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Influence of Organic Substrates and Weeding on Weeds and Rice Production in Lowland Rice Cultivation in Western Burkina Faso

Issiaka Sere[1]*, Adama Sanou[2], Siébou Pale[2], Drissa Coulibaly[2], P.V. Vara Prasad[3], B. Jan Middendorf[3], Edmond Hien[1], Hamidou Traore[2]

[1]Soils, Materials, and Environment Laboratory, UFR Life and Earth Sciences, University Joseph Ki-Zerbo, Ouagadougou, Burkina Faso
[2]Institute for the Environment and Agricultural Research, Ouagadougou, Burkina Faso
[3]Feed the Future Innovation Lab for Collaborative Research on Sustainable Intensification, Kansas State University, Manhattan, KS, USA
Email: *sereissiaka23@gmail.com

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Abstract

Weeds have a significant impact on yields in lowland rice cultivation, hence the need to implement effective management methods. The objectives of this study were to evaluate the effect of organic substrate types and weeding methods on weed management. Four types of fertilization as the main factor and four weeding methods as the secondary factor were tested using a split-plot design. The results showed the highest dry biomass with biochar and rotary hoe weeding (1.86 g/0.5m^2), biochar and chemical weeding (12.01 g/0.5m^2), and biochar and rotary hoe weeding (10.10 g/0.5m^2). In terms of pH, the most acidic levels were recorded for chemical weed control treatments. The highest nitrogen content was recorded for biochar with chemical weed control (0.11%). In terms of total phosphorus, the highest content was recorded for biochar with rotary hoe weeding (256.56 mg/kg), while the highest assimilable phosphorus content was obtained for biochar with chemical weeding (27.59 mg/kg). The highest total and assimilable potassium contents were obtained with biochar without weeding (1484.31 mg/kg) and chemical weeding with biochar (74.32 mg/kg). The highest yields were obtained with manual weeding combined with compost (3208.89 kg/ha). Phytosociological analysis identified six plant groups characteristic of weeding methods and types of fertilization. However, only two are significantly dependent on weeds. The *Cyperus diformis* L. group, consisting of three indicator species, namely *Cynodon dactylon* (L.) Pers, *Cyperus diformis* L., and *Passiflora foetida* L., is characterized by the influence of rotary hoe weeding (100%), biochar (50%), and compost (50%). The *Ammannia Pri-*

eureana group consists of three indicator species, *Ammannia Prieureana* Guill., *Bacopa floribunda* (R.Br.) Wettst. and *Cyperus diformis* L., and is characterized by the influence of manual weeding (100%), compost (30%), and chemical fertilizer (30%), as well as sugarcane bagasse (20%) and biochar (20%). In light of these results, it should be noted that fertilization is only effective when accompanied by a good weed management method.

Keywords

Weeding, Organic Substrates, Weeds, Rice Cultivation

1. Introduction

Rice is one of the most important cereals in the world. It is the staple food for more than half of the world's population [1]. In Burkina Faso, rice ranks fourth in terms of both cultivated area and production volume [2]. It is a strategic crop due to its importance in the economy and its role in food security. Its consumption is constantly increasing, while national production barely covers 53% of the population's needs [3]. Production continues to face several biotic and abiotic constraints, including drought, low technical skills among producers, weeds, etc. Weeds are the leading cause of reduced agricultural yields, with reductions of up to 32% [4]. They compete with plants for nutrients, water, and light. In lowland rice cultivation, yield losses are around 30% [5]. To address this constraint, several control methods have been developed, including varietal, biological, agronomic, and chemical control [6]-[12]. However, the effectiveness of these control methods depends on knowledge of weeds and the factors that influence their development, which explains why lowland rice cultivation continues to face pests that significantly reduce yields. Nevertheless, studies have shown the positive effect of organic substrates on plant resistance and improved rice productivity. In rice cultivation, the dynamics of pest populations, such as weeds, depend largely on a combination of factors such as weeding methods and types of fertilizer applied. With a view to contributing to the sustainable management of weeds in lowland rice cultivation in light of its potential to improve rice production in Burkina Faso, this study was initiated to address the issue of weed control with the aim of evaluating the effect of organic substrate types and weeding methods on pest management.

2. Materials and Methods

2.1. Presentation of the Study Area

The study was conducted in the low-lying rice-growing area of the INERA Banfora station (N.10, 63067 and W.004.77.846) [12]. It is characterized by a sudden or temporary rise in the water table in the middle of the rainy season, followed by a slow and steady decline at the end of the rains [13]. During the 2024 wet season, the highest rainfall was recorded in July with 226.10 mm, while the lowest was observed in February with only 0.10 mm.

2.2. Plant Material

The plant material used was the popular rice variety FKR 84 (Orylux-6), which has a sowing-to-maturity cycle of 100 days and a potential yield of 6.5 tons. The chemical fertilizers consisted of NPK (14-23-14-6SB) at a dose of 200 kg/ha and urea (46%) at a dose of 150 kg/ha. The organic substrates consisted of compost made from crop residues (5 t/ha), sugarcane bagasse (5 t/ha), and biochar (5 t/ha). Weeding was carried out using a rotary hoe. Manual weeding was carried out by pulling weeds by hand and using a small hand hoe. For chemical weeding, two herbicides with different active ingredients and modes of action were used at the recommended doses. These were selective post-emergence herbicides with the active ingredients Cyhalofop butyl 184.3 g/l + Fluroxypyr 230.7 g/l and pre-emergence herbicides for rice and weeds with the active ingredients Penoxulam 10 g/l + Butachlor 400 g/l.

2.3. Experimental Setup

The experimental design was a split-plot with three completely randomized replicates consisting of 48 treatments. Two factors were studied: type of fertilization and weeding method. The type of fertilization was the main factor, with four modalities: biochar, chemical fertilizer, compost, and sugarcane bagasse. The weeding method, with four modalities, was the secondary factor: chemical weeding, rotary hoe weeding, manual weeding, and no weeding (Table 1). The total area of the trial was 324.5 m^2. The individual plots each had an area of 6 m^2 (3 m × 2 m) and were separated by a double ridge 50 cm high and 50 cm wide. The replicates were 1 m apart.

Table 1. List of experimental treatments, wet season 2024.

