	3.58b±0.6	10.76b±1.7	14.35bc±2.3	39.46c±0.57	46.64b±4	7.18bc±1.2	32.29c±1	46.64ab±4
T2	0.0d±0	0.0b±0	3.58b±0.58	0.0c±0	0.00c±0	7.17c±1.1	0.0c±0	0.0c±0	7.17c±1.1
T3	0.0d±0	3.58b±0.6	0.0b±0	0.0c±0	50.23c±2	29abc±4.6	0.0c±0	35.88c±1.5	28.7abc±4.6
T4	0.0d±0	0.0b±0	7.17b±1.15	0.0c±0	10.76c±1.7	17.9abc±28	0.0c±0	10.76c±1.7	17.9abc±2.8

T5	0.0d±0	0.0b±0	14.35b±1.53	7.176bc±1.1	17.94c±1.5	28.7ab c±25	7.17bc±1.2	7.18c±1.15	28.7ab c±2.5
T6	0.0d ±0	0.0b±0	93.28ab ±7.5	3.588c±0.5	10.76c±1.7	53.82 ±2a	14.35bc±1	0.0c±0	53.82a ±2
T7	0.0d±0	0.0b±0	3.58b±0.6	0.0c±0	25.11c±2	10.76 bc±17	0.0c±0	25.11c ±2.1	10.76 bc±1.7
T8	0.0d±0	0.0b±0	0.0b±0	0.0c±0	0.0c±0	7.18c ±1.1	0.0±0c	0.0c±0	7.18c ±1.1
T9	50.2bc±3.2	459.3 a±28	0.0b±0	46.64bc ±4.5	326.51a ±33	21.5bc d±17	14.35bc±1.1	104.1b c±11.	0.0c±0
T10	75.34a±5.5	0.0b±0	28.70b±4.6	161.46a ±16.8	0.0c±0	64.58a ±3.6	35.88a±2.1	50.23c ±2.1	10.76 bc±2
T11	25.1bcd ±1.5	430.6 a±20	236.81a ±33	7.17bc±1.15	226.4ab ±17	0.0d±0	10.76bc±1.7	434.15 a±26	0.0c±0
T12	68.17ab ±4	0.0b±0	10.76b±1	14.35bc ±2.3	0.0c±0	0.0d±0	10.76c±1	28.70c ±4.6	0.0c±0
T13	21.52bc d±1.7	111.2 3b ±8	21.52b±1.7	0.0c±0	121.99b c±4	0.0d±0	10.76bc±1	215.28 b±15.	0.0c±0
T14	50.23ab c ±5.5	0.0±0 b	68.17b±5.8	100.46a b±1.5	0.0c±0	0.0d±0	39.47a±0.6	50.23c ±5.0	17.94a bc±3
T15	57.40ab ±4.1	125.6 b ±18	39.46b±1.5	60.99bc ±9.8	121.9bc ±10.	0.0d±0	0.0c±0	226.04 b±8	0.0c±0
T16	57.40ab ±2.08	0.0b±0	14.35b±1.15	0.0c±0	0.0c±0	0.0d±0	25.12ab±2.1	25.11c ±4.0	0.0c±0
P (0.05)	0.6891	0.004	0.28	0.24	0.17	0.084	0.21	0.0103	0.34
LSD (0.05)	49.712	184.77	158.27	93.61	164.52	39.71	20.89	149.64	37.92

Agronomic Parameters

Plant Height (cm)

Plant height as it is a crucial rice crop growth indicator that directly influences yield contributing traits and ultimately, the grain yield. The data of interaction between tillage practices and weed management shown in the figure (2a). The result indicated that plant height in the direct-seeded rice (drill) interaction herbicide application time and the broadcast-sowing interaction with no weed control, plant height in the puddling and no weed control interaction was statistically significant. The combination of puddling and no weedicide produced the tallest plants (97 cm). Direct-seeded rice (drill) combined with post-emergence weed management resulted in the shortest plant height (66.33 cm).

