



Effects of Land Preparation Timing and Weed Management Strategies on Weed Dynamics, Yield, and Profitability of Rainfed Lowland Rice

Leo G. Inocencio^{1*}, and Milen Fileza M. Inocencio²

¹ College of Agriculture, Food and Sustainable Development - Dingras Campus, Mariano Marcos State University, Philippines

² Research Directorate - Mariano Marcos State University, Philippines

* Correspondence: lginocencio@mmsu.edu.ph

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Abstract: The study aimed to evaluate the effect of the timing of land preparation on the weed population of transplanted rice, identify and document the major weeds, evaluate the most effective weed management for transplanted rice in a rainfed ecosystem, and conduct a cost and return analysis. We evaluated four land-preparation timings and three weed controls in a field experiment. The results showed that the major weed species observed at 25 DAT were *T. portulacastrum*, *S. zeylanica*, *E. crus-galli*, and *C. difformis*, which were unaffected by the timing of land preparation. Five major weed species: *A. sessilis*, *E. crus-galli*, *I. aquatica*, *S. zeylanica*, and *P. virginiana* were observed at 55 DAT. *S. zeylanica* was the most dominant weed observed in plots with hand weeding at 30 DAT. Herbicide application (Bispyribac Sodium) at 30 DAT significantly reduced *S. zeylanica* compared with hand weeding alone at 30 DAT. A combination of proper land-preparation timing and weed control also reduced the dominant weed species. Land preparation timing did not significantly affect grain yield; however, it influenced crop growth, weed dynamics, and economic returns. Among the treatments, single plowing two weeks before harrowing and final leveling (TLP2) produced the highest net income and return on investment (ROI), indicating that moderate land preparation provided better economic efficiency under rainfed conditions. The study highlights the importance of integrating appropriate land-preparation timing with effective, cost-efficient weed-management strategies to improve productivity and profitability in rainfed lowland rice systems.

Keywords: Rainfed lowland ecosystem; weed population; rice; land preparation; weed control

1. Introduction

Rice (*Oryza sativa* L) is one of the top three leading food crops in the world. It provides 21% of global human per capita energy and 15% of per capita protein [1, 2]. It is the Filipino's most important source of carbohydrates, contributing roughly 50–75% of total carbohydrate intake, based on the 2021 Expanded National Nutrition Survey [3]. Rice is the most versatile crop grown in all ecosystems, either upland or lowland rainfed areas. Aside from being a principal food, its by-products, such as rice straw and rice bran, are used as animal feed. Rice-based farmers usually use rice straw as mulch for growing garlic, onions, watermelons, and other creeping crops. Rice is native to Southeast

Asia and is cultivated in both upland and lowland areas in the Philippines. About one-third of the world's rice area is rainfed, with the Global Rice Science Partnership (GRiSP) estimating that around 31% of the global rice area is rainfed lowlands, which are characterized by non-continuous flooding and reliance on rainfall instead of irrigation [4]. In Asia, rainfed rice ecosystems cover roughly 45 million ha, representing a significant portion of rice growing area where drought and water stress are primary constraints to crop productivity.

In the Philippines, rainfed rice accounts for about 1.5 million ha of the total rice area, roughly 30–33%, and yields in rainfed systems are consistently lower than in irrigated systems due to erratic rainfall patterns and limited water control [4]. These water limitations at land preparation and crop establishment stages make yields unpredictable and contribute to weed proliferation and other biotic stresses, which significantly reduce productivity compared with irrigated rice [5]. No study has examined the timing of land preparation, specifically the timing of harrowing, which is directly related to the practices of rainfed farmers in Ilocos. Farmers prepare the land only by plowing and harrowing a day before rice transplanting, although recommended tillage practices for lowland rice include plowing the field using a rotavator or moldboard, followed by harrowing using a hand tractor 2–3 times with at least a 1-week interval [6]. This is because farmers depend on rainfall to be sufficient for land preparation and transplanting.

Studies on rainfed rice production indicate that weed infestation constitutes one of the most severe and persistent biotic constraints, with substantial yield losses, while insect pests (e.g., stem borers and rice bugs) and diseases such as blast and brown spot also significantly limit productivity [7]. Weeds cause serious yield reductions; if not controlled, they can reduce rice yield by up to 75% [8] through competition for limited resources for growth and development, such as nutrients, sunlight, and water, which they require in similar amounts. Competition occurs when a limiting resource falls short of the combined requirements of both [7]. Limited water supply contributes to weed growth and reproduction. When weeds are exposed to the soil surface and air, especially immediately after transplanting, this exposure induces weed germination and growth [9]. Low yields due to this pest are aggravated by limited farmer knowledge of effective mechanical, cultural, and chemical management methods. The present weed control recommendations, including timing, rate, and method of herbicide application, need further fine-tuning to suit farmers' field conditions, especially in rainfed lowland ecosystems.

Herbicide-based weed management nowadays is becoming the most popular method of weed control in rice because of its labor-saving innovations according to [10]. Although herbicide application effectively controls many weed species, repeated use of the same herbicide can select for tolerant or resistant biotypes, shifting weed populations. The first herbicide-resistant rice weed documented in the Philippines was *Sphenoclea zeylanica* (goosegrass), resistant to 2,4-D, identified in San Rafael, Bulacan, after prolonged 2,4-D use in rice fields. Subsequent resistance cases have also been reported as weed species adapt to continuous herbicide pressure [11]. Continuous application of the same herbicide, or herbicides with similar mechanisms of action, can exert strong selection pressure on weed populations, promoting the evolution of herbicide resistance. Additionally, improper and repeated herbicide use may lead to the accumulation of herbicide residues in soil and the broader environment, posing ecological risks and reducing the long-term sustainability of chemical weed control [12]. The advent of herbicide-resistant species is an increasingly worrying problem for farmers, extension workers, and policy-makers in many rice-producing areas worldwide. The only way to avoid these problems is to implement improved weed control within the context of integrated pest management, with particular emphasis on the weed ecobiology of prevailing species.

In rainfed lowland ecosystems, the timing of land preparation is a critical management factor because it influences soil moisture conditions, weed emergence patterns, nutrient availability, and crop establishment. Proper timing of plowing and harrowing can stimulate early weed germination before transplanting, allowing later operations to reduce weed pressure before crop establishment. Delayed or poorly timed land preparation may result in uneven crop establishment and increased weed competition, particularly under unpredictable rainfall conditions common in rainfed systems. Although several studies have evaluated tillage intensity and weed management in rice, limited information is available regarding the specific effects of land preparation timing combined with post-transplant weed control practices on weed dynamics, crop performance, and profitability under rainfed lowland conditions in the Philippines.

