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RESEARCH ARTICLE

CHARACTERIZATION OF WEED FLORA AND EVALUATION OF CHEMICAL WEED CONTROL STRATEGIES FOR IRRIGATED WHEAT IN THE MIDDLE SENEGAL RIVER VALLEY

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Abstract: The objective of this study was to characterize the weed flora of irrigated wheat and to evaluate the efficacy, selectivity, and agronomic performance of chemical weed control strategies in Fanaye, Senegal, in 2022 and 2023. A randomized complete block design comprising five treatments and four replicates was used. The flora inventory identified 35 species belonging to 20 botanical families, including 26 broadleaf weeds, six Poaceae, and three Cyperaceae. Three treatments combining pendimethalin at 1.5 L/ha with different doses of 2,4-D were compared to manual weeding and an untreated control. Treatment T3 provided the best weed control but caused greater phytotoxicity. Treatment T1, with 1 L/ha of 2,4-D, offered the best balance between efficacy, selectivity, and yield, reaching 2,321 and 2,430 kg/ha, respectively.

Keywords : Irrigated wheat, Weed flora, Chemical weed control, Phytotoxicity, Yield

INTRODUCTION

Wheat is an essential grain for human consumption and plays a key role in global food security. In Africa, growing demand and dependence on imports pose major challenges for food systems. In Senegal, wheat imports reached 982,106 metric tons in 2025, up from 904,947 metric tons in 2024 an increase of 8.5% (ANSD, 2026). In this context, improving wheat productivity and addressing the factors that limit its yield are key challenges for the development of national cereal production. Among these factors, weeds represent a major constraint because they compete with the crop for water, light, nutrients, and space.

The intensity of this competition depends, in particular, on the plant community composition, species abundance, the plants' stage of development, and agroecological conditions. Inadequate weed management can thus compromise wheat growth and reduce its yield. In the context of climate change and the intensification of production systems, weed control is an important component of the sustainability of cereal production systems (Benjamin *et al*., 2024 ; Sharma *et al*., 2024).

Understanding the floristic composition of weed communities is an essential step in developing appropriate weed control strategies. Identifying the species present makes it possible, in particular, to better target control measures and to take into account the diversity of botanical groups. In Senegal, Mballo *et al*. (2018) characterized the weed flora of irrigated rice at several sites in the Senegal river valley. However, the weed flora associated with irrigated wheat and the weed control methods suitable for this crop in the middle valley require further documentation.

Chemical weed control is one of the methods used to manage weeds in cereal crops. Pendimethalin, a pre-emergence herbicide, controls certain annual weeds during the early stages of crop development. Its effectiveness, however, depends on the weed community composition, application conditions, and environmental characteristics. Lamani *et al*. (2024) studied the efficacy of pre-emergence herbicides against various weed communities in wheat, highlighting the importance of evaluating weed control strategies under the specific conditions of each production system. Combining a pre-emergence application with a post-emergence treatment can also extend the period of weed control, provided that the products and rates used ensure sufficient selectivity toward the crop.

In the middle Senegal river valley, an evaluation of these strategies is necessary to identify weed control methods that balance herbicide efficacy, wheat tolerance, and yield maintenance. This study was conducted at the Fanaye experimental station of the Senegalese Institute for Agricultural Research (ISRA) during two cold dry-season. Its overall

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objective was to contribute to improving weed management in irrigated wheat. More specifically, it aimed to characterize the weed flora, evaluate the efficacy of three treatment combinations pairing pendimethalin with different doses of 2,4-D, assess their phytotoxicity to wheat, and determine their effects on weed biomass, yield components, and grain yield.

MATERIALS AND METHODS

Overview of the study area

The trial was conducted at the ISRA experimental station in Fanaye during the cold dry seasons of 2022 and 2023. The station is located in the middle valley of the Senegal river, approximately 160 km from Saint-Louis, in the Podor department. The experimental station (16°33 North and 15°46 West) is situated along a river branch known as Ngalanka and covers an area of 117 hectares, 12 of which have been developed and connected to a motor pump.

The Fanaye station has three main soil types: Hollaldés, which are very clayey (50–75% clay); faux Hollaldés, which are clay-loamy (30–50% clay); and Fondés, which have a loamy texture (10–30% clay). The trial was established on Hollaldé-type soil, characterized by a high clay content.