Code	Treatment	Composition
T1	**BI + DC**	Biochar combined with chemical weed control
T2	**BI + DM**	Biochar combined with rotary hoe weed control
T3	**BI + MA**	Biochar combined with manual weed control
T4	**BI + ND**	Biochar combined with no weed control
T5	**EC + DC**	Chemical fertilizer combined with chemical weeding
T6	**EC + DM**	Chemical fertilizer combined with rotary hoe weeding
T7	**EC + MA**	Chemical fertilizer combined with manual weeding
T8	**EC + ND**	Chemical fertilizer combined with no weeding
T9	**CO + DC**	Compost combined with chemical weeding
T10	**CO + DM**	Compost combined with rotary hoe weeding
T11	**CO + MA**	Compost combined with manual weeding

Continued

T12	**CO + ND**	Compost combined with no weeding
T13	**RC + DC**	Sugarcane bagasse combined with chemical weeding
T14	**RC + DM**	Sugarcane bagasse combined with rotary hoe weeding
T15	**RC + MA**	Sugarcane bagasse combined with manual weeding
T16	**RC + ND**	Sugarcane bagasse combined with no weeding

NB: NPK (14-23-14-6SB) at a dose of 200 kg/ha and urea (46%N) at a dose of 150 kg/ha were also applied to all treatments containing organic substrates.

2.4. Conducting the Trial

Plowing was carried out mechanically using a rotary tiller, followed by leveling and loosening to obtain a good seedbed. Transplanting was carried out in rows 21 days after sowing in the nursery, with spacing of 25 cm × 25 cm at one (01) plant per hole. Pre-emergence herbicide was applied at transplanting, while post-emergence herbicide was applied 15 days after transplanting. Weeding with a rotary hoe and manual weeding were carried out every 15 days after transplanting. Organic substrates were applied one week before transplanting. NPK was applied at transplanting, and urea was applied 15 and 45 days after transplanting.

2.5. Data Collection

The observations and measurements made on rice focused on the paddy yield, which was measured at harvest at a moisture content of 14%.

2.6. Soil Data

Soil samples were taken from each elementary plot using a 20 cm auger after harvesting. Three samples were taken per plot, giving a total of 48 samples per repetition. Sixteen composite samples were then created per repetition, with one sample per treatment. The samples were then ground, sieved to 2 mm, and analyzed at the Soil, Water, and Plant Laboratory of the Natural Resource Management and Production Systems (GRN/SP) program at the Farako-Bâ research station to determine pH, total soil nitrogen, total soil phosphorus, total potassium, assimilable soil phosphorus, and available potassium.

2.7. Data Collected on Weeds

- Number of weed species: The number of weed species was determined through an inventory conducted 15, 30, and 45 days after transplanting within a one-square-meter sample plot located in the center of the field.
- Herbaceous biomass: Herbaceous biomass was collected by hand from each elementary plot within a 0.5 m^2 area located on the diagonal 15, 30, and 45 days after transplanting. The weeds pulled were then weighed fresh and dried in an oven at 60˚C for 96 hours to assess the dry biomass.

2.8. Data Analysis

The data was entered and organized using Excel 2019. In addition, Excel 2019 allowed us to calculate the averages of the inventories. The analysis of variance was performed using R software version 4.4.2, and the separation of means was performed using Tukey's test at a 5% threshold after verifying normality. Phytosociological analyses (diversity, species richness) and ordination analyses were performed using PC-ORD version 5.0 ordination software [14], based on floristic surveys.

3. Results

3.1. Effects of Weeding Methods and Types of Fertilization on Variations in Soil Chemical Characteristics

Figure 1 shows the chemical characteristics of the soil according to weeding methods and types of fertilization in lowland rice cultivation. It shows that the highest pH values were recorded in plots that received manual weeding and biochar (5.64), while the most acidic plots were those that received chemical weeding and biochar (5.42). As for nitrogen content, the highest levels were recorded in plots treated with biochar and chemical weed control (0.11%), while the lowest levels were recorded in plots treated with sugarcane residues and chemical weed

