IJAAR PUBLISHING®

African Journal of Sustainable Agricultural Development | ISSN: 2714-4402
Vol. 7, Number 2 (2026) | www.ijaar.org/ajsad

EVALUATION OF WEED CONTROL METHODS ON UPLAND RICE *(Oryza* Sativa L) PRODUCTION IN KANO STATE

Audu S. D.[1], O.U. Onojah[2], I. S. Osu[3], Yusuf H. G[1], M. M. Liman[1], Muhammad Bashir[4], Aliyu Baba[1], N. Ibrahim[1] and Mijinyawa A.[5]

[1]National Cereal Research Institute Headquarters P.M.B 08 Bida, Niger State, Nigeria.

[2]Department of Crop Production Technology, School of Agronomy, Federal Polytechnic Ilaro Ogun State, Nigeria

[3]Department of Crop Production Technology, School of Agronomy and Environmental Management, College of Agriculture, Science and Technology, P.M.B 33 Lafia, Nasarawa State, Nigeria

[4]National Agricultural Development Fund (NADF), Bank of Agriculture Building, 162 Independence Avenue, Central Business District, Abuja.

[5]Department of Horticulture and Landscape Technology, School of Agronomy and Environmental Management, College of Agriculture, Science and Technology, P.M.B. 33, Lafia, Nasarawa State, Nigeria

Corresponding Author's Email: shuaibuibrahimosu@gmail.com, Tel. +234-9039125200

ABSTRACT

Field experiments were conducted during the 2024 cropping season at the Teaching and Research Farm of the Faculty of Agriculture, Bayero University, Kano (11°58′N, 8°25′E) and the National Institute for Horticultural Research (NIHORT), Bagauda Sub-station (11°33′N, 8°23′E), Kano State, Nigeria, to evaluate the effects of different weed control methods on weed suppression, growth, yield, and economic returns of upland rice (*Oryza sativa* L.). The experiment comprised seventeen weed management treatments arranged in a Randomized Complete Block Design (RCBD) with three replications. Treatments included pre-emergence application of pendimethalin at 1.0, 1.5 and 2.0 kg a.i. ha^{-1}; post-emergence application of propanil at 1.08 and 1.44 kg a.i. ha^{-1}; 2,4-D at 0.72 and 1.44 kg a.i. ha^{-1}; their sequential and tank-mixture combinations; supplementary hoe weeding; hoe weeding at 3 and 6 weeks after sowing (WAS); and a weedy check. The results revealed significant differences ($P < 0.05$) among the weed control treatments for weed cover, crop vigour, number of tillers, branches per panicle, panicle length, grains per panicle, grain yield, and economic returns at both locations. Hoe weeding at 3 and 6 WAS, pendimethalin at 1.0 and 1.5 kg a.i. ha^{-1} followed by supplementary hoe weeding at 6 WAS, pendimethalin at 1.5 kg a.i. ha^{-1} followed by propanil at 1.08 kg a.i. ha^{-1} or 2,4-D at 0.72 kg a.i. ha^{-1}, pendimethalin at 1.5 kg a.i. ha^{-1} alone, and the mixture of propanil + 2,4-D at 1.08 + 0.72 kg a.i. ha^{-1} consistently reduced weed infestation and significantly improved rice growth and yield compared with the weedy check. Hoe weeding at 3 and 6 WAS produced the highest grain yield of 2,445 and 2,650 kg ha^{-1} at

https://doi.org/10.46654/xg7bq252

Bayero University Kano and Bagauda, respectively. However, because of the high labour cost associated with manual weeding, the highest gross margins were obtained with the sequential application of pendimethalin at 1.5 kg a.i. ha^{-1} followed by propanil at 1.08 kg a.i. ha^{-1}, which recorded gross margins of ₦43,250 ha^{-1} and ₦48,400 ha^{-1} at Bayero University Kano and Bagauda, respectively. The weedy check produced the poorest crop growth, the lowest grain yield, and negative gross margins at both locations. Based on these findings, the sequential application of pendimethalin at 1.5 kg a.i. ha^{-1} followed by propanil at 1.08 kg a.i. ha^{-1} is recommended for effective, economical, and sustainable weed management in upland rice production in the Sudan Savanna zone of Nigeria.

Keywords: *Oryza sativa*, weed management, pendimethalin, propanil, 2,4-D, hoe weeding, grain yield, gross margin, upland rice, Sudan Savanna.

Introduction

1.1 Background to the Study

Rice (*Oryza sativa* L.) is one of the most important food crops in the world, providing the primary source of calories for more than half of the global population. It plays a critical role in ensuring food security, improving nutrition, generating employment, and supporting rural livelihoods, particularly in developing countries. Globally, rice consumption has continued to increase because of population growth, urbanization, and changing dietary preferences, thereby increasing the demand for sustainable rice production systems (Food and Agriculture Organization [FAO], 2024).

Nigeria is the largest producer and consumer of rice in Africa, with rice serving as one of the country's most important staple foods. Although domestic rice production has increased considerably over the past decade due to various government interventions, including the Anchor Borrowers' Programme and other agricultural development initiatives, national production remains below domestic demand. Consequently, Nigeria continues to supplement local production through rice importation, highlighting the need to improve productivity under existing production systems (FAO, 2024; United States Department of Agriculture [USDA], 2025).

Rice is cultivated under different agro-ecological systems, including irrigated, rainfed lowland, deep-water, flood-prone, and upland environments. Upland rice is predominantly grown under rainfed conditions on well-drained soils without standing water and accounts for a significant proportion of rice production in the savanna regions of Nigeria. Kano State possesses suitable climatic conditions, fertile soils, and an active farming population that supports upland rice cultivation. However, the productivity of upland rice remains relatively low compared with its genetic yield potential because of several production constraints, among which weed infestation is considered the most important biological factor limiting grain yield (Alagbo *et al.*, 2022).

Weeds are unwanted plants that compete directly with crops for light, moisture, nutrients, space, and carbon dioxide. In upland rice ecosystems, weeds emerge simultaneously with the crop and compete vigorously during the early stages of growth, thereby reducing crop establishment, tillering, biomass accumulation, grain filling, and final yield. Studies have shown that uncontrolled weeds can cause grain yield losses ranging from 50% to nearly

100% in upland rice, depending on weed density, species composition, and duration of competition (Rodenburg & Johnson, 2009; Alagbo *et al.,* 2022).

Several weed control methods are currently practiced by farmers, including manual weeding, mechanical cultivation, chemical weed control using herbicides, cultural practices, and integrated weed management. Manual weeding remains the dominant practice among smallholder farmers because it requires little capital investment and simple tools. However, it is labor-intensive, costly, and often delayed due to labor shortages during peak farming periods. Such delays expose rice plants to prolonged weed competition, resulting in significant reductions in growth and grain yield (Chauhan, 2022).

Chemical weed control through the use of herbicides offers rapid and effective weed suppression while reducing labor requirements and production costs. Nevertheless, excessive dependence on herbicides may lead to environmental pollution, herbicide-resistant weed populations, health hazards, and increased production costs when improperly applied. Consequently, researchers have advocated integrated weed management, which combines cultural, manual, mechanical, and chemical approaches to achieve effective weed suppression while minimizing environmental risks (Chauhan, 2022).

Despite the availability of different weed management strategies, many rice farmers in Kano State continue to experience substantial yield losses because of inadequate weed control practices, poor timing of weed management operations, and limited access to improved weed control technologies. Since the effectiveness of weed control methods depends on local weed flora, climatic conditions, soil characteristics, and farming practices, there is a need to evaluate the performance of different weed control methods under the agro-ecological conditions of Kano State. Such evaluation will provide scientific information for selecting the most efficient, economical, and sustainable weed management strategy for improving upland rice production.