Characterization of weed flora

The study of plant diversity involved conducting inventories of weeds present in the experimental plots every 10 days, from sowing to maturity. Taxa were identified using the flora by Berhaut (1971–1979). The APGIII classification (2009) was used to compile the list of families.

Experimental design

The experiment was conducted using a Fisher-type block design (completely randomized blocks) with 5 treatments and 4 replicates over two years. The basic plot has an area of 17.6 m² (8 m x 2.2 m). The number of elementary plots is 5 × 4 = 20. The distance between elementary plots and between replicates is 30 cm, and the distance between blocks is 1 m. The total area of the experiment is 455 m² (35 m × 13 m). The experimental block is 1 m wide.

Table 1: Treatments studied and administration methods.

Code	Treatment	Application method
T1	Pendimethalin (1.5 L/ha) + 2,4-D (1 L/ha)	Pendimethalin at 2 DAS, followed by 2,4-D at 20 DAS
T2	Pendimethalin (1.5 L/ha) + 2,4-D (1.5 L/ha)	Pendimethalin at 2 DAS, followed by 2,4-D at 20 DAS
T3	Pendimethalin (1.5 L/ha) + 2,4-D (2 L/ha)	Pendimethalin at 2 DAS, followed by 2,4-D at 20 DAS
TP	Manual weeding	At 30 and 60 DAS
TE	Weedy control	No weeding from sowing to harvest

DAS: Days After Sowing

The plant material consisted of soft wheat, Hamat variety, with a maturity cycle of 85 days and an average yield of 3.7 metric tons per hectare. The variety was registered in Senegal in 2020.

Herbicides were applied using conventional spraying with a manual backpack sprayer equipped with a slot nozzle, resulting in a treatment volume of approximately 120 L/ha.

Observations and measurements

The observations made to evaluate the effect of the treatments were as follows:

- ❖ for weeds
- visual assessment of efficacy on a scale from 0 to 100% (CILSS/CSP, 1999), on the 30th, 45th, and 60th days after sowing (DAS);
- collection of weed biomass from 3 squares of 0.25 m² per experimental plot on the 45th DAS.
- ❖ For wheat
- Visual assessment of treatment phytotoxicity on the 30th, 45th, and 60th days after sowing (DAS);
- Number of panicles per square meter (3 quadrats of 0.25 m² each per experimental plot); 1,000-kernel weight; and yield.

Statistical analysis

The data were analyzed using ANOVA to evaluate the effect of the treatments on herbicidal efficacy, weed biomass, and wheat yield parameters. Means were compared using the Newman-Keuls test at the 5% significance level. The analyses were performed using R software, version 3.4.0.

RESULTS AND DISCUSSION

Analysis of the flora

The floristic survey conducted in the irrigated wheat plots in Fanaye identified 35 weed species belonging to 20 botanical families (Table 2). Broadleaf weeds constituted the most diverse group, with 26 species belonging to 17 families, compared with six species of Poaceae and three species of Cyperaceae. Among the broadleaf weeds, the Fabaceae were the most represented, with five species, followed by the Malvaceae with four species and the Amaranthaceae with three species. The Asteraceae, Convolvulaceae, and Euphorbiaceae each had two species, while the other families were represented by only one species.

The Poaceae species identified were *Aristida mutabilis*, *Bothriochloa bladhii*, *Chloris pilosa*, *Echinochloa colona*, *Panicum laetum*, and

Pennisetum pedicellatum. The Cyperaceae included *Cyperus esculentus*, *Cyperus iria*, and *Cyperus rotundus*. The presence of these different species reflects the diversity of botanical groups associated with irrigated wheat cultivation under the agroecological conditions of Fanaye. Among the identified grasses, *Echinochloa colona* deserves special attention due to its significance as a weed in several cropping systems, particularly cereal crops.