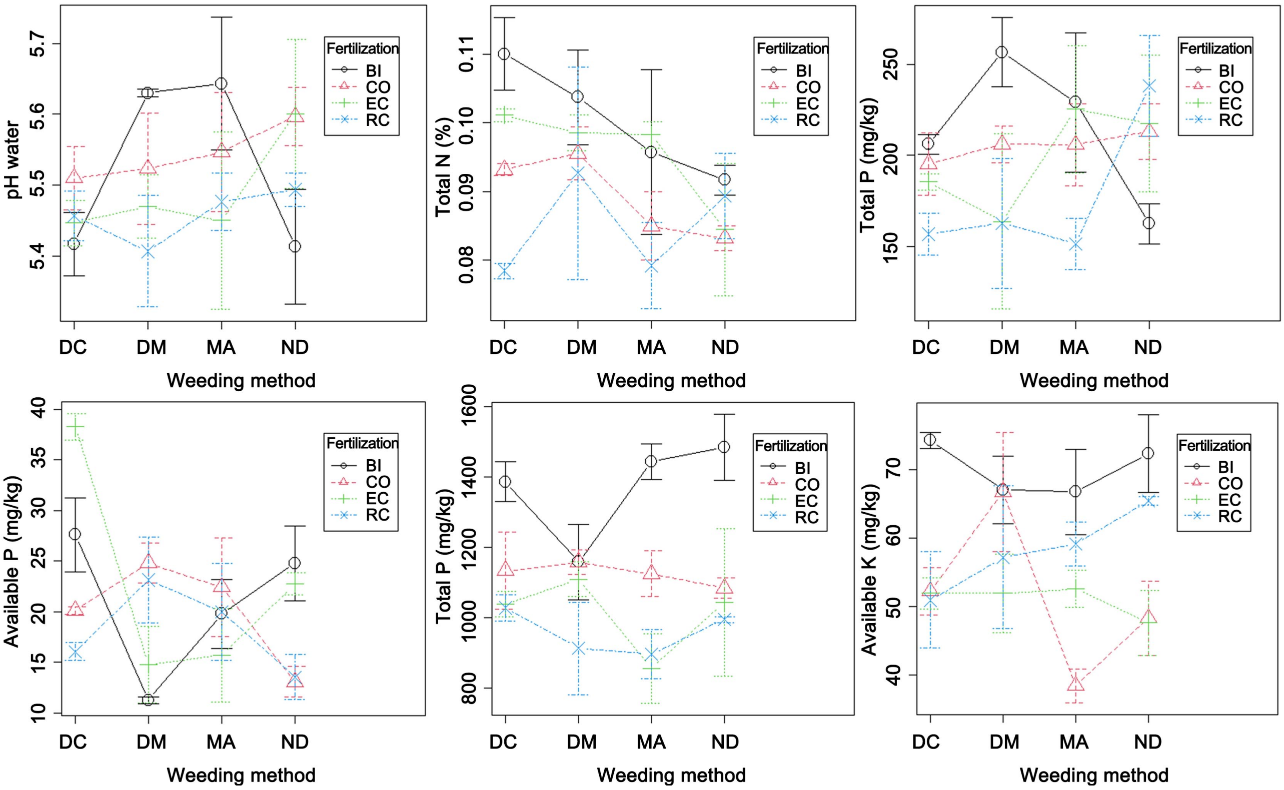

Figure 1. Variation in soil chemical characteristics in lowland rice cultivation according to weeding methods and types of fertilization, wet season 2024. **Note:** Organic matter (%): organic matter content, Total N (%): nitrogen content, Total P: total phosphorus in mg·kg^{-1} of soil, Assimilable P: assimilable phosphorus in mg·kg^{-1} of soil, Total K: available potassium in mg·kg^{-1} of soil, Available K: total potassium in mg·kg^{-1} of soil, BI: biochar, CO: compost, EC: chemical fertilizer, RC: sugar cane scum, DC: chemical weeding, DM: rotary hoe weeding, MA: manual weeding, ND: no weeding.

control (0.07%). The highest total phosphorus content was recorded for biochar combined with rotary hoe weeding (256.56 mg/kg), and the lowest for manual weeding combined with sugarcane residue (151.47 mg/kg).

The highest assimilable phosphorus content was recorded in treatments combining biochar with chemical weeding (27.59 mg/kg), and the lowest in treatments combining biochar with rotary hoe weeding (11.25 mg/kg). The highest total potassium content was recorded for biochar without weeding (1484.31 mg/kg), while the lowest content was recorded for sugarcane residue with manual weeding (120.69 mg/kg). The highest available potassium content was recorded for chemical weeding with biochar (74.32 mg/kg), while the lowest content was obtained for compost with manual weeding (38.47 mg/kg).

3.2. Effects of Treatments on Weed Infestation

3.2.1. Effects of Weed Control Methods on Dry Biomass of Weeds

At 15, 30, and 45 days after transplanting, dry weed biomass was significantly influenced ($p < 0.05$) by weeding methods (Table 2). The highest dry biomass was recorded 15 and 45 days after transplanting in plots without weeding, at 8.30 g/0.5m^2 (0.17 t/ha) and 55.11 g/0.5m^2 (1.10 t/ha), respectively. Thirty days after transplanting, manual weeding recorded the highest dry biomass, at 79.76 g/0.5m^2 (1.59 t/ha). In contrast, the lowest dry biomasses were observed with rotary hoe weeding 15 days after transplanting, at 3.73 g/0.5m^2 (0.07 t/ha), and with chemical weeding 30 and 45 days after transplanting, at 30.37 g/0.5m^2 (0.61 t/ha) and 12.65 g/0.5m^2 (0.25 t/ha), respectively.

Table 2. Dry biomass of weeds depending on weeding methods 15, 30, and 45 days after transplanting, wet season 2024.

	Dry Biomass (g/0.5m^2)		
Treatments	**15 DAT**	**30 DAT**	**45 DAT**
DC	6.74^a ± 2.09	30.37^a ± 13.46	12.65^a ± 2.74
DM	3.73^a ± 2.03	47.08^a ± 28.90	14.67^a ± 6.75
MA	7.41^{ab} ± 5.03	79.76^b ± 28.88	51.99^b ± 18.74
ND	8.30^b ± 5.28	45.00^a ± 14.16	55.11^b ± 14.41
Average	6.54 ± 3.61	50.55 ± 21.35	33.60 ± 10.66
Probability	0.0376	<0.0001	<0.0001
Significance	S	VHS	VHS

Note: DC: chemical weeding, DM: rotary hoe weeding, MA: manual weeding, ND: no weeding, DAT: day after transplanting, VHS: very highly significant, S: significant. Means labeled with the same letter belong to the same homogeneous group; means labeled with two letters belong to multiple groups.

3.2.2. Effects of Fertilization Types on Dry Biomass of Weeds

No significant difference ($p > 0.05$) was recorded in dry weed biomass according to fertilization type at 15, 30, and 45 days after transplanting (Table 3).

Table 3. Dry biomass of weeds according to fertilization types at 15, 30, and 45 days after transplanting, wet season 2024.

	Dry Biomass (g/0.5m²)		
Treatments	**15 DAT**	**30 DAT**	**45 DAT**
BI	5.53 ± 6.48	51.45 ± 41.94	29.36 ± 25.02
CO	6.96 ± 3.36	37.21 ± 15.71	34.00 ± 25.44
EC	5.84 ± 2.19	58.53 ± 22.42	35.44 ± 19.09
RC	7.85 ± 3.56	55.03 ± 26.02	35.62 ± 26.27
Average	6.54 ± 3.90	50.55 ± 26.52	33.60 ± 23.95
Probability	0.517	0.28	0.912
Significance	NS	NS	NS

Note: BI: biochar, CO: compost, EC: chemical fertilizer, RC: sugar cane scum, NS: not significant.

3.2.3. Effects of Weeding Method and Fertilization on Dry Biomass of Weeds

The effect of weeding method and fertilization showed a significant effect ($p < 0.05$) on the dry biomass of weeds at different observation dates (Figure 2). Fifteen days after transplanting, the highest dry biomass was recorded with the biochar-no-weeding treatment, at 14.30 g/0.5m^2 (0.29 t/ha). Thirty days after transplanting, manual weeding combined with chemical fertilizers yielded the highest dry biomass, at 114.61 g/0.5m^2 (2.29 t/ha), while 45 days after transplanting, the highest dry biomass was obtained with manual weeding combined with sugarcane residues, at 75.79 g/0.5m^2 (1.51 t/ha). In contrast, the lowest dry biomass was measured with biochar combined with rotary hoe weeding 15 days after transplanting, at 1.86 g/0.5m^2 (0.04 t/ha), 30 days after transplanting with biochar combined with chemical weeding, *i.e.*, 12.01 g/0.5m^2 (0.24 t/ha), and 45 days after transplanting with biochar combined with rotary hoe weeding, *i.e.*, 10.10 g/0.5m^2 (0.20 t/ha).