1.2 Statement of the Problem

Rice production in Kano State has considerable potential to contribute to household food security, employment generation, and economic development. However, the productivity of upland rice remains low due to several agronomic constraints, among which weed infestation is one of the most serious. Weeds compete aggressively with rice plants for water, nutrients, sunlight, and space during the critical stages of crop growth, leading to poor crop establishment, reduced tillering, lower grain yield, and poor grain quality.

Although farmers employ different weed control methods such as manual weeding and herbicide application, these methods often produce inconsistent results because of poor application timing, inadequate knowledge of herbicide use, high labor costs, and differences in weed species composition. Manual weeding is increasingly constrained by labor scarcity and rising wage costs, while indiscriminate herbicide use poses environmental and health concerns and may encourage the development of herbicide-resistant weed species.

Furthermore, there is limited location-specific information comparing the effectiveness of different weed control methods under the environmental conditions of Kano State. Most available recommendations are generalized and may not adequately address the prevailing

weed flora, climatic conditions, and farming practices of the area. Consequently, many farmers continue to adopt weed management practices that may not be economically efficient or environmentally sustainable, resulting in low rice productivity and reduced farm income.

Therefore, there is a need to evaluate different weed control methods in upland rice production in Kano State in order to determine the most effective approach for suppressing weeds, improving crop growth, increasing grain yield, and enhancing the profitability of rice farming.

1.3 Justification of the Study

Improving rice productivity is essential for achieving food security and reducing Nigeria's dependence on imported rice. Since weed infestation remains one of the leading causes of yield loss in upland rice production, identifying effective and sustainable weed control methods is necessary for increasing crop productivity and farmers' income.

This study will generate scientific information on the comparative effectiveness of different weed control methods under the agro-ecological conditions of Kano State. The findings will assist farmers in selecting weed management practices that provide effective weed suppression while minimizing production costs and environmental risks.

The results will also be valuable to agricultural extension personnel by providing evidence-based recommendations that can be disseminated to rice farmers for improved crop management. Researchers and academic institutions will benefit from the findings through the provision of baseline information for future studies on weed management in upland rice production.

Furthermore, policymakers, development agencies, and agricultural programmed promoting rice production will benefit from the study by obtaining reliable information that can guide the formulation of policies and interventions aimed at improving rice productivity and enhancing national food security.

Ultimately, the adoption of effective weed control methods identified by this study is expected to increase grain yield, improve farm profitability, promote sustainable crop production, and contribute to the achievement of Nigeria's agricultural development goals.

1.4 Objectives of the Study

General Objective

The general objective of this study is to evaluate the effectiveness of different weed control methods on the growth and yield of upland rice (*Oryza sativa* L.) in Kano State.

Specific Objectives

The specific objectives of the study are to:

1. Evaluate the effect of different weed control methods on weed density and weed biomass in upland rice;

2. Determine the effect of different weed control methods on the vegetative growth of upland rice;
3. Assess the influence of different weed control methods on the yield and yield components of upland rice; and
4. Identify the most effective and economically viable weed control method for upland rice production in Kano State.

MATERIALS AND METHODS

3.1 Experimental Site

The field experiment was conducted during the 2024 rainy season at two locations in Kano State, Nigeria. The first experimental site was the Teaching and Research Farm of the Faculty of Agriculture, Bayero University, Kano (11°58′N, 8°25′E; 475 m above sea level), located within the Sudan Savanna agro-ecological zone. The second site was the National Institute for Horticultural Research (NIHORT), Bagauda Sub-station, Bebeji Local Government Area, Kano State (11°33′N, 8°23′E; 481 m above sea level). Both locations experience a tropical Sudan Savanna climate characterized by a unimodal rainfall pattern, with annual rainfall ranging from 600 to 900 mm and mean temperatures between 21°C and 39°C during the growing season.

3.2 Experimental Treatments

Seventeen weed control treatments were evaluated. These consisted of pre-emergence and post-emergence herbicides applied alone or in combination, herbicide treatments supplemented with hoe weeding, two manual hoe weedings, and a weedy check (untreated control).

The treatments were as follows:

Treatment	Rate (kg a.i. ha^{-1})	Time of Application
Pendimethalin	1.0	Pre-emergence
Pendimethalin	1.5	Pre-emergence
Pendimethalin	2.0	Pre-emergence
Propanil	1.08	Post-emergence
Propanil	1.44	Post-emergence
2,4-D	0.72	Post-emergence
2,4-D	1.44	Post-emergence
Propanil + 2,4-D	1.08 + 0.72	Post-emergence
Propanil + 2,4-D	1.44 + 1.44	Post-emergence
Pendimethalin fb Supplementary Hoe Weeding	1.0	Pre-emergence + 6 WAS
Pendimethalin fb Supplementary Hoe Weeding	1.5	Pre-emergence + 6 WAS
Pendimethalin fb Propanil	1.0 fb 1.44	Pre + post-emergence
Pendimethalin fb Propanil	1.5 fb 1.08	Pre + post-emergence
Pendimethalin fb 2,4-D	1.0 fb 1.44	Pre + post-emergence
Pendimethalin fb 2,4-D	1.5 fb 0.72	Pre + post-emergence
Hoe Weeding	3 and 6 WAS	Manual
Weedy Check	Untreated	Control

fb = followed by; WAS = Weeks After Sowing.

3.3 Experimental Design and Layout

The experiment was laid out in a Randomized Complete Block Design (RCBD) with three replications at each location.

Each gross plot measured 3 m × 2 m (6 m²), while the net plot measured 1 m × 1 m (1 m²). A spacing of 1 m was maintained between adjacent plots and 2 m between blocks to minimize treatment interference and facilitate field operations.

3.4 Rice Variety

The rice variety used was NERICA 1, an early-maturing upland rice variety adapted to the Sudan Savanna ecology. The seed was obtained from the International Institute of Tropical Agriculture (IITA), Kano Sub-station.

3.5 Field Establishment and Crop Management

The experimental field was manually cleared and ploughed before being harrowed and divided into experimental plots according to the layout. Rice seeds were treated with Apron Star® at the recommended rate of 10 g per 3 kg of seed before sowing to protect against seed-borne diseases and soil pests.

Seeds were sown by dibbling at a spacing of 20 cm × 20 cm and a depth of approximately 2 cm.

Pre-emergence herbicides were applied two days after sowing using a calibrated knapsack sprayer fitted with a flat-fan nozzle. Post-emergence herbicides were applied three weeks after sowing according to the treatment schedule. Supplementary hoe weeding was carried out six weeks after sowing, where applicable.

Fertilizer was applied at the rate of 80 kg N, 40 kg P_2O_5, and 40 kg K_2O per hectare using NPK (15:15:15) fertilizer and urea. Phosphorus, potassium, and part of the nitrogen were applied as basal fertilizer, while the remaining nitrogen was top-dressed at six weeks after sowing.

The crop was harvested manually at physiological maturity when the panicles turned brown and the grains attained full maturity. Harvested panicles were sun-dried, manually threshed, winnowed, and weighed to determine grain yield.

3.6 Data Collection

Data were collected to evaluate crop performance under the different weed management practices as follows:

Weed Cover Score

Weed cover was assessed to determine the extent of weed infestation in each plot at 8 weeks after sowing (WAS) and at harvest. Visual assessment was carried out using a rating scale of 0–10, where 0 indicated no weed cover and 10 indicated complete weed cover.

Crop Growth Assessment

Crop Vigour Score: Crop vigour was assessed visually at 8 WAS using a rating scale of 0–10, where 0 represented very weak and dying plants, while 10 represented healthy and vigorous plants. The assessment was based on the overall plant height and leaf colour.

Crop Tillering Ability: Five rice plants were randomly selected from each plot, and the number of tillers per plant was counted. The mean number of tillers per plant was calculated for each plot.

Yield Characters

Panicle Length: Panicle length was determined by measuring five randomly selected panicles from each plot using a meter rule. The average panicle length was calculated for each plot.