The predominance of broadleaf weeds is comparable to the observations of Amare (2014), who studied weed management methods in wheat crops in Ethiopia. In the Senegal river valley, Mballo *et al*. (2018) also highlighted the importance of characterizing weed flora in irrigated agricultural systems. However, differences between the crops studied and the agroecological conditions limit direct comparisons between these studies. This floristic diversity requires adapting weed control strategies to the composition of the flora, the abundance of species, and their sensitivity to herbicides. Galon *et al*. (2021) showed that the efficacy and selectivity of herbicides used on wheat varied depending on the treatment and the target species. Thus, knowledge of the weed community composition is essential for interpreting the performance of the treatments evaluated at Fanaye and for guiding the choice of weed control methods.

Table 2: List of recorded species

Family	Species
POACEAE	
Poaceae	*Aristida mutabulis* Trin. & Rupr.
Poaceae	*Bothriochloa bladhii* (Retz.) S.T.Blake
Poaceae	*Chloris pilosa* Schummach.
Poaceae	*Echinochloa colona* (L.) Link.
Poaceae	*Panicum laetum* Kunth.
Poaceae	*Pennisetum pedicellatum* Trin.
CYPERACEAE	
Cyperaceae	*Cyperus esculentus* L.
Cyperaceae	*Cyperus iria* L.
Cyperaceae	*Cyperus rotundus* L.
BROAD-LEAVED WEEDS	
Aizoaceae	*Trianthema portulacastrum* L.
Amaranthaceae	*Alternanthera nodiflora* R. Br.
Amaranthaceae	*Alternanthera sessilis* (L.) R. Br. ex DC.
Amaranthaceae	*Amaranthus hybridus* (L.) Thell.
Asteraceae	*Blumea aurita* (L. f.) DC.
Asteraceae	*Eclipta alba* (L.) Hassk.
Convolvulaceae	*Ipomoea acanthocarpa* (Ch.) Asch. & Sch.
Convolvulaceae	*Ipomoea coptica* (L.) Roth.
Elatinaceae	*Bergia suffruticosa* (Delile) Fenzl
Euphorbiaceae	*Euphorbia heterophylla* L.
Euphorbiaceae	*Euphorbia hirta* L.
Fabaceae - Caesalpinoideae	*Senna obtusifolia* (L.) Irwin & Barneby
Fabaceae - Faboideae	*Aeschinomene indica* L.
Fabaceae - Faboideae	*Indigefera microcarpa* Desv.
Fabaceae - Faboideae	*Macroptilium lathyroides* (L.) Urb.

Haloragaceae	*Laurembergia tetrandra* auct.
Malvaceae - Malvoideae	*Abutilon pannosum* (G. Forst.) Schltdl.
Malvaceae - Tilioideae	*Corchorus tridens* L.
Malvaceae - Malvoideae	*Sida alba* L.
Malvaceae - Tilioideae	*Corchorus olitorius* L.
Molluginaceae	*Molugo nudicaulis* Lamarck
Phyllanthaceae	*Phyllanthus amarus* Schum. & Thion.
Portulacaceae	*Portulaca oleracea* L.
Scrophulariaceae	*Scoparia dulcis* L.
Zygophyllaceae	*Tribulus terrestris* auct.

Efficacy of treatments against weeds in wheat

In 2022, treatment efficacy ranged from 90 to 92% at 30 days after sowing (DAS). Treatments T2 and T3 performed best, with an efficacy of 92%, compared with 90% for T1 (Figure 1A). At 45 DAS, efficacy decreased for all treatments, with values ranging from 80 to 84%. T2 maintained the best performance (84%), while T1 and T3 showed 80% and 81%, respectively. At 60 days after sowing (DAS), trends varied by treatment: the efficacy of T1 continued to decline, reaching 75% ; that of T2 remained stable at 84% ; while T3 showed a gradual improvement, reaching 90% the highest value at that point.

In 2023, efficacy at 30 DAS ranged from 80% to 92% (Figure 1B). T3 performed best at 92%, followed by T2 at 88%, while T1 had the lowest value at 80%. At 45 DAS, the efficacy of T1 remained stable at 80%, while that of T2 decreased from 88% to 84% and that of T3 from 92% to 84%. At 60 DAS, a further decrease was observed for all three treatments, with efficacy rates of 70%, 78%, and 80% for T1, T2, and T3, respectively. Thus, despite the variations observed between years, T3 maintained the highest final efficacy over the two growing seasons, followed by T2, while T1 showed a more pronounced decline in performance.