The study aimed to (1) evaluate the effect of timing of land preparation on the weed population of transplanted rice, (2) identify and document the major weeds, (3) evaluate the most effective weed management for transplanted rice in a rainfed ecosystem, and (4) determine the profitability of different land preparation timings and weed control practices in rainfed lowland rice production. The results provided valuable information to rainfed lowland farmers on weeds and weed management strategies for transplanted rice. It gave farmers the option to use proper land-preparation timing while limiting chemical use.

2. Materials and Methods

The study was conducted at the Mariano Marcos State University Research Farm, Quiling Sur, Batac City, Ilocos Norte. The study used a split-plot design with three replications. Treatments were randomly arranged within each replication, with a plot size of 4x5m. The treatment details shown in Table 1 comprised of: Time of Land Preparation (Main Plot) TLP1-saturated plowing followed by harrowing and leveling (farmer’s practice); TLP 2-single plowing 2 weeks before harrowing and final leveling; TLP 3-single plowing 4 weeks before harrowing and final leveling; TLP 4-twice plowing at 2 weeks interval before harrowing and final leveling; Weed Control (Sub-Plot) WC 1- Herbicide application Bispiribac Sodium (Nominee™) applied at 30 DAT; WC 2- Hand weeding at 30 DAT; and WC 3- Application of herbicide at 30 DAT and hand weeding (spot weeding) at 40 DAT. Rice seedlings (NSIC Rc240) were transplanted at 21 days after sowing using a planting distance of 20 cm × 20 cm, equivalent to approximately 25 hills m⁻². Transplanting was done manually with 2 seedlings per hill. Fertilizer application followed the recommended rate of 90–7–60 kg ha⁻¹ N–P₂O₅–K₂O derived from soil analysis. The fertilizer materials used were complete fertilizer (14–14–14), urea (46–0–0), and muriate of potash (0–0–60). Basal application of complete fertilizer and muriate of potash was done after final land preparation, while nitrogen from urea was applied in split applications at 35 and 56 days after transplanting (DAT), after application of the weed control treatments. Fertilizer application and crop management practices were applied uniformly across all treatments throughout the experimental period. Irrigation was applied uniformly across all treatments whenever necessary. We sampled and counted weeds before and after weed control application, specifically at 25 and 55 DAT.

2.1 Soil Physicochemical Properties and Agroclimatic Conditions of the Experimental Area

The experimental area had a heavy-textured soil with a slightly alkaline pH (7.3), low organic matter content (1.90%), and low total nitrogen (0.09%) (Table 1). Available phosphorus was classified as high, whereas exchangeable potassium was deficient, indicating the need for potassium supplementation during crop establishment. Based on soil analysis, the recommended fertilizer rate for inbred rice was 90–7–60 kg ha⁻¹ N–P₂O₅–K₂O. These soil conditions provided the basis for fertilizer management throughout the experiment.

Table 1. The chemical and physical properties of the experimental site determined the recommended fertilizer rate.

%C	%OM	Texture	pH	Total N (%)	Phosphorus (ppm P)	Potassium (ppm K)	Recommended Fertilizer Rate (kg ha ⁻¹)
1.1	1.90	clay loam	7.3	0.09	high	deficient	90-7-60

The experiment was conducted from June 28 to October 19, 2024, under rainfed lowland conditions in Ilocos Norte, Philippines. Rainfall and air temperature data during the study were obtained from the Agro-Meteorological Station of Mariano Marcos State University, Batac City, Ilocos Norte (Figure 1). Rainfall during the vegetative stage ranged from 0.00 to 30.00 mm, while rainfall during the reproductive stage ranged from 0.00 to 153.60 mm. Rainfall during the early maturity stage ranged from 0.00 to 189.00 mm. Air temperature during the experimental period ranged from 17 to 34 °C, with mean maximum and minimum temperatures of 32 °C and 23 °C, respectively.

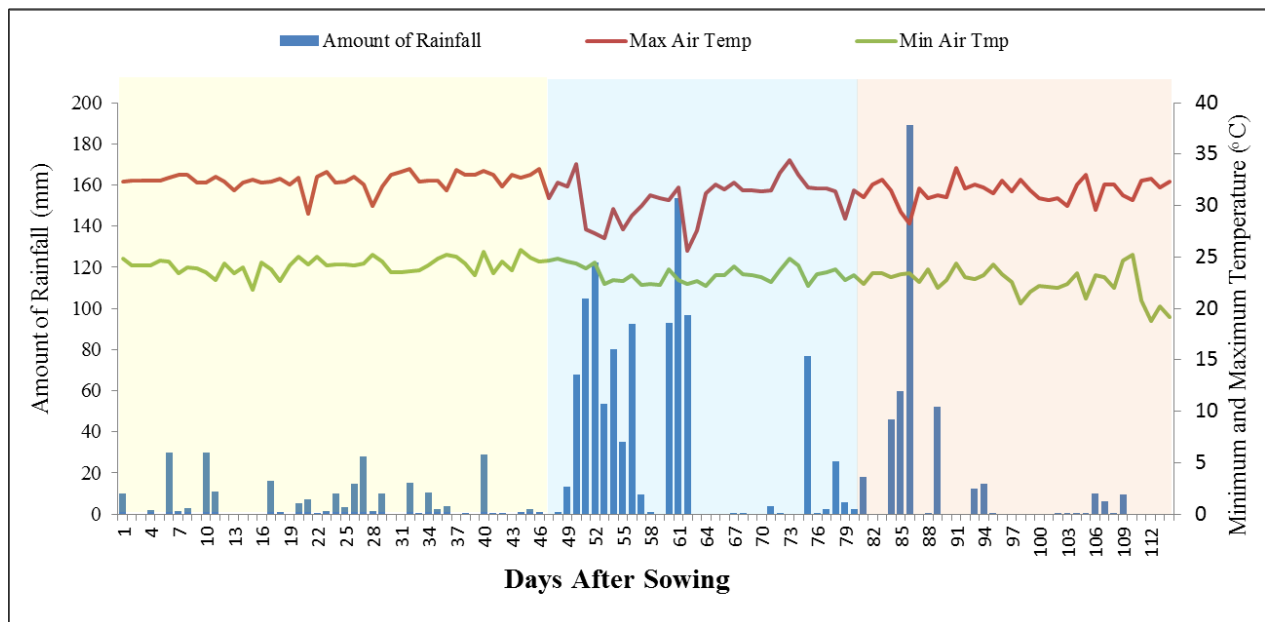


Figure 1. Amount of Rainfall (mm), and Maximum and Minimum Air Temperature (°C) Throughout the Growth Stages of the transplanted rice. MMSU, Batac City, Ilocos Norte.WS 2024.