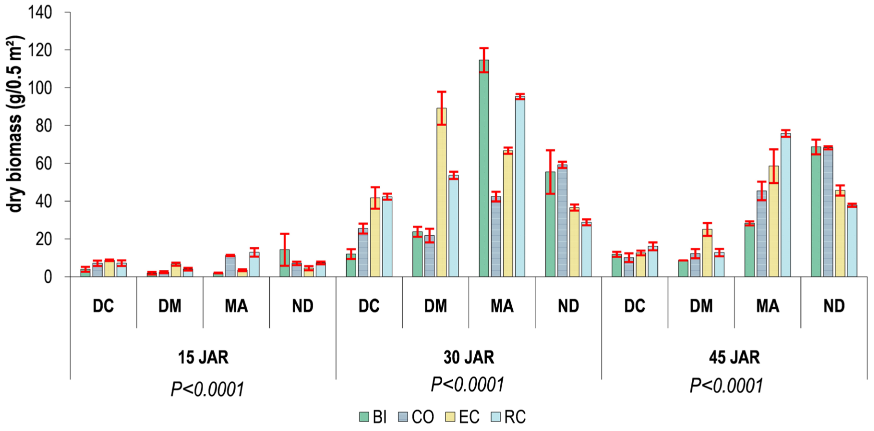

Figure 2. Dry biomass of weeds according to weeding method and fertilization at 15, 30, and 45 days after transplanting, wet season 2024. **Note:** DC: chemical weeding, DM: rotary hoe weeding, MA: manual weeding, ND: no weeding, BI: biochar, CO: compost, EC: chemical fertilizer, RC: sugarcane scum.

3.3. Effects of Treatments on Rice Yield

3.3.1. Effects of Weed Control Methods on Rice Yield

The variance analyses show that there is a significant difference between treatments in terms of paddy yield ($p < 0.05$) (**Table 4**). The highest yields were obtained using manual weeding (2703 kg/ha), and the lowest yields were obtained without weeding, at 856.66 kg/ha.

Table 4. Rendement du riz en fonction des modes de désherbages campagne humide 2024.

Treatments	Yield (kg/ha)
DC	2363.61^{a} ± 222.77
DM	2534.44^{a} ± 415.08
MA	2703.06^{a} ± 542.51
ND	856.66^{b} ± 68.55
Average	2114.44 ± 312.23
Probability	<0.0001
Significance	VHS

NB: DC: chemical weeding, DM: rotary hoe weeding, MA: manual weeding, ND: no weeding, VHS: very highly significant.

3.3.2. Effects of Fertilization Types on Rice Yield

The variance analyses show that the types of fertilization had no effect on overall rice yield in the two types of rice cultivation ($p > 0.05$) (**Table 5**).

Table 51. Rice yield according to fertilization types, wet season 2024.

Treatments	Yield (kg/ha)
BI	2110.27 ± 794.22
CO	2397.78 ± 1010.74
EC	2090.55 ± 797.92
RC	1859.17 ± 660.69
Average	2114.44 ± 815.89
Probability	0.47
Significance	NS

Note: BI: biochar, CO: compost, EC: chemical fertilizer, RC: sugar cane scum, NS: not significant.

3.3.3. Effects of the Interaction between Weeding Method and Fertilization on Yield

The analyses show that interactions between fertilization types and weeding methods had an effect on crop yields in lowland rice cultivation and irrigated rice cultivation ($p < 0.05$) (**Figure 3**). In upland rice cultivation, the highest yields were obtained by manual weeding combined with compost, at 3208.89 kg/ha, and the lowest yields were obtained by no weeding combined with compost, at 804.44 kg/ha.

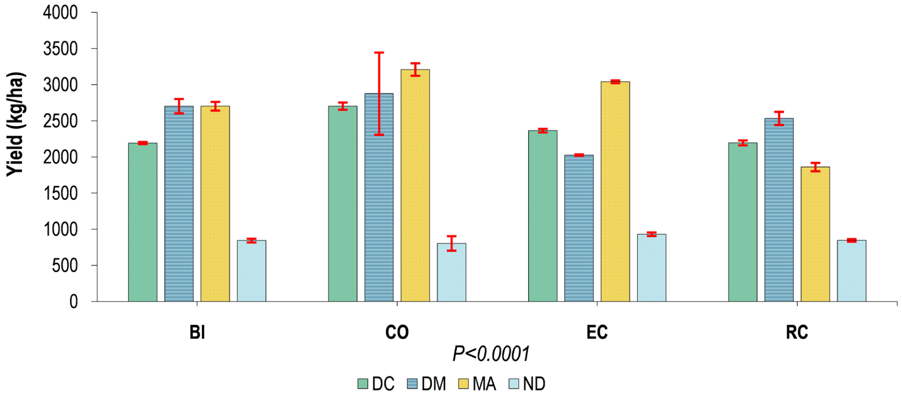

Figure 3. Effect of weeding method and fertilization types on paddy rice yield, wet season 2024. **Note:** DC: chemical weeding, DM: rotary hoe weeding, MA: manual weeding, ND: no weeding, BI: biochar, CO: compost, EC: chemical fertilizer, RC: sugar cane scum.

3.4. Pearson Correlation Coefficient between Variables

Analysis of the correlation between variables shows that correlation coefficients vary between −0.581 and 0.70 in lowland rice cultivation (Table 6). The highest correlations were obtained between dry biomass and recovery rate (0.70). In contrast, the lowest correlations were obtained between yield and dry biomass (−0.58). Furthermore, the table shows that the correlations between dry biomass and height, dry biomass and yield, dry biomass and number of tillers, height coverage rate, and yield coverage rate are negative.

Table 6. Pearson's correlation coefficient between variables, wet season 2024.