The differences in efficacy trends between the two years could be related to variations in weed flora, application conditions, or environmental factors. Ghosh *et al*. (2017) demonstrated that combining pre-emergence pendimethalin with post-emergence 2,4-D reduced the density of dicotyledons and weed biomass in wheat. Hundal and Dhillon (2018) also demonstrated that sequential herbicide applications combining a pre-emergence treatment with a post-emergence treatment improved weed control and wheat yield. These results are consistent with those obtained in Fanaye, where the application of pendimethalin 2 days after sowing, followed by 2,4-D 20 days after sowing, resulted in high efficacy. However, the superior final efficacy of T3 must be interpreted while taking into account its effects on the crop.

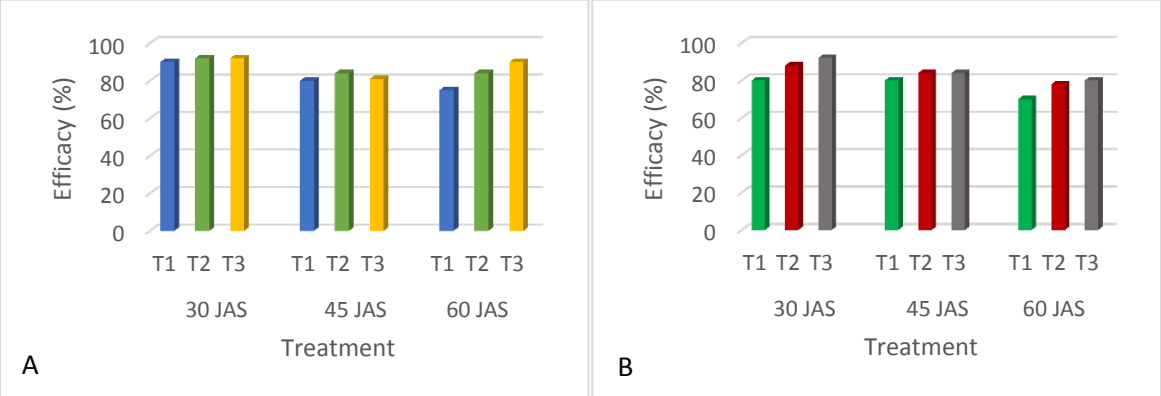


Figure 1 : Evolution of herbicide treatment efficacy across observation periods and years.

Phytotoxicity of treatments on wheat

Observations revealed differences in phytotoxicity among the treatments over the two years of the experiment (Table 3). T1, as well as the manually weeded control (TP) and the weeded control (TE), caused no visible symptoms, with phytotoxicity scores of zero on all three observation dates. In contrast, T2 caused slight and temporary yellowing of the lower leaves. Phytotoxicity scores were 0.5, 0.1, and 0 in 2022, at 30, 45, and 60 DAS, respectively, compared to 0.7, 0.5, and 0.2 in 2023. These results indicate a more pronounced intensity in

the second year, despite a gradual decrease in symptoms.

T3 exhibited the most pronounced symptoms during both growing seasons. In 2022, phytotoxicity scores were 1.5 at 30 DAS, 1.1 at 45 DAS, and 0.5 at 60 DAS. In 2023, they were 1.3, 1.0, and 0.7, respectively. The symptoms observed included leaf necrosis and yellowing, as well as plant death in 2023. Although their intensity decreased over time, these observations indicate that T3 has more limited selectivity toward wheat.

Colombo *et al*. (2022) also showed that herbicides can differ in their selectivity and the damage they cause to wheat. Khogali and Mohamed (2023), in a study conducted in northern Sudan, reported no visible phytotoxic symptoms with the tested doses of pendimethalin, unlike some other herbicides that caused mild symptoms at high doses. These observations are consistent with T1's good tolerance at Fanaye, while taking into account that the treatments evaluated in this study combined pendimethalin with a subsequent application of 2,4-D.

Table 3: Changes in treatment phytotoxicity in wheat across years and observation periods.