2.2 Weed Population

To monitor weed population, a 1m x 1m quadrat sampling was done per treatment plot 5 days before weed control application and at 25 and 55 DAT. We identified and documented the weed species. The relative weed density, relative fresh weight, and summed dominance (SDR) ratio were obtained using the formula:

$$\text{Relative fresh weight} = \frac{\text{Fresh weight of weed species}}{\text{Total fresh weight of all weed species}} \times 100 \quad [13]$$

$$\text{Relative weed density} = \frac{\text{Number of weed species}}{\text{Total number of all weed species}} \times 100 \quad [13]$$

$$\text{Sum dominance ratio} = \frac{\text{Relative fresh weight} + \text{Relative weed density}}{2} \times 100 \quad [13]$$

2.3 Plant Height and Tiller Number

Plant height was measured from the ground level to the tip of the longest leaf using ten sample plants at 30 and 60 days after transplanting (DAT) and at maturity, with the final height recorded from the ground level to the neck node of the panicle. Tiller number and panicle-bearing tillers were determined by counting all tillers from ten randomly selected hills at the same growth stages, and tillers with fewer than five seeds per panicle were classified as unproductive.

2.4 Yield and Yield Parameters

Yield and yield parameters were determined by measuring panicle length as the linear distance from the base node to the tip of the panicle. Grain yield (kg ha^{-1}) was obtained from a 3 m x 2 m harvest area per plot and adjusted to 14% moisture content using the formula: $\text{Yield} = \text{Fresh weight (kg)} \times (10,000 \text{ m}^2 / \text{crop-cut area in m}^2) \times (100 - \text{MC}) / 86$ [14]. To minimize border effects and reduce spatial variability, harvesting was limited to the inner 3 m x 2 m sampling area located at the center of each plot. We excluded border rows and outer plants from harvest sampling to avoid interference from adjacent treatments and edge effects. This ensured that yield data represented the actual treatment response under uniform crop stand conditions. Percent filled grains and seed size were also evaluated from representative grain samples collected at harvest. Seed size was also evaluated by weighing 1000 rice seeds per treatment.

2.5 Cost and Return Analysis

The cost of rice production was recorded using prevailing market prices of inputs and outputs. Production cost was computed as the sum of material and labor expenses. Gross income was computed using the prevailing farmgate price of palay at PhP 19.00 kg⁻¹ during the cropping period (PhP = Philippine Peso). Net income was calculated by subtracting total production cost from gross income, while return on investment (ROI) was computed as: $ROI (\%) = (\text{Net income} / \text{Production cost}) \times 100$. Production cost was estimated based on prevailing local prices of farm inputs, labor, and machinery services during the study. The prevailing labor wage rate during the cropping period was PhP 200.00 day⁻¹. Machine operation costs were computed based on local custom rates of PhP 0.50 m⁻² for rotation and PhP 0.35 m⁻² for harrowing. Weed control costs were based on the actual labor time and input expenses incurred per plot and were subsequently converted to a per-hectare basis. Additional costs under WC3 included herbicide application and spot hand weeding at 40 DAT.

2.6 Data Analysis

Data were analyzed using analysis of variance (ANOVA) for a split-plot design with Statistical Tool for Agricultural Research (STAR) version 2.0.1, developed by the International Rice Research Institute (IRRI), Los Baños, Laguna, Philippines. Treatment means were compared using Duncan's Multiple Range Test (DMRT) at the 5% level of significance.

3. Results and Discussion

3.1 Weed dominance as affected by land preparation and weed control

Summed dominance ratio (SDR) analysis showed that weed control practices, rather than land preparation timing, primarily influenced weed dominance at 55 days after transplanting (DAT) (Table 2b). Land preparation timing alone did not significantly alter the dominance of major weed species, indicating that soil preparation without post-transplant intervention was insufficient to suppress weed establishment under rainfed lowland conditions. At 25 DAT, SDR values of dominant weeds (*Cyperus difformis*, *Echinochloa crus-galli*, *Sphenoclea zeylanica*, and *Trianthema portulacastrum*) did not differ significantly among treatments (Table 2a), reflecting early weed emergence largely governed by the soil seed bank and favorable moisture conditions following transplanting, as the soil seed bank serves as the reservoir of viable weed seeds that germinate when conditions become conducive for emergence [15]. By 55 DAT, weed control treatments differed significantly (Table 2b), particularly for *Sphenoclea zeylanica*, *Ipomoea aquatica*, *Physalis virginiana*, and *Echinochloa crus-galli*. Herbicide application at 30 DAT effectively reduced *S. zeylanica* dominance, whereas hand weeding alone resulted in higher SDR values, indicating inadequate suppression and possible regrowth or late emergence. Similar limitations of single manual weeding in rice systems have been widely reported, especially under conditions that favor successive weed flushes, where manual weeding alone was less effective than combined strategies [16, 17]. The integrated herbicide–hand weeding treatment provided more balanced weed suppression across species, supporting the effectiveness of integrated weed management approaches in rice systems [18].

The interaction between time of land preparation and weed control significantly affected the summed dominance ratio (SDR) of *Echinochloa crus-galli* at 55 DAT (Table 2b; Figure 2), indicating that the effectiveness of weed control practices depended on the land preparation method employed. The highest SDR was observed under TLP 3 combined with WC3, suggesting that *E. crus-galli* was able to persist or re-establish despite integrated weed management. This response may be attributed to the high adaptability and staggered emergence behavior of *E. crus-galli* under rainfed conditions. Lower SDR values were generally observed in treatments subjected to more intensive land preparation and herbicide application, particularly under TLP 4, indicating that repeated plowing may have enhanced weed suppression by reducing weed emergence before transplanting. This finding aligns with the principles of integrated weed management (IWM), where combining cultural practices and herbicide application improves overall weed control efficiency. [19] emphasized that integrating complementary weed management approaches rather than relying on a single method is essential for effective and sustainable weed management. Overall, the significant interaction suggests that effective suppression of *E. crus-galli* requires synchronization of pre-plant land preparation and post-transplant weed management strategies to minimize weed persistence during later crop growth stages.

Table 2a. Summed dominance ratio of different weed species sampled at 25 days after transplanting (DAT) as affected by land preparation and weed control in rainfed lowland ecosystems in Ilocos Norte, WS 2024.

Treatments	Summed dominance ratio (%)			
	<i>C. diformis</i>	<i>E. crus-galli</i>	<i>S. zeylanica</i>	<i>T. Portulacastrum</i>
Main Plot: Time of Land Preparation (TLP)	ns	ns	ns	ns
TLP 1	38.66	29.36	25.80	4.92
TLP 2	61.91	8.99	19.61	3.57
TLP 3	48.69	16.32	16.56	1.57
TLP 4	32.31	26.74	24.26	0.80
Subplot: Weed Control (WC)	ns	ns	ns	ns
WC 1	48.0	16.0	21.80	3.1
WC 2	50.5	16.9	18.40	3.7
WC 3	37.7	28.1	24.50	1.3
TLP x WC	ns	ns	ns	ns
CV% (a)	46.29	54.29	64.00	60.61
CV% (b)	40.98	66.91	27.51	82.73

ns- not significant

CV- coefficient of variation

Table 2b. Summed dominance ratio of different weed species sampled at 55 days after transplanting (DAT) as affected by land preparation and weed control in rainfed lowland ecosystems in Ilocos Norte, WS 2024.