Number of Branches per Panicle: The number of branches on five randomly selected panicles from each plot was counted, and the mean number of branches per panicle was computed.

Number of Grains per Panicle: Five panicles were randomly selected from each plot, manually threshed, and the grains counted. The average number of grains per panicle was then calculated.

Grain Yield: Grain yield was determined by harvesting panicles from a 1 m × 1 m net plot. The harvested panicles were dried, threshed, and winnowed to separate the grains from the chaff. The grains were weighed, and the yield was converted to kilograms per hectare (kg ha^{-1}).

Economic Analysis

Economic analysis was conducted to determine the production cost, revenue, and gross margin associated with each treatment. The costs of herbicides and their application were recorded, while the cost of hoe weeding was estimated using the prevailing labor rates in the study area. The selling price of paddy rice was based on the prevailing market price in Kano at the time of harvest. Revenue was estimated from the grain yield of each treatment, and gross margin was calculated by subtracting the total production cost from the total revenue.

3.7 Statistical Analysis

All data collected were subjected to analysis of variance (ANOVA) appropriate for a Randomized Complete Block Design using the General Linear Model (GLM) procedure of Statistical Analysis System (SAS).

Treatment means were separated using Duncan's Multiple Range Test (DMRT) at the 5% level of probability ($P \leq 0.05$).

RESULTS AND DISCUSSION

RESULTS

4.1 Effect of Weed Control Methods on Weed Cover Score at 8 Weeks After Sowing (WAS) at BUK and Bagauda

The weed control methods significantly ($P < 0.05$) influenced weed cover score at 8 WAS at both BUK and Bagauda (Table 2). At BUK, the lowest weed cover scores were recorded in plots treated with Pendimethalin at 1.0 and 1.5 kg a.i. ha^{-1} followed by supplementary hoe weeding (SHW) at 6 WAS and in plots that received hoe weeding at 3 and 6 WAS. Pendimethalin applied alone at 2.0 kg a.i. ha^{-1} also produced a significantly lower weed cover score than the weedy check. However, Pendimethalin applied at 1.0 and 1.5 kg a.i. ha^{-1} alone, Propanil, 2,4-D, their combinations, and sequential herbicide applications did not differ significantly from one another. The weedy check consistently recorded the highest weed cover score.

Similarly, at Bagauda, plots treated with Pendimethalin at 1.0 and 1.5 kg a.i. ha^{-1} followed by supplementary hoe weeding at 6 WAS, as well as those subjected to hoe weeding at 3 and 6 WAS, produced significantly lower weed cover scores than the weedy check. No significant differences were observed among the remaining herbicide treatments, all of which recorded weed cover scores comparable to the weedy check.

Overall, integrating Pendimethalin with supplementary hoe weeding or adopting hoe weeding at 3 and 6 WAS provided more effective weed suppression than the sole application of herbicides, resulting in the lowest weed cover scores at both experimental locations.

Table 4.1. Effect of Weed Control Methods on Weed Cover Score at Eight Weeks After Sowing (8 WAS) at BUK and Bagauda

Treatments	Rate kg a.i. ha^{-1}	BUK 8 WAS	Bagauda 8 WAS
Pendimethalin	1.0	7.33ab	7.00a
Pendimethalin	1.5	6.33bcd	6.33a
Pendimethalin	2.0	5.33d	6.67a
Propanil	1.08	7.67ab	6.33a
Propanil	1.44	7.67ab	6.67a
2,4-D	0.72	7.33abc	7.00a
2,4-D	1.44	7.33abc	6.67a
Propanil + 2,4-D	1.08+0.72	7.00abc	6.00a
Propanil + 2,4-D	1.44+1.44	6.33bed	6.33a
Pendimethalin fb SHW	1.0 Fb SHW	4.33e	4.33b
Pendimethalin fb SHWF	1.5 Fb SHW	4.33e	3.00b
Pendimethalin fb propanil	1.0 Fb1.44	6.67bc	6.33a
Pendimethalin b propanil	1.5 Fb1.08	6.00cd	6.00a
Pendimethalin fb 2,4-D	1.0 Fb1.44	7.00abc	6.00a
Pendimethalin fb 2,4-D	1.5 Fb 0.72	6.00cd	6.33a
Hoe weeding	@ 3 and 6 WAS	4.33e	3.00b
Weedy check		8.33a	7.33a
LSD		**1.50**	**1.57**

LSD = Least Significant Difference. SHW = Supplementary hoe weeding; fb = followed by; WAS = Weeks after sowing. Means followed by the same letter(s) within the same column are not significantly different at the 5% probability level according to Duncan's New Multiple Range Test (DNMRT).

4.2 Effect of Weed Control Methods on Weed Cover Score at Harvest at BUK and Bagauda

Weed control methods significantly ($P < 0.05$) influenced weed cover score at harvest at both BUK and Bagauda (Table 4.2). At BUK, the lowest weed cover scores were recorded in plots treated with hoe weeding at 3 and 6 WAS, followed by Pendimethalin at 1.0 and 1.5 kg a.i. ha^{-1} each followed by supplementary hoe weeding (SHW) at 6 WAS. These treatments were statistically similar and produced significantly lower weed cover scores than the weedy check, which recorded the highest weed cover score. Sequential application of Pendimethalin at 1.5 kg a.i. ha^{-1} followed by Propanil at 1.08 kg a.i. ha^{-1} also reduced weed cover compared with the weedy check, although its effect was less pronounced than that of the integrated weed management treatments.

Similarly, at Bagauda, Pendimethalin applied at 1.5 kg a.i. ha^{-1} followed by supplementary hoe weeding at 6 WAS produced the lowest weed cover score and was statistically comparable with hoe weeding at 3 and 6 WAS and Pendimethalin at 1.0 kg a.i. ha^{-1} followed by supplementary hoe weeding. These treatments significantly suppressed weed cover compared with the weedy check. The remaining herbicide treatments produced intermediate weed cover scores and were generally more effective than the weedy check but less effective than the integrated weed management treatments.

Overall, integrating Pendimethalin with supplementary hoe weeding or adopting hoe weeding at 3 and 6 WAS provided superior season-long weed suppression at both locations, while the weedy check consistently recorded the highest weed cover score at harvest.

Table 4.2. Effect of Weed Control Methods on Weed Cover Score at Harvest for BUK and Bagauda

Treatments	Rate kg a.i. ha^{-1}	BUK	Bagauda
Pendimethalin	1.0	8.67ab	8.33ab
Pendimethalin	1.5	8.33abc	8.00bc
Pendimethalin	2.0	8.00abc	8.00Obc
Propanil	1.08	8.67ab	8.00bc
2,41)	0.72	8.67ab	8.33ab
2,4-D	1.44	8.33abc	8.00bc
Propanil + 2,4-D	1.08+0.72	8.00abc	7.67bc
Propanil + 2,4-D	1.08+0.72	8.00abc	7.67bc
Propanil +2,4-D	1.44+1.44	8.33abc	7.67bc
Pendimethalin fbSHW	1.0 Fb SHW	6.67de	6.67de
Pendimethalin fb SHW	1.5 Fb SHW	6.67de	5.67f
Pendimethalin fb propanil	1.0Fb1.44	8.00abc	7.67bc
Pendimethalin fb propanil	1.5 Fb1.08	7.33cde	7.6bc
Pendimethalin fb 2,4-D	1.0Fb1.44	8.00abc	7.33cd
Pendimethalin fb 2,4-D	1.5 Fb 0.72	7.67bcd	7.67bc
Hoe weeding	@ 3 and 6 WAS	6.33e	6.00ef
Weedy check		9.00a	9.00a
LSD		**1.23**	**0.99**

LSD = Least Significant Difference. SHW = Supplementary hoe weeding; fb = followed by; WAS = Weeks after sowing. Means followed by the same letter(s) within the same column are not significantly different at the 5% probability level according to Duncan's New Multiple Range Test (DNMRT)

4.3 Effect of Weed Control Methods on Crop Vigour Score at 8 Weeks After Sowing (WAS) at BUK and Bagauda

The crop vigour score at 8 weeks after sowing (WAS) was significantly ($P < 0.05$) influenced by the weed control methods at both BUK and Bagauda (Table 4.3).