	Dry Biomass of Weeds	Rice Height	Rice Yield (Kg/ha)	Rice Tillering	Weed Coverage Rate
Dry Biomass of Weeds	1.00				
Rice Height	−0.49***	1.00			
Rice Yield (Kg/ha)	−0.58***	0.5***	1.00		
Rice Tillering	−0.32*	0.36*	0.05	1.00	
Weed Coverage Rate	0.70***	−0.06	−0.09	−0.24	1.00

Note: *: significant, **: highly significant, ***: very highly significant.

3.5. Comprehensive and Phytoecological Analysis of the Weed Community

3.5.1. Frequency of Weed Classes and Families

A total of 25 weed species were identified. They belong to 20 genera and 14 families, the most dominant of which are Poaceae (20.00%), Cyperaceae (20.00%), Asteraceae (8%), Juncaceae (8.00%), and Pontederiaceae (8.00%). The dicotyledonous class (52%) is the most important, and the most important biological type is that of (54.17%) (Figure 4).

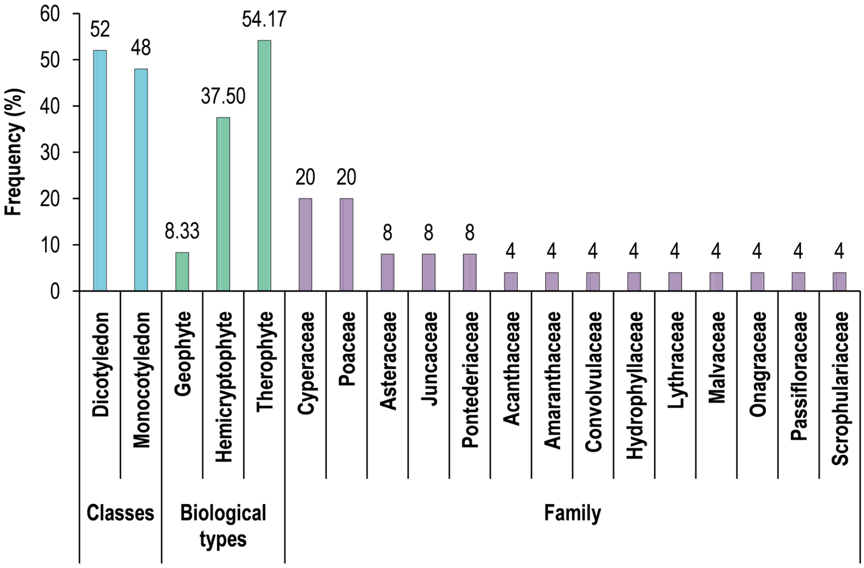

Figure 4. Frequency of weed classes and families inventoried, wet season 2024.

3.5.2. Frequency of Occurrence of Weed Species

The analysis shows variation in the frequencies of occurrence of the species inventoried (**Figure 5**). *Ammannia prieureana* Guill., *Bacopa floribunda* (Aubl.) Wettst., and *Heteranthera callifolia* Rchb. ex Kunth had the highest frequency of occurrence (100%). The lowest frequencies of occurrence were obtained by *Eclipta alba* (L.) Hassk, *Syphanochloa* sp, *Echinochloa colona* (L.) Link, and *Ipomoea aquatica* Forssk, at 2.08%.

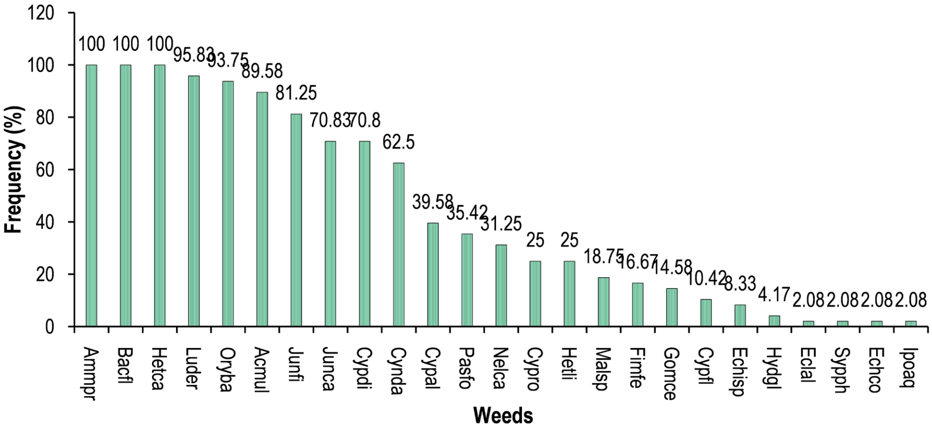

Figure 5. Frequency of occurrence of weed species, wet season 2024. **Note:** Acmul: *Acmella uliginosa* A. Chev, Ammpr: *Ammannia prieureana* Guill., Bacf: *Bacopa floribunda* (Aubl.) Wettst., Cynda: *Cynodon dactylon* (L.) Pers., Cypdi: *Cyperus difformis* L., Fimfe: *Fimbristylis ferruginea* (L.) Vahl, Gomce: *Gomphrena celosioides* C, Mart, Hetca: *Heteranthera callifolia*, ex Kunth, Hydgl: *Hydrolea glabra* Schum, & Thonn, Junfi: *Juncus filiformis* L., 1753, Luder: *Ludwigia erecta* (L.) H. Hara, Nelca: *Nelsonia canescens* (Lamark) Sprengel, Oryba: *Oryza bartii* A. Chev., Cypal: *Cyperus alternifolius* L., Echisp: *Echinochloa* sp, Eclal: *Eclipta prostrata* (L.) L, Junca: *Juncus calliformis* L., 1753, Sypph: *Syphanochloa* sp, Cypfl: *Cyperus flavescence* L., Cypro: *Cyperus rotundus* L., Echco: *Echinochloa colona* (L.) Link, Ipoaq: *Ipomoea aquatica* Forssk, Malsp: *Malvastrum* sp, Marmu: *Marsilea munita* L., Pasfo: *Passiflora foetida*., *Heteranthera limosa* (Sw.) Willd.