Treatments	Summed dominance ratio (%)			
	<i>P. virginiana</i>	<i>I. aquatica</i>	<i>S. zeylanica</i>	<i>E. crus-galli</i>
Main Plot: Time of Land Preparation (TLP)	ns	ns	ns	ns
TLP 1	22.40	44.04	22.48	5.98
TLP 2	44.80	18.71	12.40	3.44
TLP 3	30.24	24.65	18.09	16.76
TLP 4	28.39	25.40	26.20	0.00
Subplot: Weed Control (WC)	**	*	**	*
WC 1	42.7 b	43.7 b	0.0 a	2.4 a
WC 2	5.0 a	10.8 a	59.4 b	8.3 b
WC 3	46.7 b	30.1 b	0.0 a	8.9 b
TLP x WC	ns	ns	ns	**
CV% (a)	88.58	63.82	46.16	105.70
CV% (b)	60.33	72.37	49.27	55.38

**- significant at 1 % level

*- significant at 5 % level

ns- not significant

CV- coefficient of variation

Means marked with the same letters within a column are not significantly different.

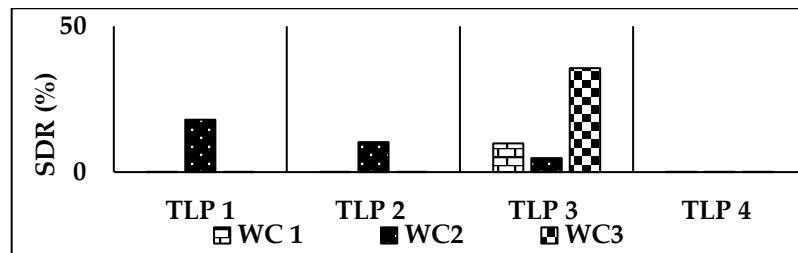


Figure 2. Interaction effect of time of land preparation (TLP) and weed control practices (WC) on the summed dominance ratio (SDR) of *Echinochloa crus-galli* at 55 days after transplanting (DAT) in rainfed lowland rice ecosystems in Ilocos Norte, WS 2024.

TLP1- saturated plowing followed by harrowing and leveling (farmer's practice)

TLP2- single plowing 2 weeks before harrowing and final leveling

TLP3- single plowing 4 weeks before harrowing and final leveling

TLP4- twice plowing at 2-week intervals before harrowing and final leveling

WC1- Herbicide application Bispiribac Sodium (Nominee™) applied at 30 DAT

WC2- Hand weeding at 30 DAT

WC3- Application of herbicide at 30 DAT and hand weeding (spot weeding) at 40 DAT

3.2 Tillering and plant height response to land preparation and weed control

Land preparation timing and weed control practices differentially influenced rice tillering and plant height across growth stages (Table 3a and 3b). Overall, land preparation more strongly influenced early tiller production, whereas weed control influenced plant height at later growth stages, reflecting differences in how these management factors modify below- and above-ground competition. At 30 and 60 days after transplanting (DAT), tiller number was significantly affected by the timing of land preparation ($P < 0.05$), with earlier and repeated land preparation (TLP 3 and TLP 4) producing more tillers than the farmer's practice (TLP 1). These responses can be attributed to improved soil tilth, reduced soil strength, and enhanced nutrient availability, which collectively favor early root development and tiller initiation. However, the absence of significant differences at maturity indicates compensatory tiller mortality and tiller extinction as the crop transitions from vegetative to reproductive stages, a pattern commonly observed in rice where maximum tillering is followed by tiller loss before maturity [20]. Weed control practices did not significantly affect tiller number at any growth stage, suggesting that tillering was more sensitive to soil physical conditions established during land preparation than to post-emergence weed suppression. This pattern is consistent with recent field observations showing that, once rice has achieved adequate early crop establishment and vigor, tiller number may be relatively insensitive to weed competition duration during mid-vegetative stages [21]. Plant height was not significantly influenced by land preparation or weed control at early stages, but was significantly affected at maturity (Table 3b). Taller plants under twice plowing (TLP 4) likely reflect sustained nutrient availability and reduced root impedance during later growth stages. Although WC2 (hand weeding at 30 DAT) produced significantly taller plants at 60 DAT and maturity, it did not correspondingly increase tiller number. This response may be associated with the relatively high summed dominance ratio (SDR) of *Sphenoclea zeylanica* observed under WC2 at 55 DAT, which may have imposed competitive stress on rice plants during later vegetative stages. Under such conditions, reduced tillering and increased stem elongation may occur as adaptive responses to competition for light and space. Similar compensatory growth responses have been reported in rice subjected to prolonged weed interference, where plants allocate more assimilates to vertical growth rather than tiller production under competitive environments and nutrient stress [22-24].

The interaction between land preparation timing and weed control practices had minimal effect on rice plant height at 30 DAT (Table 3b; Figure 3). Plant height across treatment combinations was generally comparable, indicating relatively uniform early vegetative growth under varying management practices. Among the land preparation treatments, TLP4 tended to produce slightly taller plants, possibly due to improved soil tilth, better root development, and enhanced soil moisture conditions associated with repeated

plowing and proper leveling. In contrast, TLP1 and TLP3 generally produced relatively shorter plants, suggesting that less intensive or delayed land preparation may slightly reduce early crop vigor under rainfed conditions. Since weed control treatments were imposed at 30 DAT, differences in plant height among weed control treatments at this stage were minimal and may not yet reflect the full effect of weed management practices on crop growth. The results, therefore, suggest that early plant height was influenced more by land preparation conditions than by post-emergence weed control interventions. Overall, the results indicate that the time of land preparation mainly enhances early crop vigor through increased tillering, while effective weed control ensures sustained plant growth at later stages. This functional separation explains why improvements in vegetative growth did not necessarily translate into significant yield differences associated with land preparation alone. In rainfed lowland systems, combining appropriate soil preparation with effective weed management remains essential for stabilizing crop growth under variable moisture and labor constraints.

Table 3a. Number of tillers of rice plants as affected by land preparation and weed control in rainfed lowland ecosystems in Ilocos Norte, WS 2024.