Number of Tillers per Plant

The production of rice grains is greatly influenced by tillers. Having fewer tillers will result in fewer panicles, whereas having too many tillers will result in

greater panicles, worse grain filling, and lower grain yield. The result of both AWD and drill sowing produced significant results in terms of the number of tillers per plant (figure.2b). Alternate wetting and drying methods produced the highest number of tillers per plant (12.79), followed by puddling (12.27). Direct-seeded rice (Drill) produced the lowest number of tillers per plant (9.94). Weed management techniques had no discernible effect on the number of tiller plant⁻¹. The interaction of direct-seeded rice (Drill) with post-emergence weed control was statistically significant compared to the interaction of AWD and puddling with pre-emergence weed control and no weedicide application. The interaction of AWD with pre-emergence weedicide applications showed the maximum number of tillers per plant (14.92). The interaction of direct seeded rice (drill) and control produced the minimum number of tillers per plant (5.33) (figure 2b).

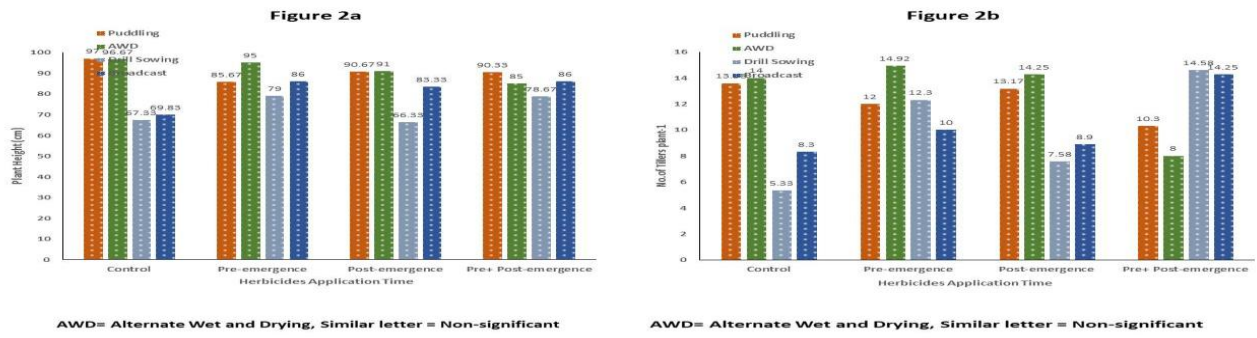


Figure 2. Effect of tillage and herbicide application strategies on agronomic parameters (Plant height (cm) and No. of tillers plant⁻¹)

100 Grain Weight (g)

An essential measure of rice milling yield is grain weight. Test weight in AWD practice was statistically significant as compared to direct-seeded rice (Drill) (Figure 3a). All of the weed management techniques showed statistically non-significant differences. The interaction of direct seeded rice (Drill) with all weed control methods, except for control, was significantly impacted by the 100-grain weight in the combination of AWD without weed control. The combination of AWD and control produced the highest value of 100 grains weight (1.79 g). Drill sowing combined with pre+post emergence weed management produced the lowest value of 100 grain weight (1.08).

Grain Productivity (tons ha⁻¹)

Grain productivity in AWD was statistically significant compared to that in broadcast and direct

drill sowing as shown in the figure (3b). Drill sowing produced the lowest yield, 2.18 tons per acre. Pre+post emergence weedicide application and post-emergence weedicide application resulted in significantly different grain yields. Grain yield was found to be significantly impacted by the interaction of pre+ post-emergence weed control and puddling, as well as by the interaction of broadcast sowing with all weed control techniques and direct seeded rice (drill) with all weed control techniques, except for the combination of pre+ post-emergence weed control. The combination of pre+post emergence weed management and puddling produced the highest grain production (7.60 tons per hectare). Drill planting combined with post-emergence weedicide spraying had the lowest grain yield (0.75 tons ha⁻¹) (Figure 3b).