Treatment	Year	30 DAS	45 DAS	60 DAS	Visual symptoms observed
T1	2022	0.0	0.0	0.0	No
	2023	0.0	0.0	0.0	No
T2	2022	0.5	0.1	0.0	Mild, transient yellowing of the lower leaves
	2023	0.7	0.5	0.2	Mild, transient yellowing of the lower leaves
T3	2022	1.5	1.1	0.5	Leaf necrosis and yellowing
	2023	1.3	1.0	0.7	Plant death, leaf necrosis and yellowing
TP	2022	0.0	0.0	0.0	No
	2023	0.0	0.0	0.0	No
TE	2022	0.0	0.0	0.0	No
	2023	0.0	0.0	0.0	No

DAS: Days After Sowing

Effects of treatments on weed biomass, yield components, and wheat yield in 2022.

The 2022 results show that weed control strategies influenced weed biomass and wheat yield (Table 4). Weed biomass was particularly high in the weedy control (TE), at 241 ± 58.8 g/m², compared to 11.10 ± 1.19 g/m² for T1, 10.00 ± 1.28 g/m² for T2, and 5.48 ± 0.53 g/m² for T3. Manual weeding (TP) resulted in zero biomass. T3 thus had the lowest residual biomass among the herbicide treatments. However, the observed differences were not statistically significant ($p = 0.448$). These trends are consistent with the results of Ghosh *et al*. (2017), who demonstrated the benefits of sequential applications of pendimethalin and post-emergence herbicides for reducing weed biomass in wheat. Similarly, Pisal and Sagarka (2013) highlighted the effectiveness of integrated strategies combining pendimethalin with complementary measures.

Yield components also varied among treatments. The number of panicles ranged from 342 ± 86.3 panicles/m² in the grassed control to 448 panicles/m² in T1 and TP. T2 and T3 recorded 422 ± 31.9 and 374 ± 68.9 panicles/m², respectively. The thousand-kernel weight ranged from 35 to 36.5 g. However, the differences were not significant for either the number of panicles ($p = 0.279$) or the thousand-kernel weight ($p = 0.353$).

In contrast, grain yield showed highly significant differences among the treatments ($p = 9.51 \times 10^{-6}$). The highest yield was obtained with manual weeding (TP), at 2,343 ± 178 kg/ha, followed by T1 (2,321 ± 300 kg/ha) and T2 (2,306 ± 55.8 kg/ha). T3 recorded a lower yield of 2,050 ± 121 kg/ha, while the weedy control had the lowest yield (1,237 ± 153 kg/ha). These results highlight the importance of weed control for maintaining crop production. They are consistent with Ghosh *et al*. (2017), who reported a yield of 4.3 t/ha in the weeded control, comparable to that obtained with certain sequential herbicide strategies. The differences in yield between the two studies must nevertheless be interpreted in light of the experimental and agroecological conditions.

Despite its low residual weed biomass, T3 yielded less than T1 and T2. This result could be related to the phytotoxic symptoms observed with T3, particularly yellowing and leaf necrosis; however, this relationship remains a hypothesis that has not been statistically demonstrated. Galon *et al*. (2021) thus emphasize the importance of jointly evaluating herbicide efficacy, selectivity, and agronomic performance. Under the trial conditions, T1 appears to offer the best compromise, with a yield close to that of the clean control and no visible symptoms of phytotoxicity.

Table 4: Effects of treatments on weed biomass and wheat yield in 2022.

Treatment	Total weed biomass (g/m^2)	Number of panicles/m^2	Thousand-grain weight (g)	Yield (kg/ha)
T1	11.10 ±1.19	448 ±49.7	35.40 ±0.85	2321 ± 300
T2	10.00 ±1.28	422 ± 31.9	35.40 ±0.25	2306 ±55.8
T3	5.48 ± 0.53	374 ±68.9	35.90 ±0.85	2050 ±121
TE	241 ± 58.8	342 ±86.3	35 ±1.83	1237 ±153
TP	0	448 ±109	36.5 ±0.577	2343 ±178
Mean	53.58	406.65	35.63	2051.37
Cv (%)	49.31	19.29	2.94	9.16
Probability (p-value)	0.448	0.279	0.353	$9.51e^{-06}$ ***

T1, T2 and T3 = herbicide treatments; TP = manual weeding; TE = weedy control; CV = coefficient of variation

Effects of treatments on weed biomass, yield components, and wheat yield in 2023.