At BUK, the highest crop vigour scores were recorded in plots treated with Pendimethalin at 1.5 kg a.i. ha^{-1} followed by supplementary hoe weeding (SHW) at 6 WAS and those subjected to hoe weeding at 3 and 6 WAS. These treatments were statistically similar and produced significantly higher crop vigour scores than the weedy check. Pendimethalin applied at 1.0 kg a.i. ha^{-1} followed by supplementary hoe weeding and Pendimethalin applied alone at 2.0 kg a.i. ha^{-1} also resulted in high crop vigour scores and were statistically comparable with the best-performing treatments. The remaining herbicide treatments produced intermediate crop vigour scores, while the weedy check recorded the lowest crop vigour score.

Similarly, at Bagauda, Pendimethalin applied at 1.5 kg a.i. ha^{-1} followed by supplementary hoe weeding produced the highest crop vigour score and was statistically comparable with Pendimethalin at 1.0 kg a.i. ha^{-1} followed by supplementary hoe weeding, hoe weeding at 3 and 6 WAS, and Pendimethalin at 1.5 kg a.i. ha^{-1} followed by Propanil at 1.08 kg a.i. ha^{-1}. Pendimethalin applied alone at 1.5 and 2.0 kg a.i. ha^{-1}, Propanil applied at 1.08 kg a.i. ha^{-1}, and the tank mixture of Propanil + 2,4-D at 1.08 + 0.72 kg a.i. ha^{-1} also produced significantly higher crop vigour scores than the weedy check. Although the remaining treatments produced intermediate crop vigour scores, they were generally superior to the untreated control, which consistently recorded the lowest crop vigour score.

Overall, integrated weed management involving Pendimethalin followed by supplementary hoe weeding and hoe weeding at 3 and 6 WAS enhanced crop vigour more effectively than the sole application of herbicides. In contrast, the weedy check consistently exhibited the poorest crop vigour at both experimental locations, highlighting the adverse effects of uncontrolled weed competition on rice growth.

Table 4.3. Effect of Weed Control Methods on Crop Vigor Score at 8 WAS for BUK and Bagauda

Treatments	Rate kg a.i. ha^{-1}	BUK 8WAS	Bagauda 8WAS
Pendimethalin	1.0	35.33c	6.00e
Pendimethalin	1.5	5.00c	7.00bcd
Pendimethalin	2.0	7.00ab	6.67cd
Propanil	1.08	5.33c	7.00bcd
Propanil	1.44	5.00c	6.00e
2,4-D	0.72	5.00c	6.33de
2,4-D	1.44	5.00c	5.00f
Propanil + 2,4-D	1.08+0.72	6.00bc	7.33bc
Propanil + 2,4-D	1.44+1.44	5.00c	5.00f
Pendimethalin Fb SHW	1.0 Fb SHW	7.00ab	7.67ab
Pendimethalin Fb SHW	1.5 Fb SHW	7.67a	8.33a
Pendimethalin Fb propanil	1.0 Fb1.44	5.67bc	7.00bcd
Pendimethalin Fb propanil	1.5 Fb1.08	6.00bc	7.67ab
Pendimethalin Fb 2,4-D	1.0 Fb1.44	5.00c	7.33bc
Penmethalin Fb 2,4-D	1.5 Fb 0.72	6.00bc	6.33de
Hoe weeding	@ 3 and 6 WAS	7.67a	7.67ab
Weedy check	Control	3.33d	4.00g
LSD		**1.43**	**0.92**

LSD = Least Significant Difference. SHW = Supplementary hoe weeding; fb = followed by; WAS = Weeks after sowing. Means followed by the same letter(s) within the same column are not significantly different at the 5% probability level according to Duncan's New Multiple Range Test (DNMRT)

4.4 Effect of Weed Control Methods on Number of Tillers per Stand at Harvest at BUK and Bagauda

The number of tillers per stand at harvest was significantly ($P < 0.05$) influenced by the weed control methods at both BUK and Bagauda (Table 4.4).

At both locations, hoe weeding at 3 and 6 WAS and Pendimethalin applied at 1.5 kg a.i. ha^{-1} followed by supplementary hoe weeding (SHW) at 6 WAS produced the highest number of tillers per stand and were statistically similar. These treatments significantly outperformed the weedy check. Pendimethalin applied at 1.0 kg a.i. ha^{-1} followed by supplementary hoe weeding, Pendimethalin at 1.0 and 1.5 kg a.i. ha^{-1} followed by Propanil, and Pendimethalin at 1.5 kg a.i. ha^{-1} followed by 2,4-D also produced significantly higher numbers of tillers per stand than the weedy check.

Similarly, the tank mixture of Propanil + 2,4-D applied at 1.08 + 0.72 kg a.i. ha^{-1} resulted in significantly higher tiller numbers than the untreated control at both locations. In contrast, the sole application of Pendimethalin, Propanil, and 2,4-D generally produced intermediate tiller numbers, with most of these treatments not differing significantly from one another.

The weedy check consistently recorded the lowest number of tillers per stand at both BUK and Bagauda, indicating that uncontrolled weed competition markedly suppressed tiller production. Overall, integrated weed management involving Pendimethalin followed by supplementary hoe weeding or sequential herbicide application, together with hoe weeding at 3 and 6 WAS, proved more effective in promoting tillering than the sole application of herbicides.

Table 4.4: Effect of Weed Control Methods on Number of Tillers per Stand at Harvest for BUK and Bagauda

Treatments	Rate kg a.i. ha^{-1}	BUK	Bagauda
Pendimethalin	1.0	8de	9d
Pendimethalin	1.5	9cd	9d
Pendimethalin	2.0	9cd	8d
Propanil	1.08	9cd	9d
Propanil	1.44	8de	9d
2,4-D)	0.72.	9cd	8d
2,4-D	1.44	7e	8d
Propanil + 2,4-D	1.08+0.72	10c	11c
Propanil + 2,4-D	1.44+1.44	7e	8d
Pendimethalin Fb SHW	1.0 Fb SHW	13ab	13ab
Pendimethalin Fb SHW	1.5 Fb SHW	14a	14a
Pendimethalin Fb propanil	1.0 Fb1.44	12ab	12bc
Pendimethalin Fb propanil	1.5Fb1.08	12ab	13ab
Pendimethalin Fb 2,4-D	1.0 Fb1.44	10c	11c
Penmethalin Fb 2,4-D	1.5 Fb 0.72	12ab	12bc
Hoe weeding	@ 3 and 6 WAS	14a	14a
Weedy check	Control	3f	4e
LSD		**1.2**	**1.2**

LSD = Least Significant Difference. SHW = Supplementary hoe weeding; fb = followed by; WAS = Weeks after sowing. Means followed by the same letter(s) within the same column are not significantly different at the 5% probability level according to Duncan's New Multiple Range Test (DNMRT)

4.5 Effect of Weed Control Methods on Number of Branches per Panicle at BUK and Bagauda

The number of branches per panicle was significantly ($P < 0.05$) influenced by the weed control methods at both BUK and Bagauda (Table 4.5).

At BUK, hoe weeding at 3 and 6 WAS produced the highest number of branches per panicle and was statistically comparable with Pendimethalin applied at 1.0 and 1.5 kg a.i. ha^{-1} followed by supplementary hoe weeding (SHW) at 6 WAS, Pendimethalin at 1.0 and 1.5 kg a.i. ha^{-1} followed by Propanil at 1.44 and 1.08 kg a.i. ha^{-1}, respectively, and Pendimethalin at 1.5 kg a.i. ha^{-1} followed by 2,4-D at 0.72 kg a.i. ha^{-1}. These treatments produced significantly higher numbers of branches per panicle than the weedy check. In addition, Pendimethalin applied alone at 1.5 kg a.i. ha^{-1} and the tank mixture of Propanil + 2,4-D at 1.08 + 0.72 kg a.i.

ha⁻¹ also resulted in significantly higher numbers of branches per panicle than the untreated control.