Treatments	Tillers/hill		
	30 DAT	60 DAT	Maturity
Main Plot: Time of Land Preparation (TLP)	*	*	ns
TLP 1	14.41 a	16.28 a	12.09
TLP 2	16.39 ab	19.29 b	13.57
TLP 3	16.01 bc	18.18 b	12.98
TLP 4	17.74 c	18.31 b	12.82
Subplot: Weed Control (WC)	ns	ns	ns
WC 1	16.2	18.5	12.9
WC 2	16.5	17.3	12.5
WC 3	15.7	18.3	13.2
TLP x WC	ns	ns	ns
CV% (a)	8.65	7.75	24.15
CV% (b)	13.11	11.74	19.75

*- significant at 5 % level

ns- not significant

CV- coefficient of variation

Means marked with the same letters within a column are not significantly different.

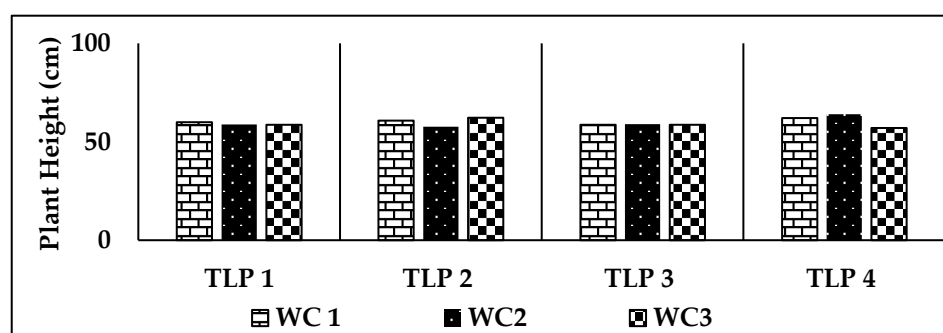


Figure 3. Interaction effect of time of land preparation (TLP) and weed control practices (WC) on the plant height of the transplanted rice at 30 days after transplanting (DAT) in rainfed lowland rice ecosystems in Ilocos Norte, WS 2024.

TLP1- saturated plowing followed by harrowing and leveling (farmer's practice)

TLP2- single plowing 2 weeks before harrowing and final leveling

TLP3- single plowing 4 weeks before harrowing and final leveling

TLP4- twice plowing at 2-week intervals before harrowing and final leveling

WC1- Herbicide application Bispiribac Sodium (Nominee™) applied at 30 DAT

WC2- Hand weeding at 30 DAT

WC3- Application of herbicide at 30 DAT and hand weeding (spot weeding) at 40 DAT

Table 3b. Plant height of rice plants as affected by land preparation and weed control in rainfed lowland ecosystems in Ilocos Norte, WS 2024.

Treatments	Plant Height		
	30 DAT	60 DAT	Maturity
Main Plot: Time of Land Preparation (TLP)	ns	ns	**
TLP 1	59.11	71.44	99.74 a
TLP 2	60.20	73.50	101.48 bc
TLP 3	58.73	70.90	104.31 ab
TLP 4	61.04	71.38	106.31 c
Subplot: Weed Control (WC)	ns	**	*
WC 1	60.3	70.0 a	101.8 a
WC 2	59.9	75.3 b	105.0 b
WC 3	59.2	70.2 a	102.1 a
TLP x WC	*	ns	ns
CV% (a)	3.06	2.55	3.10
CV% (b)	3.73	3.11	2.91

** - significant at 1 % level

* - significant at 5 % level

ns - not significant

CV - coefficient of variation

Means marked with the same letters within a column are not significantly different.

3.3 Yield and yield component responses to land preparation and weed control

Grain yield and associated yield components of rice varied with land preparation timing and weed control practices under rainfed lowland conditions (Table 4). Neither factor significantly affected total grain yield when considered independently, indicating that rice plants compensated for early growth differences by adjusting yield components. Such yield stability despite variation in management has been widely reported in rainfed rice systems, where environmental constraints (e.g., water supply and soil fertility limitations) often limit the full expression of treatment effects and lead to plants compensating through adjustments in yield components rather than total grain yield differences [25]; [26]. Among the yield components, percent filled grain was the most responsive parameter, showing significant effects of both land preparation ($P < 0.05$) and weed control ($P < 0.01$). The highest proportion of filled grains was recorded under twice plowing (TLP 4), suggesting that Improved soil physical conditions that enhance nutrient availability and dry matter distribution to panicles can support assimilate supply during grain filling and increase the proportion of filled grains [27]. Weed control practices also significantly influenced percent filled grain, with higher values observed under hand weeding at 30 DAT (WC2) and the combined herbicide application followed by spot weeding (WC3). In contrast, lower filled grain percentages under herbicide-only treatment (WC1) may reflect late-emerging or herbicide-tolerant weeds that competed with the crop during grain filling. Previous studies have shown that weed interference during the reproductive phase has a stronger impact on grain filling and related yield components than on panicle formation or seed size, especially as weeds compete more intensely for light and nutrients during late development stages in rice [28]; [29].

The interaction between time of land preparation and weed control practices had minimal influence on panicle length (Figure 4), as values remained relatively comparable across treatment combinations. However, treatments involving TLP4 generally produced slightly longer panicles, particularly when combined with WC1 and WC2, suggesting that improved soil conditions and effective weed suppression may favor reproductive development and assimilate allocation toward panicle formation [30]. In contrast, the interaction effect was more evident in percent filled grain (Figure 5). Treatment combinations involving TLP4

and WC2 showed higher filled grain percentages, indicating that intensive land preparation combined with timely hand weeding improved grain-filling efficiency by reducing competition for nutrients, moisture, light, and space during reproductive stages [31]. Lower filled grain percentages in some TLP3 combinations suggest that delayed or less intensive land preparation may slightly reduce crop vigor and assimilate translocation to developing grains. This suggests that management interactions influenced rice productivity primarily through grain filling rather than panicle development under rainfed lowland conditions. Overall, the results indicate that yield formation in rainfed lowland rice was governed primarily by reproductive efficiency rather than absolute biomass production. Optimizing land preparation and integrated weed control to protect grain filling is therefore more critical for sustaining yield than maximizing early vegetative growth alone.

Table 4. Yield and yield parameters such as panicle length, percent filled grain, and seed size of rice plants as affected by land preparation and weed control in rainfed lowland ecosystems in Ilocos Norte, WS 2024.

Treatments	Grain Yield (kg ha ⁻¹)	Panicle Length (cm)	Filled Grain (%)	Seed Size (g/1000 seeds)
Main Plot: Time of Land Preparation (TLP)	ns	ns	**	ns
TLP 1	5798.89	22.85	93.39 b	24.49
TLP 2	6516.00	22.72	93.96 b	24.51
TLP 3	5943.67	22.88	89.79 a	24.50
TLP 4	6344.00	23.12	94.08 c	24.49
Subplot: Weed Control (WC)	ns	ns	**	ns
WC 1	6209.3	23.0	92.4 a	24.5
WC 2	6183.0	22.8	94.0 b	24.5
WC 3	6059.6	22.9	92.0 a	24.5
TLP x WC	ns	**	**	ns
CV% (a)	16.12	2.16	0.76	0.14
CV% (b)	17.23	1.42	0.82	0.17

** - significant at 1 % level

ns - not significant

* - significant at 5 % level

CV - coefficient of variation

Means marked with the same letters within a column are not significantly different.