In 2023, herbicide treatments significantly reduced weed biomass compared to the weedy control (TE), which had 208 ± 14.4 g/m², versus zero biomass in the clean control (TP) (Table 5). Among the herbicide treatments, T3 had the lowest residual biomass (5.30 ± 0.26 g/m²), followed by T2 (9.88 ± 0.30 g/m²) and T1 (11.80 ± 0.34 g/m²). The differences were highly significant ($p = 2.45 \times 10^{-14}$). These results are consistent with those of Ghosh *et al*. (2017) and Pisal and Sagarka (2013), who demonstrated the benefits of strategies combining pendimethalin with complementary treatments. However, Khogali and Mohamed (2023) noted that herbicide efficacy may vary depending on botanical groups.

The number of panicles ranged from 316 ± 12.5 panicles/m² in the weedy control to 452 ± 10.4 panicles/m² in the clean control. T1 and T2 recorded 450 ± 11.5 and 427 ± 9.63 panicles/m², respectively, compared to 374 ± 7.68 panicles/m² for T3. The differences were highly significant ($p = 2.37 \times 10^{-10}$). In contrast, the thousand-kernel weight, ranging from 35 to 36 g, did not show a significant difference (p = 0.0625). These results are consistent with those of Agostinetto *et al*. (2008), who highlighted the importance of competition between weeds and wheat in determining yield losses.

Grain yield also differed significantly among treatments ($p = 2.38 \times 10^{-15}$). T1 yielded the highest grain yield (2,430 ± 35.4 kg/ha), followed by the clean control (2,412 ± 32.3 kg/ha), T2 (2,316 ± 25.3 kg/ha), and T3 (2,102 ± 24.7 kg/ha). The weeded control recorded the lowest yield, at 1,212 ± 52.0 kg/ha, confirming the importance of weed control for maintaining production. Ghosh *et al*. (2017) also reported a yield of 4.3 t/ha in the weeded control, comparable to that of certain sequential herbicide strategies.

Despite its superior control of weed biomass, T3 yielded less than T1 and T2. This difference may be related to the phytotoxic symptoms observed, including yellowing and leaf necrosis, as well as the presence of dead plants. Under the trial conditions, T1 represents the best agronomic compromise, combining a significant reduction in weed biomass, the absence of visible phytotoxicity symptoms, and the highest yield among the herbicide treatments.

Table 5: Effects of treatments on weed biomass and wheat yield in 2023.

Treatment	Total weed biomass (g/m^2)	Number of panicles/m^2	Thousand-grain weight (g)	Yield (kg/ha)
T1	11.80 ±0.34	450 ±11.50	35.50 ±0.58	2430 ±35.40
T2	9.88 ±0.30	427 ±9.63	35.80 ±0.50	2316 ±25.30
T3	5.3 ±0.26	374 ±7.68	36 ±0.82	2102 ±24.7
TE	208 ±14.4	316 ±12.5	35 ±0.82	1212 ±52.0
TP	0	452 ±10.40	35 ±0.82	2412 ±32.30
Mean	46.91	403.9	35.45	2051.38
Cv (%)	13.84	2.26	1.46	9.16
Probability (p-value)	$2.45e^{-14}$ ***	$2.37e^{-10}$ ***	0.0625	$2.38e^{-15}$ ***

T1, T2 and T3 = herbicide treatments; TP = manual weeding; TE = weedy control; CV = coefficient of variation

CONCLUSION

This study, conducted at the ISRA experimental station in Fanaye in 2022 and 2023, identified 35 weed species belonging to 20 botanical families, with broadleaf weeds predominating. Overall, the herbicide treatments provided good control of these weeds and reduced their biomass compared to the weedy control.

Among the strategies evaluated, T1 (pendimethalin at 1.5 L/ha followed by 2,4-D at 1 L/ha) proved to be the best treatment, thanks to its good balance between herbicidal efficacy, selectivity, and yield. It caused no visible symptoms of phytotoxicity and yielded the highest yields among the herbicide treatments, with 2,321 kg/ha in 2022 and 2,430 kg/ha in 2023. In contrast, despite its superior weed control efficacy, T3 applied with 2 L/ha of 2,4-D resulted in more pronounced symptoms of phytotoxicity and lower yields.

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