Similarly, at Bagauda, Pendimethalin applied at 1.5 kg a.i. ha⁻¹ followed by supplementary hoe weeding at 6 WAS produced the highest number of branches per panicle and was statistically similar to hoe weeding at 3 and 6 WAS. The tank mixture of Propanil + 2,4-D at both application rates, Pendimethalin followed by supplementary hoe weeding, Pendimethalin followed by Propanil, and Pendimethalin followed by 2,4-D generally produced intermediate to high numbers of branches per panicle, all of which were superior to the weedy check.

Across both locations, the weedy check consistently recorded the lowest number of branches per panicle, indicating that uncontrolled weed competition adversely affected panicle development. Overall, integrated weed management involving Pendimethalin followed by supplementary hoe weeding, together with hoe weeding at 3 and 6 WAS, proved to be the most effective treatments for enhancing panicle branching.

Table 4.5: Effect of Weed Control Methods on Number of Branches per Panicle for BUK and Bagauda.

Treatments	Rate kg a.i. ha^{-1}	BUK	Bagauda
Pendimethalin	1.0	8ed	9cd
Pendimethalin	1.5	9bc	9cd
Pendimethalin	2.0	8cd	8de
Propanil	1.08	7de	9cd
Propanil	1.44	8ed	9cd
2,4-D	0.72	8cd	9cd
2,4-D	1.44	7de	9cd
Propanil + 2,4-D	1.08+0.72	9bc	10bc
Propanil +2,4-D)	1.44+1.44	8cd	10bc
Pendimethalin Fb SHW	1.0 Fb SHW	10ab	10bc
Pendimethalin Fb SHW	1.5 Fb SHW	10ab	12a
Pendimethalin Fb propanil	1.0 Fb1.44	10ab	9cd
Pendimethalin Fb propanil	1.5 Fb1.08	10ab	10bc
Pendimethalin Fb 2,4-D	1.0 Fb1.44	8cd	9cd
Penmethalin Fb 2,4-D	1.5 Fb 0.72	10ab	10bc
Hoe weeding	@ 3 and 6 WAS	11a	11ab
Weedy check	Control	6e	7e
LSD		1.62	1.44

LSD = Least Significant Difference. SHW = Supplementary hoe weeding; fb = followed by; WAS = Weeks after sowing. Means followed by the same letter(s) within the same column are not significantly different at the 5% probability level according to Duncan's New Multiple Range Test (DNMRT)

4.6 Effect of Weed Control Methods on Panicle Length (cm) at BUK and Bagauda

The panicle length of rice was significantly ($P < 0.05$) influenced by the weed control methods at both BUK and Bagauda (Table 4.6).

At BUK, hoe weeding at 3 and 6 WAS, Pendimethalin applied at 1.0 and 1.5 kg a.i. ha^{-1} followed by supplementary hoe weeding (SHW) at 6 WAS, Pendimethalin applied alone at 1.0 kg a.i. ha^{-1}, Propanil at 1.08 kg a.i. ha^{-1}, and 2,4-D applied at 0.72 and 1.44 kg a.i. ha^{-1} produced statistically similar and significantly longer panicles than the weedy check. Pendimethalin applied at 1.5 kg a.i. ha^{-1} and the tank mixture of Propanil + 2,4-D at 1.08 + 0.72 kg a.i. ha^{-1} also resulted in relatively long panicles, although they did not differ significantly from most other herbicide treatments. In contrast, Pendimethalin applied at 2.0 kg a.i. ha^{-1}, Propanil at 1.44 kg a.i. ha^{-1}, Pendimethalin followed by 2,4-D, the tank mixture of Propanil + 2,4-D at 1.44 + 1.44 kg a.i. ha^{-1}, and the weedy check produced comparatively shorter panicles.

At Bagauda, Pendimethalin applied at 1.5 kg a.i. ha^{-1} followed by Propanil at 1.08 kg a.i. ha^{-1}, Pendimethalin applied at 1.5 kg a.i. ha^{-1} followed by 2,4-D at 0.72 kg a.i. ha^{-1}, and hoe weeding at 3 and 6 WAS produced the longest panicles and were statistically similar. Pendimethalin followed by supplementary hoe weeding and the tank mixture of Propanil + 2,4-D at 1.08 + 0.72 kg a.i. ha^{-1} also produced relatively long panicles. Although most of the remaining treatments did not differ significantly from one another, the tank mixture of Propanil + 2,4-D at 1.44 + 1.44 kg a.i. ha^{-1} and the weedy check recorded the shortest panicles.

Overall, integrated weed management practices involving Pendimethalin followed by supplementary hoe weeding or sequential application with post-emergence herbicides, together with hoe weeding at 3 and 6 WAS, enhanced panicle length compared with the untreated control. The consistently shorter panicles observed in the weedy check demonstrate the detrimental effect of unchecked weed competition on panicle development.

Table 4.6: Effect of Weed Control Methods on Panicle Length for BUK and Bagauda

Treatments	Rate kg a.i. ha^{-1}	BUK	Bagauda
Pendimethalin	1.0	10.00a	9.30e
Pendimethalín	1.5	9.33ab	10.00bcde
Pendimethalin	2.0	9.00b	10.00bcde
Propanil	1.08	9.50ab	9.8cde
Propanil	1.44	9.00b	9.30e
2,4-D	0.72	9.40ab	9.70cde
2,4-D	1.44	9.30ab	10.00bcde
Propanil + 2,4-D	1.08 + 0.72	9.70ab	10.40abcd
Propanil + 2,4-D	1.44+1.44	9.00b	8.00f
Pendimethalin Fb SHW	1.0 Fb SHW	10.00a	10.60abc
Pendimethalin Fb SHW	1.5 Fb SHW	10.00a	10.00bcde
Pendimethalin Fb propanil	1.0 Fb1.44	9.60ab	9.50e
Pendimethalin Fb propanil	1.5 Fb1.08	9.57ab	11.00a
Pendimethalin Fb 2,4-D	1.0 Fb1.44	9.00c	10.40abcd
Pendimethalin Fb 2,4-D	1.5 Fb 0.72	9.00b	11.00a
Hoe weeding	@3 and 6 WAS	10.00a	10.80a
Weedy check	Control	9.00b	8.30f
LSD		**0.83**	**0.93**

LSD = Least Significant Difference. SHW = Supplementary hoe weeding; fb = followed by; WAS = Weeks after sowing. Means followed by the same letter(s) within the same column are not significantly different at the 5% probability level according to Duncan's New Multiple Range Test (DNMRT)

4.7 Effect of Weed Control Methods on Number of Grains per Panicle at BUK and Bagauda

The number of grains per panicle was significantly ($P < 0.05$) influenced by the weed control methods at both BUK and Bagauda (Table 4.7).

At BUK, hoe weeding at 3 and 6 WAS produced the highest number of grains per panicle and was statistically comparable with Pendimethalin applied at 1.0 and 1.5 kg a.i. ha^{-1} followed by supplementary hoe weeding (SHW) at 6 WAS, as well as Pendimethalin applied at 1.0 and 1.5 kg a.i. ha^{-1} followed by Propanil at 1.44 and 1.08 kg a.i. ha^{-1}, respectively. These treatments produced significantly higher numbers of grains per panicle than the weedy check. Pendimethalin followed by 2,4-D at 0.72 kg a.i. ha^{-1} and the tank mixture of Propanil + 2,4-D at 1.08 + 0.72 kg a.i. ha^{-1} also improved the number of grains per panicle compared with the untreated control, although their effects were less pronounced than those of the best-performing treatments. The weedy check recorded the lowest number of grains per panicle, followed by plots treated with 2,4-D at 1.44 kg a.i. ha^{-1} and Propanil applied alone at 1.44 and 1.08 kg a.i. ha^{-1}.