3.5.3. Distribution of Weeds According to Treatments

The first two axes of the Detrended Correspondence Analysis (DCA, DECORANA) explain 21.39% of the relationship between weed species and the farming practices evaluated (**Figure 6**). Analysis of indicator species shows that 42.31% of species in the optimum group (GV6) were significantly influenced by the treatments, which are subdivided into six species subgroups (**Figure 6**). The dendrogram resulting from the hierarchical classification reveals heterogeneity between the treatments that influence the plant groupings of the identified weed species (**Figure 7**). At approximately 27% of the remaining information on the dendrogram, six groups can be observed. However, only two groups have a P-value of less than 0.05 according to the Monte Carlo test (**Table 7**). These are the *Cyperus diformis* L. group, consisting of three indicator weed species, namely *Cynodon dactylon* (L.) Pers, *Cyperus diformis* L., and *Passiflora foetida* L. This grouping is characterized by the influence of 100% rotary hoe weeding in terms of weeding methods and 50% biochar and 50% compost in terms of fertilization. There is also group 5, or the *Ammannia prieureana* group, which also consists of three indicator weed species, namely *Ammannia prieureana* Guill., *Bacopa floribunda* (R.Br.) Wettst, and *Cyperus diformis* L. This group is characterized by the influence of 100% manual weeding in terms of weeding methods. In terms of fertilization, it is characterized by compost and chemical fertilizer at 30% each, and sugarcane bagasse and biochar at 20% each.

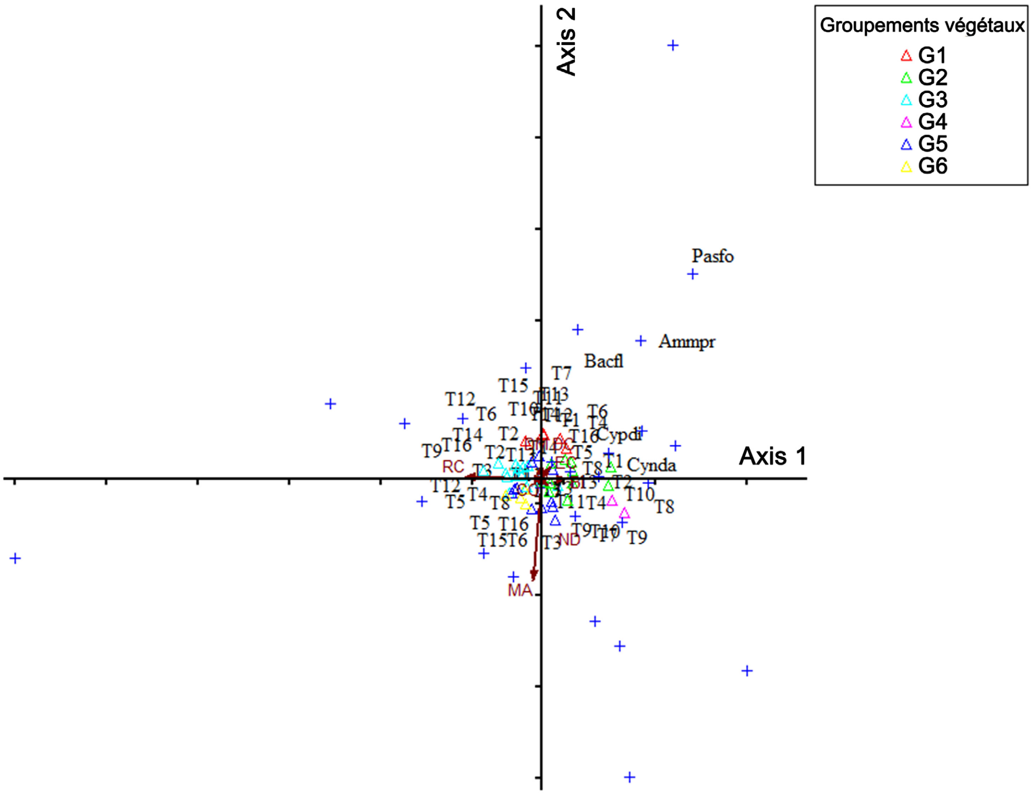

Figure 6. Distribution based on treatments of inventoried weed species, wet season 2024.

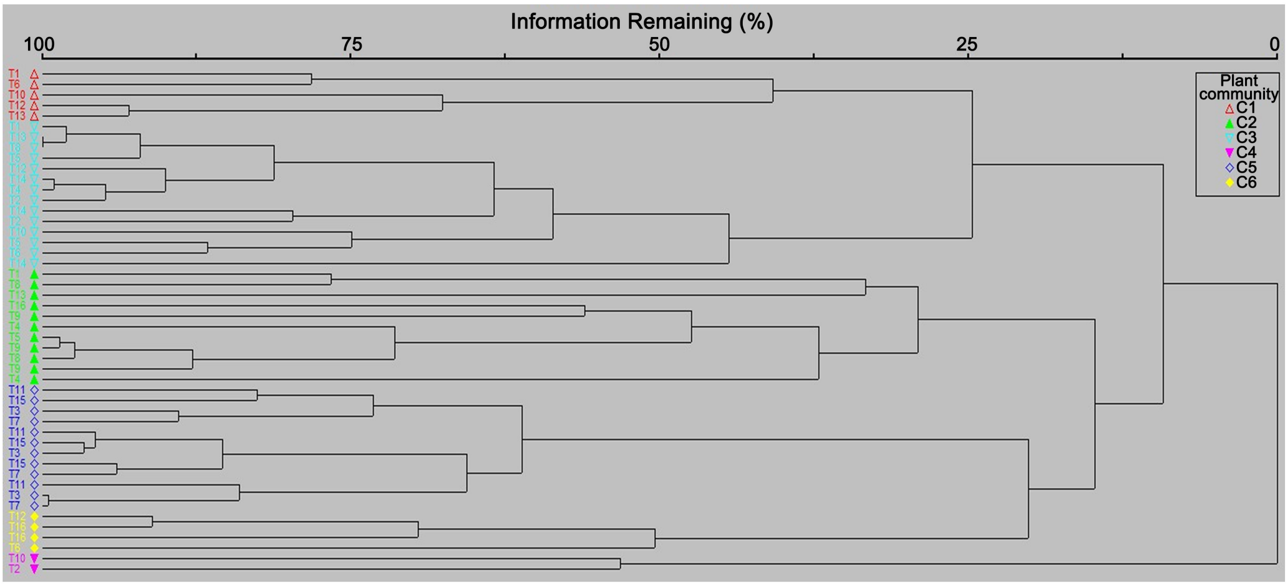

Figure 7. Dendrogram classifying inventoried weed species, wet season 2024.