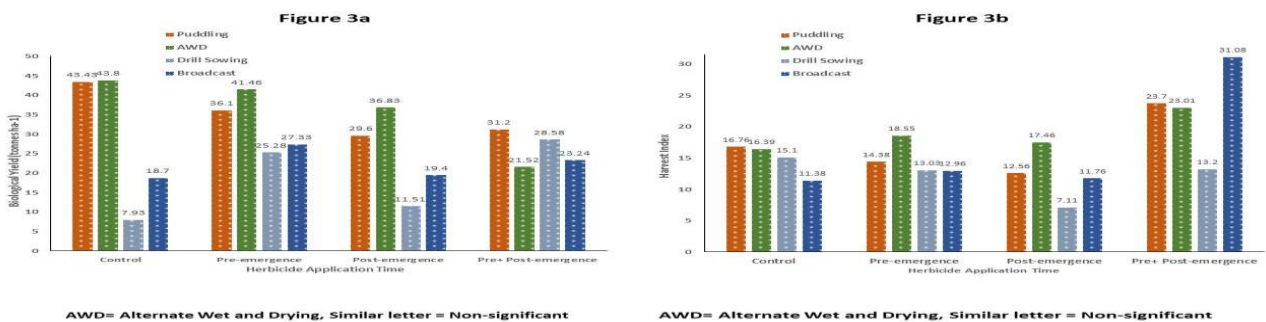


Figure 3. Effect of tillage and herbicide application strategies on 1000 grain weight (g) and Grain Yield (tons ha⁻¹)

Biological Yield (tons ha⁻¹)

Statistical analysis results showed that biological yield in AWD methods was statistically significant to that in drill & broadcast sowing. Biological yield in pre-emergence weed control was statistically significant to biological yield in post-emergence weed control. Biological yield in the interaction of alternate wetting

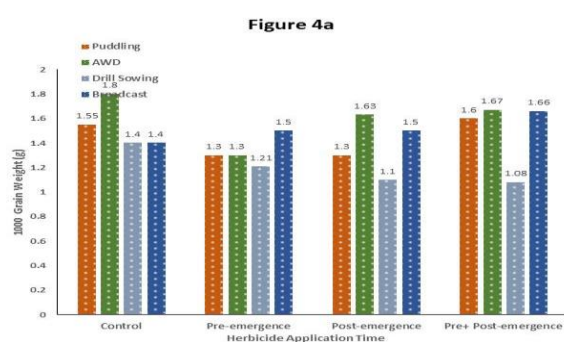
and drying with no weed control was statistically significant to biological yield produced from the interaction of direct seeded rice (drill & broadcast) with all weed control methods. Maximum biological yield (43.75 t ha⁻¹) was found in the interaction of AWD with no weed control. The lowest biological yield was recorded in the interaction of direct seeded

rice (Drill) with no weed control (7.92 t ha^{-1}) (Figure 4a).

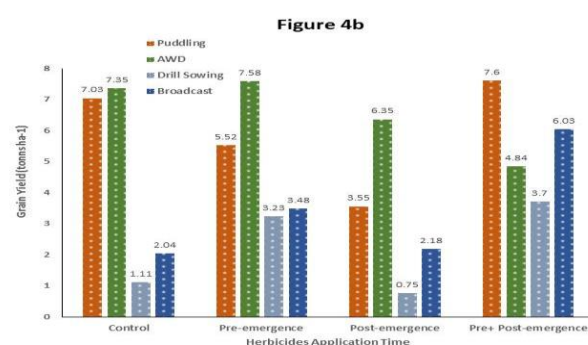
Harvest Index

One measure of efficiency is the harvest index. Calculating the difference between potential and actual yield is helpful. The statistical results indicated that only post-emergence weed control was significantly impacted by pre+ post-emergence weed control. Only the interactions of alternate wetting and drying with pre+ post-emergence weed control and

puddling without weed control and pre+ post-emergence weed control were non-significant in terms of the harvest index from the broadcast with pre+ post-emergence interaction. The combination of direct-seeded rice (Broadcast) and pre+ post-emergence weed control yielded the highest harvest index value (55.11). The combination of post-emergence weed management and direct seeded rice (Drill) had the lowest harvest index value (8.02) (Figure 4b).