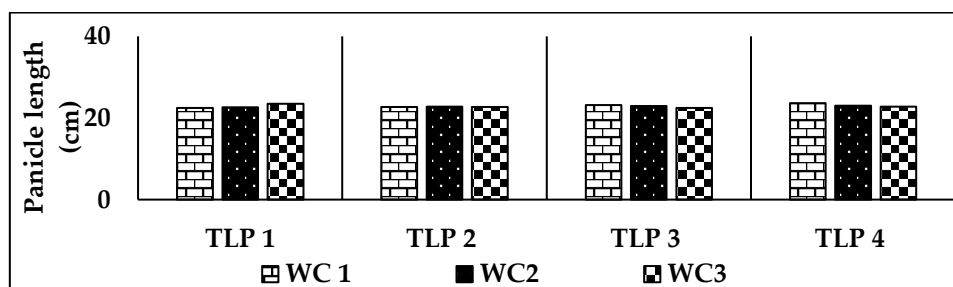


Figure 4. Interaction effect of time of land preparation (TLP) and weed control practices (WC) on the panicle length of the transplanted rice at 30 days after transplanting (DAT) in rainfed lowland rice ecosystems in Ilocos Norte, WS 2024.

TLP1- saturated plowing followed by harrowing and leveling (farmer's practice)

TLP2- single plowing 2 weeks before harrowing and final leveling

TLP3- single plowing 4 weeks before harrowing and final leveling

TLP4- twice plowing at 2-week intervals before harrowing and final leveling

WC1- Herbicide application Bispiribac Sodium (Nominee™) applied at 30 DAT

WC2- Hand weeding at 30 DAT

WC3- Application of herbicide at 30 DAT and hand weeding (spot weeding) at 40 DAT

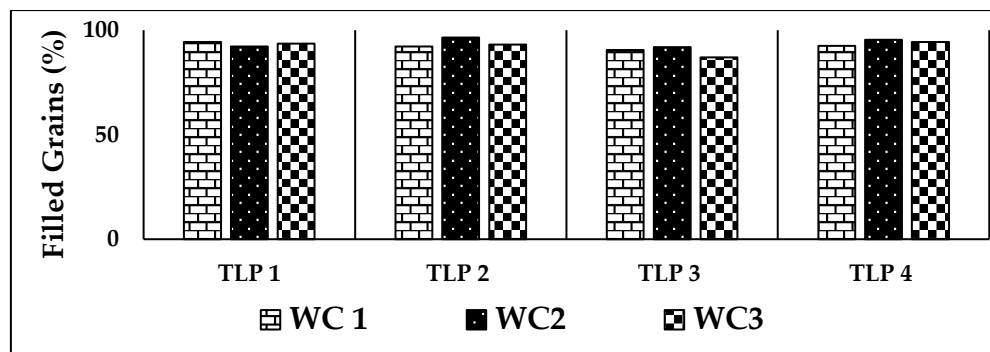


Figure 5. Interaction effect of time of land preparation (TLP) and weed control practices (WC) on the panicle length of the transplanted rice at 30 days after transplanting (DAT) in rainfed lowland rice ecosystems in Ilocos Norte, WS 2024.

TLP1- saturated plowing followed by harrowing and leveling (farmer's practice)

TLP2- single plowing 2 weeks before harrowing and final leveling

TLP3- single plowing 4 weeks before harrowing and final leveling

TLP4- twice plowing at 2-week intervals before harrowing and final leveling

WC1- Herbicide application Bispiribac Sodium (Nominee™) applied at 30 DAT

WC2- Hand weeding at 30 DAT

WC3- Application of herbicide at 30 DAT and hand weeding (spot weeding) at 40 DAT

3.4. Cost and Return Analysis

The economic analysis revealed that differences in profitability among treatments were driven more by variations in gross income than by production costs (Table 5). Production costs among TLP1, TLP2, and TLP3 were nearly similar because these treatments involved the same number of land preparation operations. In contrast, TLP4 incurred slightly higher production costs because it included an additional plowing operation before harrowing and final leveling. Similarly, differences among weed control treatments reflected the actual labor time and input costs incurred per plot and converted to a per-hectare basis. The integrated weed control treatment (WC3) had relatively higher production costs because of additional herbicide application and spot hand weeding operations. Among land preparation treatments, single plowing two weeks before harrowing (TLP 2) generated the highest net income (Php 68,070.79 ha⁻¹) and ROI (122%). This treatment achieved a favorable balance between moderate production cost and improved gross income, suggesting that earlier land preparation enhanced crop performance without requiring additional field operations. In contrast, twice plowing (TLP 4) incurred the highest production cost but resulted in only moderate net income and ROI, indicating diminishing economic returns from additional land preparation. Similar trends have been reported in rainfed rice systems, where excessive land preparation increases production costs without proportional gains in grain yield, reducing net income and economic efficiency compared with reduced tillage or simpler land preparation practices [32-33].

Weed control practices showed narrower differences in economic returns compared with land preparation. Hand weeding at 30 DAT (WC 2) produced the highest net income (Php 61,767.81 ha⁻¹) and ROI (111%), followed closely by herbicide application at 30 DAT (WC 1). Although integrated weed control (WC 3) improved weed suppression and crop growth in earlier analyses, its higher labor and input costs reduced overall profitability. This finding agrees with previous studies showing that the economic advantage of integrated weed management depends on labor availability and cost structure, particularly in rainfed systems, where herbicide-based integrated methods can reduce costly labor and improve profitability compared with purely manual approaches [34]; [35]. Overall, the results indicate that moderate land preparation combined

with timely, cost-efficient weed control maximized economic returns. These findings highlight the importance of evaluating agronomic benefits alongside economic performance when recommending management practices for rainfed lowland rice production.

Table 5. Summary of cost and return analysis per hectare of the different treatments in rainfed lowland ecosystems in Ilocos Norte, WS 2024.