Table 7. Characteristics of plant groups of weed species inventoried during the wet season of 2024.

Code	Group Name	RS	Species Characteristics	IV (%)	p-value (Monte Carlo)	Dominant Class	Dominant Family	Ish	IS	IE
G4	Grouping with *Cyperus diformis* L.	13	*Cynodon dactylon* (L.) Pers	39.4	0.0528	Monocotyledone (66.67%)	Poaceae (33.33%) Cyperaceae (33.33%) Passifloraceae (33.33)	2.334	0.884	0.910
			Cyperus diformis L.	66.5	0.0024					
			Passiflora foetida L.	54.8	0.0260					
G5	Grouping at *Ammannia prieureana* Guill.	18	*Ammannia prieureana* Guill.	28.0	0.0014	Dicotyledone (60%)	Cyperaceae (26.67%)	2.581	0.910	0.893
			Bacopa floribunda (R.Br.) Wettst.	29.8	0.0014					
			Cyperus diformis L.	36.8	0.0016					
Means		15.67						2.394	2.389	0.887

Legend: SR: specific richness; IVI: species indicator value; ISh: Shannon indices; IS: Simpson index; IE: Pielou's evenness index.

Table 8. Correlation coefficients between treatments, wet season 2024.

Treatments	Axis 1		Axis 2	
	r	tau	r	tau
BI	0.161	0.100	0.034	0.029
EC	0.047	0.049	−0.005	0.017
CO	0.080	0.074	−0.076	−0.089
RC	−0.288	−0.223	0.047	0.043
DC	−0.097	0.089	0.119	0.072
DM	−0.038	−0.077	0.128	0.117

Continued

MA	−0.099	−0.040	−0.333	−0.266
ND	0.040	0.029	0.086	0.077

Legend: r: square of the correlation coefficient, tau: Kendall's tau, CF: chemical fertilizer, C: compost, SC: sugarcane bagasse, CH: chemical weeding, MW: mechanical weeding, MW: manual weeding, NW: no weeding.

The correlation coefficients range from −0.288 (RC) to 0.161 (BI) for axis 1 and from −0.333 (MA) to 0.128 (DM) for axis 2 (**Table 8**). Cane scum, rotary hoe weeding, and manual weeding show negative correlations with respect to axis 1. Chemical fertilizer, compost, and manual weeding show negative correlations with respect to axis 2.

4. Discussion

Chemical herbicides have led to acidification. This can be explained by the fact that herbicides cause the release of chemicals that acidify the soil. During the nitrification process, ammonium (NH_4^+) from mineral fertilizers or certain chemical compounds is oxidized by nitrifying bacteria into nitrite (NO_2^-) and then nitrate (NO_3^-). This transformation is accompanied by the release of protons (H^+), causing a decrease in soil pH. In addition, certain herbicides can alter the microbial composition and accelerate the loss of basic cations (Ca^{2+}, Mg^{2+}, K^+) through leaching, thereby accentuating the acidification phenomenon. These results corroborate those of [12], who recorded high pH levels following the use of chemical weedkillers. Furthermore, it was found that combining compost with chemical weed control slightly raised the acidity level, with maximum values. Compost has the ability to buffer pH thanks to its high organic matter content, which improves soil structure. These results corroborate those of [15] and [11], who highlighted the need to combine chemical weedkillers with organic matter to avoid the phenomenon of ferrous toxicity, which is common in acidic soils. Biochar-based treatments and chemical weed control led to an increase in nitrogen levels compared to the others, with maximum values. This increase could be explained by biochar's ability to retain nitrogen compounds. In addition, some herbicides can have an indirect effect on mineralization and nitrification by modifying soil microbial activity. [16] pointed out that the application of biochar significantly increased the N content of the grassland. [17] reported, however, that in the short term, biochar can cause nitrogen immobilization in the soil.

Compared to other treatments, biochar with chemical weed control and without weed control led to an increase in total and available phosphorus, with maximum values. This can be explained by the fact that biochar corrects soil acidity, releases phosphorus, and promotes microbial activity, which in turn promotes phosphorus mineralization. Regarding total and available potassium, the best levels were recorded with chemical weed control combined with biochar. This can be explained by the fact that biochar limits leaching losses by improving the physical and chemical properties of the soil. Indeed, applying biochar to the soil can improve the cation exchange capacity (CEC) of soils, which leads to a reduction in nutrient leaching [18]-[21]. Other studies have reported significant reductions in nitrogen fertilizer leaching from secondary forest residues [22] and reductions in nitrogen and phosphorus leaching of 11% and 69%, respectively [23].

Weeding methods influenced weed biomass. The highest dry biomass was obtained with treatments without weeding. This could be explained by the fact that in treatments that were not weeded, weeds drew enough nutrients necessary for their development, resulting in an increase in dry matter weight. These results corroborate those of [12], who made the same observations in lowland rice cultivation. Furthermore, the analyses show that rotary hoeing and chemical weeding methods effectively reduced the dry biomass of weeds. This can be explained by the fact that rotary hoeing and chemical weeding, compared to other weeding methods, reduced weed infestation by killing weeds, inhibiting their growth, uprooting them, or physically destroying them, thereby reducing their competition for nutrients, water, and light. [24] also showed that integrated weeding combining pendimethalin and rotary hoeing reduced weeds by 85% and increased paddy rice yields by 1.5 t/ha. In addition, we found that the effectiveness of rotary hoeing was observed on the 15th day after transplanting, unlike chemical weeding. These results contradict those of [25], who reported that rotary hoeing increased competition for water and nutrients by significantly increasing the floristic density of weeds on the test plots, promoting their rapid regrowth on the one hand and the emergence of new weed species on the other.

With regard to fertilization types, it appears that there is no significant difference in dry biomass. This can be explained by the fact that, beyond the different amendments, all treatments received the same doses of chemical fertilizers. It should also be noted that most amendments do not have an immediate effect in the first year. Several studies have shown that organic amendments have no significant effect during the first year of experimentation, suggesting that their impact on soil properties and crop productivity may take a long time to become apparent. Our results are similar to those of [26], who, by adding biochar during the production of their compost, obtained a 14% increase in yield for biochar alone and a 19% increase for co-compost compared to compost alone in the third year of the experiment.