Similarly, at Bagauda, hoe weeding at 3 and 6 WAS produced the highest number of grains per panicle and was statistically similar to Pendimethalin applied at 1.5 and 1.0 kg a.i. ha^{-1} followed by supplementary hoe weeding at 6 WAS, and Pendimethalin applied at 1.5 and 1.0 kg a.i. ha^{-1} followed by Propanil at 1.08 and 1.44 kg a.i. ha^{-1}, respectively. These treatments recorded significantly higher numbers of grains per panicle than the weedy check. Most of the remaining herbicide treatments produced intermediate values, whereas the untreated control consistently recorded the lowest number of grains per panicle.

Overall, integrated weed management practices involving Pendimethalin followed by supplementary hoe weeding or sequential application with Propanil, together with hoe weeding at 3 and 6 WAS, were the most effective in increasing the number of grains per panicle at both locations. The poor performance of the weedy check highlights the adverse effect of uncontrolled weed competition on grain formation and panicle productivity.

Table 4.7: Effect of Weed Control Methods on Number of Grains per Panicle for BUK and Bagauda

Treatments	Rate kg a.i. ha^{-1}	BUK	Bagauda
Pendimethalin	1.0	110c	109,3efg
Pendimethalin	1.5	120d	124cdef
Pendimethalin	2.0	105ef	110efg
Propanil	1.08	102f	111.3efg
Propanil	1.44	100fg	105fg
2,4-D	0.72	105ef	109efg
2,4-D)	1.44	96g	101fg
Propanil +2,4-D	1.08+0.72	120d	125cdef
Propanil + 2,4-D	1.44+1.44	110e	113defg
Pendimethalin Fb SHW	1.0 Fb SHW	135bc	139abc
Pendimethalin Fb SHW	1.5 Fb SHW	140b	149ab
Pendimethalin Fb propanil	1.0 Fb1.44	130c	137abc
Pendimethalin Fb propanil	1.5 Fb1.08	130c	139abc
Pendimethalin Fb 2,4-D	1.0 Fb1.44	110e	117cdef
Pendimethalin Fb 2,4-D	1.5 Fb 0.72	120d	128bcde
Hoe weeding	@3 and 6 WAS	150a	157a
Weedy check	Control	85h	93g
LSD		**5.39**	**22.92**

LSD = Least Significant Difference. SHW = Supplementary hoe weeding; fb = followed by; WAS = Weeks after sowing. Means followed by the same letter(s) within the same column are not significantly different at the 5% probability level according to Duncan's New Multiple Range Test (DNMRT)

4.8 Effect of Weed Control Methods on Grain Yield (kg ha^{-1}) at BUK and Bagauda

Grain yield was significantly ($P < 0.05$) affected by the weed control methods at both BUK and Bagauda (Table 4.8).

At both locations, hoe weeding at 3 and 6 WAS produced the highest grain yield and was statistically comparable with Pendimethalin applied at 1.5 and 1.0 kg a.i. ha^{-1} followed by supplementary hoe weeding (SHW) at 6 WAS. These treatments consistently outperformed the untreated control, demonstrating the effectiveness of integrating chemical and manual weed control in improving rice productivity.

At BUK, Pendimethalin applied at 1.5 kg a.i. ha^{-1} alone, the tank mixture of Propanil + 2,4-D at 1.08 + 0.72 kg a.i. ha^{-1}, Pendimethalin applied at 1.5 kg a.i. ha^{-1} followed by Propanil at 1.08 kg a.i. ha^{-1}, and Pendimethalin applied at 1.5 kg a.i. ha^{-1} followed by 2,4-D at 0.72 kg a.i. ha^{-1} also produced significantly higher grain yields than the weedy check. Likewise, Pendimethalin applied at 1.0 kg a.i. ha^{-1} followed by Propanil at 1.44 kg a.i. ha^{-1} resulted in a marked improvement in grain yield over the untreated control.

A similar trend was observed at Bagauda, where integrated weed management treatments involving Pendimethalin followed by supplementary hoe weeding, Propanil, or 2,4-D produced significantly higher grain yields than the weedy check. The tank mixture of Propanil + 2,4-D at 1.08 + 0.72 kg a.i. ha^{-1} also performed well and was among the higher-yielding treatments. In contrast, the sole application of Propanil, 2,4-D, or Pendimethalin at lower rates generally resulted in intermediate grain yields.

The weedy check consistently recorded the lowest grain yield at both locations, indicating severe yield losses due to uncontrolled weed competition. Overall, integrated weed management practices, particularly Pendimethalin followed by supplementary hoe weeding and hoe weeding at 3 and 6 WAS, were the most effective in maximizing grain yield under the conditions of this study.

Table 4.8: Effect of Weed Control Methods on Grain Yield (kg ha^{-1}) per hectare for BUK and Bagauda.

Treatments	Rate kg a.i. ha^{-1}	BUK	Bagauda
Pendimethalin	1.0	1,390fgh	1,800h
Pendimethalin	1.5	2,150ab	2,280cde
Pendimethalin	2.0	1,400fgh	1,800h
Propanil	1.08	1,650def	1,900gh
Propanil	1.44	1,500ef	1,520i
2,4-D	0.72	1,480efg	1,850h
2,4-D	1.44	1,300gh	1,315k
Propanil + 2,4-D	1.08+0.72	2,150ab	2,230def
Propanil + 2,4-D	1.44+1.44	1,400fgh	1,380j
Pendimethalin fb SHW	1.0 Fb SHW	2,350ab	2,48Obc
Pendimethalin fb SHW	1.5 Fb SHW	2,400ab	2,560ab
Pendimethalin fb propanil	1.0 Fb1.44	2,050bc	2,100efg
Pendimethalin fb propanil	1.5 Fb1.08	2,280ab	2,450bed
Pendimethalin fb 2,4-D	1.0 Fb1.44	1,830cd	2,000fgh
Pendimethalin fb 2,4-D	1.5 Fb 0.72	2,220ab	2,380cd
Hoe weeding	@3 and 6 WAS	2,445a	2,650a
Weedy check	Control	500i	6801
LSD		**42.82**	**23.74**

LSD = Least Significant Difference. SHW = Supplementary hoe weeding; fb = followed by; WAS = Weeks after sowing. Means followed by the same letter(s) within the same column are not significantly different at the 5% probability level according to Duncan's New Multiple Range Test (DNMRT)

4.9 Effect of Weed Control Methods on Production Cost, Revenue and Gross Margin at BUK and Bagauda

The weed control methods significantly ($P < 0.05$) influenced production cost, revenue, and gross margin at both BUK and Bagauda (Tables 4.9 and 4.10).

At both locations, hoe weeding at 3 and 6 WAS incurred the highest production cost because of the labour required for manual weed control. Despite the high cost, this treatment generated the highest revenue owing to its superior grain yield. However, it did not produce the highest gross margin, indicating that the increased labour cost reduced its overall economic advantage.

Among the herbicide-based treatments, Pendimethalin applied at 1.5 kg a.i. ha^{-1} followed by Propanil at 1.08 kg a.i. ha^{-1} produced the highest gross margin at both BUK (₦43,250 ha^{-1}) and Bagauda (₦48,400 ha^{-1}). This treatment combined relatively moderate production costs with high grain yield, making it the most economically rewarding weed management option. Pendimethalin applied at 1.5 kg a.i. ha^{-1} followed by 2,4-D at 0.72 kg a.i. ha^{-1}, Pendimethalin at 1.5 kg a.i. ha^{-1} followed by supplementary hoe weeding (SHW), Pendimethalin at 1.0 kg a.i. ha^{-1} followed by SHW, and the tank mixture of Propanil + 2,4-D (1.08 + 0.72 kg a.i. ha^{-1})

also produced high revenues and gross margins, demonstrating the economic benefits of integrated weed management.