TREATMENTS	Production Cost (PhP)	Gross Income (PhP)	Net Income (PhP)	ROI (%)
Timing of Land Preparation (TLP)				
TLP 1	55,941.54	110,178.89	54,237.35	97
TLP 2	55,733.20	123,803.99	68,070.79	122
TLP 3	55,733.20	112,929.67	57,196.47	103
TLP 4	60,441.54	120,536.00	60,094.46	99
Weed Control (WC)				
WC 1	56,914.48	117,977.34	61,062.86	107
WC 2	55,709.19	117,477.00	61,767.81	111
WC 3	58,263.44	115,132.08	56,868.64	98

4. Conclusions

The findings suggest that appropriate timing of land preparation combined with effective weed management practices can improve weed suppression, grain filling, and economic returns in rainfed lowland rice production. For practical field application, farmers under rainfed conditions may benefit from intensified land preparation combined with timely hand weeding or integrated weed management strategies to minimize weed competition during critical crop growth stages. Further studies conducted across multiple seasons and locations are recommended to validate the consistency of treatment responses under varying environmental and rainfall conditions. Additional research on labor efficiency, herbicide integration, and long-term weed population dynamics may also help improve sustainable weed management strategies for rainfed rice ecosystems.

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References

- [1] *The State of Food and Agriculture 2021*; Food and Agriculture Organization of the United Nations (FAO): Rome, 2021. <https://doi.org/10.4060/cb4476en>
- [2] Glauber, J. W.; Mamun, A. *Global Rice Market: Current Outlook and Future Prospects*. RePEc: Research Papers in Economics. <https://hdl.handle.net/10568/168523>

- [3] Department of Science and Technology-Food and Nutrition Research Institute (DOST-FNRI). *Philippine Nutrition Facts and Figures: 2021 Expanded National Nutrition Survey (ENNS): Food Consumption Survey*; DOST-FNRI: Taguig City, Metro Manila, Philippines, 2024.
- [4] Banayo, N. P. M. C.; Haefele, S. M.; Desamero, N. V.; Kato, Y. On-Farm Assessment of Site-Specific Nutrient Management for Rainfed Lowland Rice in the Philippines. *Field Crops Res.* **2017**, *220*, 88–96. <https://doi.org/10.1016/j.fcr.2017.09.011>
- [5] Hayashi, K.; Llorca, L. P.; Bugayong, I. D.; Agustiani, N.; Capistrano, A. O. V. Evaluating the Predictive Accuracy of the Weather-Rice-Nutrient Integrated Decision Support System (WeRise) to Improve Rainfed Rice Productivity in Southeast Asia. *Agriculture* **2021**, *11*(4), 346. <https://doi.org/10.3390/agriculture11040346>
- [6] Department of Agriculture-Philippine Rice Research Institute (DA-PhilRice); Korea Program on International Agriculture (KOPIA) Center-Philippines. *PalayCheck System-Based Rice Cultivation in the Philippines*; DA-PhilRice Headquarters: Maligaya, Science City of Muñoz, Nueva Ecija, Philippines, 2018.
- [7] Fahad, S.; Adnan, M.; Noor, M.; Arif, M.; Alam, M.; Khan, I. A.; Ullah, H.; Wahid, F.; Mian, I. A.; Jamal, Y.; Basir, A.; Hassan, S.; Saud, S.; Amanullah; Riaz, M.; Wu, C.; Khan, M. A.; Wang, D. Major Constraints for Global Rice Production. In *Advances in Rice Research for Abiotic Stress Tolerance*; Elsevier, 2019; pp 1–22. <https://doi.org/10.1016/B978-0-12-814332-2.00001-0>
- [8] Mir, M. S.; Singh, P.; Bhat, T. A.; Kanth, R. H.; Nazir, A.; Al-Ashkar, I.; Kamran, M.; Hadifa, A. A.; El Sabagh, A. Influence of Sowing Time and Weed Management Practices on the Performance and Weed Dynamics of Direct Drum Seeded Rice. *ACS Omega* **2023**, *8*(29), 25861–25876. <https://doi.org/10.1021/acsomega.3c01361>
- [9] Fukuda, M.; Imaizumi, T.; Koarai, A. Seed Germination Responses to Temperature and Water Availability in Weedy Rice. *Pest Manage. Sci.* **2023**, *79*(2), 870–880. <https://doi.org/10.1002/ps.7256>
- [10] Zhang, Z.; Wang, H.; Gu, T.; Cao, J.; Lou, Y.; Li, G. Propyrisulfuron plus Cyhalofop Butyl as One-Shot Herbicides Provide High Weed Control Efficiency and Net Economic Performance in Mechanically Transplanted Rice. *Front. Plant Sci.* **2023**, *14*, 1281931. <https://doi.org/10.3389/fpls.2023.1281931>
- [11] Baltazar, A. M. Herbicide-Resistant Weeds in the Philippines: Status and Resistance Mechanisms. *Weed Biol. Manage.* **2017**, *17*(2), 57–67. <https://doi.org/10.1111/wbm.12120>
- [12] Parven, A.; Meftaul, I. M.; Venkateswarlu, K.; Megharaj, M. Herbicides in Modern Sustainable Agriculture: Environmental Fate, Ecological Implications, and Human Health Concerns. *Int. J. Environ. Sci. Technol.* **2025**, *22*(2), 1181–1202. <https://doi.org/10.1007/s13762-024-05818-y>
- [13] Islam, A. K. M. M.; Nasir, M.; Akter Mou, M.; Yeasmin, S.; Islam, M. S.; Ahmed, S.; Anwar, M. P.; Hadifa, A.; Baazeem, A.; Iqbal, M. A.; Juraimi, A. S.; El Sabagh, A. Preliminary Reports on Comparative Weed Competitiveness of Bangladeshi Monsoon and Winter Rice Varieties under Puddled Transplanted Conditions. *Sustainability* **2021**, *13*(9), 5091. <https://doi.org/10.3390/su13095091>
- [14] Department of Agriculture-Philippine Rice Research Institute (DA-PhilRice). *Rice Competitiveness Enhancement Fund (RCEF) Facilitator's Guide*; DA-PhilRice: Science City of Muñoz, Nueva Ecija, Philippines, 2020. <https://ati2.da.gov.ph/ati-5/content/sites/default/files/users/user17/RCEF-FACILITATORS-GUIDE> (accessed February 1, 2026).
- [15] Shamina, C.; Singh, D. R.; Ramessh, C.; Pandian, S. P.; Renuka, R. Weed Seed Bank and Weed Population as Influenced by Weed Management Practices in Rice Var. Co 54. *J. Appl. Nat. Sci.* **2022**, *14*(3), 796–804. <https://doi.org/10.31018/jans.v14i3.3586>
- [16] Bhuiyan, M.; Salam, M.; Kabir, M. Integrated Weed Management Strategies for Sustainable Rice Production in Bangladesh. *Bangladesh Rice J.* **2021**, *24*(2), 133–159. <https://doi.org/10.3329/brj.v24i2.53454>
- [17] Yakadri, M.; Suvidh, M. S.; Vaishnav, S. A Review on Integrated Weed Management in Transplanted Rice. *Int. J. Plant Soil Sci.* **2022**, *34*(22), 238–247. <https://doi.org/10.9734/ijpss/2022/v34i2231374>
- [18] Rastogi, M.; Vivek; Dhyani, B. P.; Kumar, M.; Singh, A.; Verma, S. The Impact of Integrated Weed Management Practices on Nutrient Uptake in Rice (*Oryza sativa* L.). *J. Sci. Res. Rep.* **2024**, *30*(10), 169–176. <https://doi.org/10.9734/jsrr/2024/v30i102443>