The interaction between the weeding method and the type of fertilization influenced the dry biomass of weeds. The best results were observed with: rotary hoe weeding combined with biochar, biochar combined with chemical weeding, and biochar combined with mechanical weeding. The combined action of these substrates and the effectiveness of rotary hoeing and chemical weeding significantly reduced weed infestation. Fertilization modifies the growth dynamics of weeds, while weeding influences their elimination or regeneration when done properly. Our results contradict those of [12], in lowland rice cultivation, who did not observe any significant difference in the interaction between weeding method and fertilization type. However, regardless of the weeding method, they found that compost application reduced weed biomass compared to the treatment without compost application.

Rice yields were significantly influenced by weeding methods compared to the control. The best yields were obtained by manual weeding in rice cultivation. Manual weeding allows for the complete removal of weeds, including those that can regrow; hence, the better yields obtained with manual weeding. [27] indicated that the more diversified the weeding methods, *i.e.*, characterized by a combination of manual hoeing with manual pulling and burial of the hoed biomass, the less dominant the weed species were, with a very marked presence of *Cyperus rotundus* and *Portulaca quadrifida*. The lower the degree of weed infestation, the fewer the dominant species, and the higher the yield with high-yield weeding methods.

The interactions between weeding methods and fertilization had a significant effect on yield. This can be explained by the fact that weeding and fertilization have complementary effects on plant growth and competition, hence the need to combine them. In eastern India, researchers compared fertilization combined with different weeding methods and obtained gains of +9% in rice biomass, +10% in yield, and +3% - 7% in nutrient absorption compared to chemical treatments alone [28]. Although biochar combined with chemical weed control has shown the best weed control, it should be noted that the best paddy yield was obtained by manual weeding combined with compost. Biochar has a stable structure that improves the physical properties of the soil, but it is not rich in elements that can be directly assimilated by plants, and chemical weed control can release elements that limit plant production. Compost enrichment enriches the soil with nutrients, making more nutrients available to the plant, while manual weeding allows plants to be pulled up without harming the crop. Biochar, with its stable and extremely porous structure, can improve the physical properties of the soil [29] by facilitating oxygen supply [30] and increasing its water retention capacity [29]. Compost helps improve the organic status of the soil. It also promotes mineral nutrition in crops thanks to the mineral elements it contains [31].

The most important classes and types were represented by dicotyledons and therophytes. This could be explained by the much wider distribution of dicotyledons and their ability to adapt to ecosystems disturbed by agricultural activities. These results are similar to those of [32], supported by [11], highlighting the dominance of dicotyledons in the main cereal crops of Burkina Faso. In addition, [33] reported that the cultivation techniques used facilitate the development of therophytes compared to other biological types. The inventory also shows that the most important families were Poaceae, Cyperaceae, Asteraceae, Juncaceae, and Pontederiaceae. This could also be explained by the Sahelian distribution of these species and their ability to adapt to biotopes disturbed by agricultural activities [34]. Regarding the frequency of occurrence of weed species, it appears that the most frequent species were *Ammannia prieureana* Guill., *Bacopa floribunda* (Aubl.) Wettst and *Heteranthera callifolia* Rchb. ex Kunth. According to [6], climatic, edaphic, and cultural factors are the main factors dictating the behavior of species in Burkina Faso. The variation in species could be explained by differences in water conditions, soil type, and cultural practices, which favor the development of weeds adapted to each environment.

Our study identified six weed groups, but only two weed groups were significantly dependent on fertilization and weeding practices according to the Monte Carlo test ($p < 0.05$). This could be explained by the fact that these practices create ecological conditions that favor the grouping of species with similar requirements and ecological adaptations. Our results are similar to those [35] and [12], who showed, respectively, that herbaceous flora can group together according to soil and climate conditions and farming practices. The factor that most influenced the behavior of the species inventoried was manual weeding. According to [36], the most influential factor is identified by the largest arrow in the ordination diagram. According to [37], "the effects of cropping systems on weeds are complex. They are likely to influence the various processes of the species' life cycle (emergence, competition, seed production, etc.), and weed species respond differently depending on their biology." The treatments with the highest Shannon and Simpson indices were obtained by the group based on manual weeding combined with either chemical fertilizer, compost, biochar, or sugarcane bagasse, demonstrating great diversity within this group. The highest Pielou equitability indices were recorded by the group based on rotary hoe weeding combined with either biochar, compost, or sugar, indicating a large number of species with low diversity.

5. Conclusion

The overall objective of this study was to evaluate the effect of organic substrate types and weeding methods on weed management in order to improve the productivity of the rice farming system in Burkina Faso. Chemical weed treatments recorded the most acidic pH levels. The highest nitrogen contents were recorded for biochar with chemical weeding. Total and available phosphorus levels were highest with biochar combined with rotary hoe weeding and biochar combined with chemical weeding. Total and available potassium levels were highest with biochar without weeding and sugarcane residues with manual weeding. The lowest dry biomass levels were measured with biochar combined with rotary hoe weeding at 15 days after transplanting, with biochar combined with chemical weeding at 30 days, and with biochar combined with rotary hoe weeding at 45 days after transplanting. Manual weeding combined with compost produced the highest yields. The results also reveal that the 25 species inventoried in lowland rice cultivation formed six groups based on the influence of the treatments. Only two groups had indicator species. These were the *Cyperus diformis* L. group, consisting of 100% rotary hoe weeding combined with either 50% biochar or 50% compost, with indicator species such as *Cynodon dactylon* (L.) Pers, *Cyperus diformis* L., and *Passiflora foetida* L. The other group was the *Ammannia prieureana* Guill. group, characterized by the influence of 100% manual weeding combined with either 30% compost and 30% chemical fertilizer or 20% sugarcane bagasse and 20% biochar. With indicator species such as *Ammannia prieureana* Guill., *Bacopa floribunda* (R.Br.) Wettst. and *Cyperus diformis* L. Looking ahead, it would be interesting to assess the effect of weeding methods on weed diversity in lowland rice cultivation, given its production potential, and to evaluate the effect of co-compost on weed diversity in rice cultivation.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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