AWD= Alternate Wet and Drying, Similar letter = Non-significant



AWD= Alternate Wet and Drying, Similar letter = Non-significant

Figure 4. Effect of tillage and herbicide application strategies on Biological Yield (tons ha^{-1}) and harvest index

DISCUSSION

Rice is a crop that requires a lot of water and is typically produced in puddles., which results in lower water productivity and other environmental issues. Direct-seed rice (DSR) and Alternate wetting and drying (AWD) are water saving techniques which results in increasing water productivity of rice. Weedy rice is also important problem in direct seeded rice but through use of pre and post emergence weedicides weeds can be successfully controlled.

In our study plant height in transplanted rice is significant to plant height in direct seeded rice. Our findings are consistent with those of Kumhar, who found that transplanted rice produced the tallest plants. The largest plant height was also achieved by the interaction of puddled rice and no weed control. Aslam and Ehsanullah also recorded that height of plant was significantly more than direct seeded rice [21, 22]. Birhane and Gathala also found similar results [23, 25]. It could be a result of less competition for nutrients, sunshine, and space in transplanted crops compared to direct seeding, which increases the crop height after transplanting. It is possible that the well-puddled soil in transplanted rice, which improved deep root penetration and resulted in effective nutrient uptake and healthy plant growth, is what caused the maximum plant height in that crop.

Yaqub found that number of productive tillers were statistically high in transplanted rice. In our study maximum number of productive tillers per plant are in alternate wetting and drying and puddled rice [26]. Results of Kumhar on number of productive tillers are similar to our results in which he recorded maximum numbers of tillers in transplanted rice and in interaction of alternate wetting and drying with pre-emergence weed control [27]. Similar results were reported by [28, 30]. This was mostly caused by regular transplanting having more tillers at various growth stages than direct seeding. This may have been attributed to enhanced photosynthetic translocation from source to sink, which may have led to higher yield qualities upon transplanting, as well as the proper utilization of all available terrestrial growth resources.

In our research work grain yield in transplanted rice is statistically significant to direct seeded rice. Highest grain yield was recorded in interaction of puddling with pre and post emergence weed control and lonely in alternate wetting and drying method. Our findings are in accordance with results reported by [30]. Hassan also reported that transplanted method of rice recorded higher grain yield [31]. Sorour stated that application of transplanted method significantly increased grain yield of rice [32]. This was mostly

caused by regular transplanting having more tillers at various growth stages than direct seeding. These findings concur strongly with those made public by Javaid and Gathala.

In our study work straw yield in puddling and alternate wetting and drying was statistically significant to other treatments. Highest straw yield was noted in transplanted method (Interaction of puddling and alternate wetting and drying with no weed control). Same result was found by [33]. Dileep also reported that maximum straw yield was recorded from paddy transplanted after puddling [30]. Kumhar also found similar results [27]. The advantages of transplanting over direct seedling could be attributed to the plants' greater emergence and growth.

In our research total dry matter/ biological yield in transplanted rice (Puddled and AWD) alone and in combination with weed control was statistically significant to direct seeded rice. Maximum dry matter production was in alternate wetting and drying followed by puddling. The results of Kumhar and Dileep are in accordance with our results [27, 30].

Harvest index in our findings is highest in transplanted rice. Our results are in line with finding of [30]. Salahuddin also found similar results [34]. Higher grain production, which was attained through greater performance in most yield-attributing qualities, was

the primary cause of the high harvest index. Additionally, our findings concur with those of Rahman and Gill [24, 35].

In our study highest number of empty grains were recorded in drill sowing and lowest in alternate wetting and drying. These results are similar to the findings of Gathala and Saharawat [25,36].

CONCLUSION

The study highlights the importance of integrating effective weed control methods with suitable tillage practices to improve rice yield and resource efficiency. Alternate wetting and drying (AWD) emerged as a highly resource-efficient method, offering better weed control and water productivity. The combined use of pre- and post-emergence herbicides significantly reduced weed density and dry matter, leading to higher grain yields, particularly under AWD and puddling systems. In direct-seeded rice, the broadcast sowing method performed well with combined herbicide application, while drill sowing resulted in higher yield losses when herbicides were not used or only post-emergence herbicides were applied. These findings emphasize the potential of AWD and integrated herbicide strategies to enhance rice productivity and sustainability in resource-constrained environments.

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