- [19] Chauhan, B. S.; Johnson, D. E. Row Spacing and Weed Control Timing Affect Yield of Aerobic Rice. *Field Crops Res.* **2011**, 121 (2), 226–231. <https://doi.org/10.1016/j.fcr.2010.12.008>
- [20] Yuan, R.; Mao, Y.; Zhang, D.; Wang, S.; Zhang, H.; Wu, M.; Ye, M.; Zhang, Z. The Formation of Rice Tillers and Factors Influencing It. *Agronomy* **2024**, 14, 2904. <https://doi.org/10.3390/agronomy14122904>
- [21] Bansal, T.; Dhillon, B. S.; Kumar, V.; Sagwal, P.; Bhatia, D. Assessing Weed Competitive Abilities of Rice Genotypes in Direct-Seeded Rice Using Purple Rice as Model Weed. *Indian J. Weed Sci.* **2024**, 56(1), 73–79. <https://doi.org/10.5958/0974-8164.2024.00012.1>
- [22] Hirani, A. K.; Korav, S.; Rajanna, G. A.; Elansary, H. O.; Mahmoud, E. A. Determination of Critical Crop-Weed Competition Period: Impact on Growth, Nutrient Dynamics and Productivity of Green Gram (*Vigna radiata*). *Heliyon* **2024**, 10(17), e36855. <https://doi.org/10.1016/j.heliyon.2024.e36855>
- [23] Savić, A.; Popović, A.; Đurović, S.; Pisinov, B.; Ugrinović, M.; Todorović, M. J. A Framework for Understanding Crop-Weed Competition in Agroecosystems. *Agronomy* **2025**, 15(10), 2366. <https://doi.org/10.3390/agronomy15102366>
- [24] Singh, R.; Choudhary, S.; Mehta, R. S.; Aishwath, O. P.; Lal, G. Yield Losses Due to Weeds, Critical Period for Weed-Crop Competition in Fenugreek (*Trigonella foenum-graecum* L.). *Legume Res.* **2021**, No. LR-4369. <https://doi.org/10.18805/LR-4369>
- [25] Agustin, A. M. L.; Ordonio, J. L.; Natividad, M. B. S.; Lucob-Agustin, N. B.; Suralta, R. R.; Ehara, H.; Mitsuya, S.; Kano-Nakata, M. Specialty Rice (*Oryza sativa* L.) with High and Stable Grain Yield under Rainfed Lowland Conditions. *Agriculture* **2023**, 13(10), 1985. <https://doi.org/10.3390/agriculture13101985>
- [26] Awio, T.; Senthilkumar, K.; Dimkpa, C. O.; Otim-Nape, G. W.; Struik, P. C.; Stomph, T. J. Yields and Yield Gaps in Lowland Rice Systems and Options to Improve Smallholder Production. *Agronomy* **2022**, 12(3), 552. <https://doi.org/10.3390/agronomy12030552>
- [27] Ye, C.; Zheng, G.; Tao, Y.; Xu, Y.; Chu, G.; Xu, C.; Chen, S.; Liu, Y.; Zhang, X.; Wang, D. Effect of Soil Texture on Soil Nutrient Status and Rice Nutrient Absorption in Paddy Soils. *Agronomy* **2024**, 14, 1339. <https://doi.org/10.3390/agronomy14061339>
- [28] Emmanuel, K.; Aremu, A.; Raphael, A.; Samuel, D.; Jacob, B. The Effect of Weed Control Timing on the Growth and Yield of Upland Rice (*Oryza sativa* L.). *J. Agric. Sci. Belgrade* **2021**, 66(1), 27–38. <https://doi.org/10.2298/JAS2101027E>
- [29] Maimunah, M. A.; Kautsar, V.; Bimantara, P. O.; Kimani, S. M.; Torita, R.; Tawarayama, K.; Murayama, H.; Utami, S. N. H.; Purwanto, B. H.; Cheng, W. Weeding Frequencies Decreased Rice-Weed Competition and Increased Rice N Uptake in Organic Paddy Field. *Agronomy* **2021**, 11(10), 1904. <https://doi.org/10.3390/agronomy11101904>
- [30] Singh, M.; Kushwaha, M. Effect of Establishment Methods on Weed Management under Puddled Lowlands Rice (*Oryza sativa*). *Int. J. Res. Agron.* **2024**, 7(8), 314–316. <https://doi.org/10.33545/2618060X.2024.v7.i8e.1246>
- [31] Samoy-Pascual, K.; Bautista, E. G.; Valdez, H. V.; Gagelonia, E. C. Effect of Wetland Preparation Period on Weed Density and Grain Yield of Transplanted Lowland Rice. *Philipp. J. Crop Sci.* **2019**, 44(1), 44–50.
- [32] Manir, M. R.; Halder, K. P.; Rashid, M. M.; Begum, S.; Salauddin, A. K. M.; Hasan, K. Effect of Tillage Operation on the Productivity and Profitability of Rice Cultivation. *Asian J. Adv. Agric. Res.* **2025**, 25(7), 158–165. <https://doi.org/10.9734/ajaar/2025/v25i7655>
- [33] Marahatta, S.; Yadav, M.; Sah, S. K.; Regmi, A. P.; Bastola, S.; Timsina, J. Tillage and Residue Management Strategies Enhance Crop Yields, Soil Health, and Profitability in the Rice-Wheat System of Nepal's Western Terai. *Soil Secur.* **2026**, 22, 100216. <https://doi.org/10.1016/j.soisec.2025.100216>
- [34] Ahmed, S.; Kumar, V.; Alam, M.; Dewan, M. R.; Bhuiyan, K. A.; Miajy, A. A.; Saha, A.; Singh, S.; Timsina, J.; Krupnik, T. J. Integrated Weed Management in Transplanted Rice: Options for Addressing Labor Constraints and Improving Farmers' Income in Bangladesh. *Weed Technol.* **2021**, 35(5), 697–709. <https://doi.org/10.1017/wet.2021.50>
- [35] Kumar, G. A.; Shukla, R.; Jejal, A.; Dadhich, D. K.; Sm, M.; Ram, H.; Tv, V. Yield and Economic Performance of Herbicide-Based Integrated Weed Management in Lowland Transplanted Rice. *Int. J. Res. Agron.* **2025**, 8(12), 1217–1221. <https://doi.org/10.33545/2618060X.2025.v8.i12q.4565>