In contrast, the sole application of Pendimethalin, Propanil, or 2,4-D generally produced lower revenues and gross margins than the integrated treatments. The application of 2,4-D at 1.44 kg a.i. ha^{-1} and the tank mixture of Propanil + 2,4-D at 1.44 + 1.44 kg a.i. ha^{-1} were among the least profitable herbicide treatments because of their relatively low grain yields.

The weedy check consistently recorded the lowest revenue and resulted in negative gross margins at both BUK (–₦29,500 ha^{-1}) and Bagauda (–₦23,900 ha^{-1}), indicating that the income generated from grain yield was insufficient to offset the production costs. This finding demonstrates the severe economic losses associated with uncontrolled weed infestation.

Overall, integrated weed management strategies involving Pendimethalin followed by Propanil, supplementary hoe weeding, or 2,4-D were economically superior to the sole application of herbicides. Although hoe weeding alone achieved the highest grain yield and revenue, the greater labour cost reduced its profitability. Consequently, Pendimethalin applied at 1.5 kg a.i. ha^{-1} followed by Propanil at 1.08 kg a.i. ha^{-1} emerged as the most profitable weed control option under the conditions of this study.

Table 4.9: Effect of Weed Control Methods on the Production Cost, Revenue and Margin for BUK

Treatments	Rate (Kga.i. ha^{-1})	Production Cost (₦ha^{-1})	Revenue (₦ha^{-1})	Margin (₦ha^{-1})
Pendimethalin	1.0	55,150m	62,550m	7,400n
Pendimethalin	1.5	56,350j	96,750f	40,400f
Pendimethalin	2.0	57,550g	63,0001	5,450o
Propanil	1.08	55,000n	74,250i	19,250j
Propanil	1.44	55,750k	67,500j	11,7501
2,4-D	0.72	53,450p	66,600k	13,150k
2,4-D	1.44	54,150o	58,500n	4,350p
Propanil + 2,4-D	1.08+0.72	55,7001	96,750f	41,050d
Propanil + 2,4-D	1.44+1.44	57,150i	63,0001	9,450m
Pendimethalin Fb SHW	1.0 Fb SHW	65,150c	105,750c	40,600e
Pendimethalin	1.0	55,150m	62,550m	7,400n
Pendimethalin Fb SHW	1.5 Fb SHW	66,350b	108,000b	41,650b
Pendimethalin Fb propanil	1.0 Fb1.44	58,700e	92,250g	33,550h
Pendimethalin Fb propanil	1.5 Fb1.08	59,350d	102,600d	43,250a
Pendimethalin Fb 2,4-D	1.0 Fb1.44	57,300h	81,000h	23,700i
Pendimethalin Fb 2,4-D	1.5 Fb 0.72	57,800f	99,000e	41,200c
Hoe weeding	@3 and 6 WAS	72,000a	110,025a	38,025g
Weedy check	Control	52,000q	22,500o	-29,500p

LSD = Least Significant Difference. SHW = Supplementary hoe weeding; fb = followed by; WAS = Weeks after sowing. Means followed by the same letter(s) within the same column are not significantly different at the 5% probability level according to Duncan's New Multiple Range Test (DNMRT). Price of paddy rice for100 kg at harvest = N4, 500.

Table 4.10: Effect of Weed Control Methods on the Production Cost, Revenue and Margin for Bagauda

Treatments	Rate (kga.i. ha^{-1})	Production Cost (Nha^{-1})	Revenue (Nha^{-1})	Margin (Nha^{-1})
Pendimethalin	1.0	57,650m	81,0001	23,3501
Pendimethalin	1.5	58,850k	102,600f	43,750d
Pendimethalin	2.0	60,050g	81,0001	20,950m
Propanil	1.08	57,500n	85,500j	28,000j
Propanil	1.44	58,250k	68,400m	10,150n
2,4-D	0.72	55,950p	83,250k	27,300k
2,4-D	1.44	56,650c	59,150o	2,525p
Propanil + 2,4-D	1.08+0.72	58,2001	100,350g	42,050e
Propanil + 2,4-D	1.44+1.44	59,650i	62,100n	2,450o
Pendimethalin Fb SHW	1.0 Fb SHW	70,150c	111,600c	41,450f
Pendimethalin Fb SHW	1.5 Fb SHW	71,350b	115,200b	43,850c
Pendimethalin Fb propanil	1.0 Fb1.44	61,400e	94,500h	33,100h
Pendimethalin Fb propanil	1.5 Fb1.08	61,850d	110,250d	48,400a
Pendimethalin Fb 2,4-D	1.0 Fb1.44	59,800h	90,000i	30,200i
Pendimethalin Fb 2,4-D	1.5 Fb 0.72	60,300f	107,100e	46,800b
Hoe weeding	@3 and 6 WAS	79,500a	119,250a	39,750g
Weedy check	Control	54,500q	30,600p	-23,900q

LSD = Least Significant Difference. SHW = Supplementary hoe weeding; fb = followed by; WAS = Weeks after sowing. Means followed by the same letter(s) within the same column are not significantly different at the 5% probability level according to Duncan's New Multiple Range Test (DNMRT). Price of paddy rice per100 kg at harvest = N4,500.

Discussion

Weed Cover Score

Integrated weed management involving hoe weeding at 3 and 6 WAS and Pendimethalin (1.0 or 1.5 kg a.i. ha^{-1}) followed by supplementary hoe weeding at 6 WAS provided the most effective weed suppression at both locations. The reduced weed cover was attributed to timely weed control, which minimized weed competition throughout the crop growth period. This finding agrees with Stauber et al. (1991), who reported that Pendimethalin-based weed management achieved 90–95% control of major rice weeds.

Crop Vigour Score

Higher crop vigour was recorded in plots treated with Pendimethalin followed by supplementary hoe weeding, as well as hoe weeding alone, due to effective weed suppression and reduced crop injury. Similarly, Propanil alone and in combination with 2,4-D improved crop vigour through effective post-emergence weed control. These results are consistent with Rhodes and Hayes (1995), Smith (1974), and Akobundu (1987), who reported improved rice growth following effective herbicide application.

Number of Tillers per Stand

Treatments involving hoe weeding at 3 and 6 WAS and Pendimethalin followed by supplementary hoe weeding produced the highest number of tillers per stand. Increased tillering was attributed to reduced competition for moisture, nutrients, and light during the critical growth stages. These findings agree with Ahmed and Moody (1980), Akobundu and Ahissou (1984), Brown et al. (1987), and Street et al. (1983), who reported that integrated weed management promotes tiller development and overall crop performance.

Number of Branches per Panicle

Integrated weed management significantly increased the number of branches per panicle compared with the weedy check. The improved branching resulted from effective weed control, which enhanced nutrient availability and crop growth. This observation agrees with the reports of Okafor (1986), FAO (1994), and Akobundu (1987), who associated effective weed control with improved yield components.

Panicle Length

Longer panicles were obtained in plots receiving hoe weeding or integrated Pendimethalin-based weed control, whereas the weedy check produced the shortest panicles due to severe weed interference. This agrees with the findings of Sharma et al. (1977), De Datta (1980), and Oudhia (2004), who reported that uncontrolled weeds adversely affect panicle development and rice productivity.

Number of Grains per Panicle

The highest numbers of grains per panicle were produced by hoe weeding and Pendimethalin integrated with supplementary hoe weeding or Propanil. Improved grain production was attributed to effective weed suppression, which enhanced crop growth and assimilate partitioning. These results corroborate the findings of Stauber et al. (1991), who reported that integrated herbicide application provides excellent weed control without causing crop injury.

Grain Yield

Hoe weeding at 3 and 6 WAS and Pendimethalin followed by supplementary hoe weeding produced the highest grain yields at both locations. Other integrated herbicide treatments also significantly improved grain yield compared with the weedy check. The higher yields resulted from effective weed control during the critical period of crop growth, while

uncontrolled weeds caused substantial yield losses. These findings are consistent with Ndahi (1986) and Akobundu (1987), who reported that integrated weed management improves rice yield and minimizes yield losses caused by weed competition.

Gross Margin

Although hoe weeding generated the highest grain yield and revenue, it also incurred the highest production cost because of labor requirements. In contrast, Pendimethalin applied at 1.5 kg a.i. ha^{-1} followed by Propanil at 1.08 kg a.i. ha^{-1} produced the highest gross margin by combining effective weed control with lower production costs. This finding agrees with Srinivason and Pothiraj (1989), Ikuenobi et al. (2005), Aliyu and Lagoke (2000), and Muhd and Muhd (1988), who reported that herbicide-based weed management reduces labour costs and improves farm profitability.

SUMMARY, CONCLUSION, AND RECOMMENDATIONS

5.1 Summary

Field experiments were conducted during the 2024 cropping season at two locations: the Teaching and Research Farm of the Faculty of Agriculture, Bayero University, Kano (11°58′N, 8°25′E; 475 m above sea level), located within the Sudan Savanna agro-ecological zone of Nigeria, and the National Institute for Horticultural Research (NIHORT), Bagauda Sub-station, Bebeji Local Government Area, Kano State (11°33′N, 8°23′E; 481 m above sea level). The study evaluated the performance of upland rice (*Oryza sativa* L.) under different weed management strategies.

The results obtained at both locations showed that weed management practices significantly influenced weed infestation, crop growth, yield components, grain yield, and economic returns. Hoe weeding at 3 and 6 weeks after sowing (WAS), pre-emergence application of Pendimethalin at 1.0 and 1.5 kg a.i. ha^{-1} followed by supplementary hoe weeding, Pendimethalin applied alone at 1.5 kg a.i. ha^{-1}, the tank mixture of Propanil + 2,4-D (1.08 + 0.72 kg a.i. ha^{-1}), and Pendimethalin at 1.5 kg a.i. ha^{-1} followed by either Propanil at 1.08 kg a.i. ha^{-1} or 2,4-D at 0.72 kg a.i. ha^{-1} produced superior crop vigour, higher tiller production, improved yield components, and higher grain yield than the other treatments.

The weedy check consistently recorded the highest weed cover score and the lowest values for growth, yield components, grain yield, and economic returns at both locations, demonstrating the adverse effects of uncontrolled weed infestation on rice productivity.

Economic analysis revealed that although hoe weeding produced the highest grain yield and revenue, its high labour cost reduced the gross margin. In contrast, integrated herbicide treatments, particularly Pendimethalin at 1.5 kg a.i. ha^{-1} followed by Propanil at 1.08 kg a.i. ha^{-1}, generated the highest gross margin because they combined effective weed control with lower production costs.

5.2 Conclusion

Based on the findings of this study, it can be concluded that weed management strategy significantly influences weed suppression, crop growth, grain yield, and profitability in upland rice production.

Integrated weed management involving the pre-emergence application of Pendimethalin at 1.5 kg a.i. ha^{-1} followed by post-emergence application of Propanil at 1.08 kg a.i. ha^{-1} or 2,4-D at 0.72 kg a.i. ha^{-1}, as well as the tank mixture of Propanil + 2,4-D (1.08 + 0.72 kg a.i. ha^{-1}), effectively controlled weeds and produced high grain yields with superior economic returns. Likewise, Pendimethalin at 1.5 kg a.i. ha^{-1} followed by supplementary hoe weeding and hoe weeding at 3 and 6 WAS also resulted in high grain yields.

Although hoe weeding produced the highest grain yield, its relatively high labour cost reduced profitability. Conversely, chemical weed control, particularly Pendimethalin followed by Propanil, provided the highest gross margin, making it the most economically efficient weed management option for upland rice production.

5.3 Recommendations

Based on the results of this study, the pre-emergence application of Pendimethalin at 1.5 kg a.i. ha^{-1} followed by post-emergence application of Propanil at 1.08 kg a.i. ha^{-1} is recommended for effective and economical weed management in upland rice production. This treatment provided excellent weed control, high grain yield, and the highest gross margin, making it the most profitable weed management strategy among those evaluated.

Where herbicides are not readily available or where farmers prefer integrated weed management, the application of Pendimethalin at 1.5 kg a.i. ha^{-1} followed by supplementary hoe weeding at 6 WAS is also recommended as an effective alternative for achieving high grain yield and satisfactory economic returns.

REFERNCES

Ahmed, M. K., & Moody, K. (1980). *Weed control in rice*. International Rice Research Institute.

Akobundu, I. O. (1987). *Weed Science in the Tropics: Principles and Practices*. John Wiley & Sons.

Akobundu, I. O., & Ahissou, A. (1984). Effects of weed control methods on rice growth andyield. *Tropical Pest Management*, 30(3), 214–219.

Alagbo, O. O., Akinyemiju, O. A., & Chauhan, B. S. (2022). Weed management in rainfed upland rice fields under varied agro-ecologies in Nigeria. *Rice Science, 29*(4), 328–339. https://doi.org/**10.1016/j.rsci.2021.11.004

Aliyu, L., &Lagoke, S. T. O. (2000). Economic evaluation of herbicide use in rice production in Nigeria. *Nigerian Journal of Weed Science*, 13, 45–52.

Brown, H. M., Chandler, J. M., & McCauley, G. N. (1987). Performance of Pendimethalin in rice weed management. *Weed Technology*, 1(4), 317–321.

Chauhan, B. S. (2022). *Weed management in rice*. CAB International.

De Datta, S. K. (1980). *Principles and Practices of Rice Production*. John Wiley & Sons.

Food and Agriculture Organization (FAO). (1994). *Rice Production Manual*. Food and Agriculture Organization of the United Nations.

Food and Agriculture Organization. (2024). *The state of food and agriculture 2024*. FAO.

Ikuenobi, C. S., Udensi, E. U., &Chikoye, D. (2005). Economic benefits of herbicide use in rice production. *Nigerian Journal of Weed Science*, 18, 35–42.

Ndahi, W. B. (1986). Integrated weed management for improved rice production. *Nigerian Journal of Weed Science,* 1, 29–36.

Okafor, L. I. (1986). Evaluation of post-emergence herbicides for weed control in rice. *Nigerian Journal of Weed Science*, 1, 21–28.

Oudhia, P. (2004). *Weed management in rice*. Scientific Publishers.

Rhodes, G. N., & Hayes, R. M. (1995). Evaluation of Pendimethalin for weed control in rice. *Weed Technology*, 9(3), 520–525.

Rodenburg, J., & Johnson, D. E. (2009). Weed management in rice-based cropping systems in Africa. In *Realizing Africa's Rice Promise* (pp. 157–173). CABI.

Sharma, A. R., Singh, V. P., & Singh, C. M. (1977). Weed competition effects on rice growth and yield. *Indian Journal of Agronomy*, 22(3), 227–231.

Smith, R. J. (1974). Weed control in rice with Propanil. *Weed Science*, 22(3), 250–254.

Srinivason, K., &Pothiraj, P. (1989). Comparative economics of hand weeding and herbicide use in transplanted rice. *International Rice Research Newsletter*, 14(2), 26–27.

Stauber, M. S., Chandler, J. M., & McCauley, G. N. (1991). Evaluation of Pendimethalin and post-emergence herbicides for weed control in rice. *Weed Technology*, 5(4), 735–740.

Street, J. E., Snipes, C. E., & Buchanan, G. A. (1983). Control of barnyard grass and sprangletop with Pendimethalin and Propanil combinations in rice. *Weed Science*, 31(3), 331–336.

United States Department of Agriculture. (2025). *Nigeria grain and feed annual report*. USDA Foreign Agricultural Service.