Original Article:

Diversity, structure, and dynamics of weeds in rainfed rice cultivation at badiatte and essyl, ziguinchor (senegal)

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Citation Diallo A. , Diedhiou M.A.A., Sambou A. , Goudiaby A.O.K., Sagna N.G., Senghor R.G.I., 2022. Tillage coupled with crop establishment methods and zinc application influences weed dynamics and yield of direct-seeded rice, 5(2), 105-117.

http://dx.doi.org/10.26655/JRWEEDSCI.2022.5.4

Article info

Received: 2022-05-06
Accepted: 2022-10-07

Checked for Plagiarism: Yes.

Peer reviewers approved by: Dr. Mohammad Mehdizadeh

Editor who approved publication: Dr. Amin Baghizadeh

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Keywords: Rainfed Rice; Weed; Structure, Diversity, Dynamics, Cultivation Practices.

ABSTRACT

Over the past decades, human and natural changes had led to an increase in the diversity and abundance of weeds in cultivated lands of not only Senegal, but also across the world. However, weed structure and dynamics were not well-known by local populations. This research intended to study some cultural practices and some factors that can influence the weeds presence in rice crops. Therefore, a survey and inventory were carried out at Badiatte and Essyl. Interviews by using a questionnaire were done on cultural practices and perceptions of local populations. To study the dynamics and structure of weeds, the quadrant point method was used. Abiotic factors that can influence the weeds presence, such as soil texture and pH were determined. In total, 31 species belonging to 25 genera and 11 families were inventoried in the two villages. The *Cyperaceae* (*Cyperus rotundus* L., *Cyperus esculentus* L., *Killinga pumila* Michx., *Cyperus amabilis* Vahl, *Fimbristylis littoralis* Gaudich, *Pycreus macrostachyos* Lam., *Schoenoplectus senegalensis* Steud., *Fimbristylis hispidula* (Vahl) Kunth followed by *Fabaceae* (*Desmodium triflorum* L.), and *Amaranthaceae* (*Amaranthus viridis* L.) were most abundant in terms of individuals. The specific diversity was higher in Badiatte. The structure and dynamics of weeds changed over time due to the agricultural practices and management. They differed from one site to another depending on maintenance practices, soil preparation, and environmental conditions. The weeds evolution was influenced by soil proprieties and cultural practices (ploughing, varieties cultivated, weeding, and fertilization).

Introduction

In Senegal, arable lands are estimated to 3.8 million hectares, which is assumed to be approximately 20% of the surface area of the country. These lands are unevenly distributed across the agro-geographic zones as 57% in the Groundnut Basin, 20% in Casamance, 10% in Eastern Senegal, 8% in the Senegal River, 4% in the sylvo-pastoral zone (Ferlo), and 1% in the Niayes (Sylla, 2015). The cultivated area is about 2.5 million hectares per year and only 2% is devoted to irrigated crops, developed mainly in the Senegal River valley (FAO, 2011). According to Sylla (2015), the four main cereal crops grown are millet, sorghum, maize, and rice. The rainfed rice is one of the most important crops in terms of production, and concentrated mainly in Casamance, the southeastern Senegal, and southern groundnut basin (FAO, 2013; ANSD, 2014; Ka and et *al*., 2020). Over the past decades, Senegal was one of the largest consumers of rice in West Africa with an average rice consumption of 90 kg per capita per year (Diagne, 2018). Senegalese rice farming is mainly practiced by smallholders and directly supported between 200,000 and 300,000 households with at least 1.5 million people, most of whom relied on rice as a staple food (Kouakou, 2017). However, national rice production could only cover between 20 and 30% of national rice demand. This dependence on rice importation for such a strategic food staple has remained a major concern of the Government since the early 2000s. In 2008, the National Rice Self-Sufficiency Program was set up to counteract this dependence. This program was part of the national strategy to fight poverty.

Rice yield losses varied from 50 to 90% and were due to inadequate weed control (Chauhan and Openña, 2012). Despite the efforts to increase rice yields, low yields remained due to certain factors, including irregular rainfall, low soil fertility, poor management of rice plots, and the weeds presence. Weeds competed with crops for nutrients, light, and water (Yildirim and Turna, 2016). Thus, to control these weeds, farmers adopted manual technique which is tedious and ineffective as they come back just a few days after weeding. The most appropriate weed management strategies depended on the means available to these farmers, but were likely to combine the following elements: fallow systems, soil preparation, crop competitiveness, water management, manual weeding, and herbicide use (Johnson, 1997).

A thorough knowledge of weeds in rice field and associated cropping practices is necessary for effective weed control. We hypothesized that agricultural practices and environmental factors play an important role in the spatial and temporal distributions of weeds. The objective of this study is to contribute to a better knowledge of the weeds that accompany rained rice cultivation in relation to cropping practices for better management of weed species.

Materials and Methods

Study site and climate

This study was carried out at two villages (Badiatte and Essyl) located in Enampore commune. This commune is located between longitude 16° 26′ 56″ West and latitude 12° 30′ 42″ North (Sow, 2014) in the province and district of Ziguinchor (Figure 1). The climate is characterized by the southern Sudanese-Guinean type dominated by two seasons: a dry season from November to May and a rainy season from June to October. The annual average temperature of the area is about 27 °C with thermal amplitude of 22 °C (April: 37 °C - January: 20 °C). The rainfall in Enampore commune has varied over the past ten years between 1000 and 1600 mm (PDD, 2016). Except for the year 2004, the commune has recorded rainfall above 1000 mm during the decade. The ten-year average is 1250 mm, which makes the area favourable for rain-fed crop development (PDD, 2016).

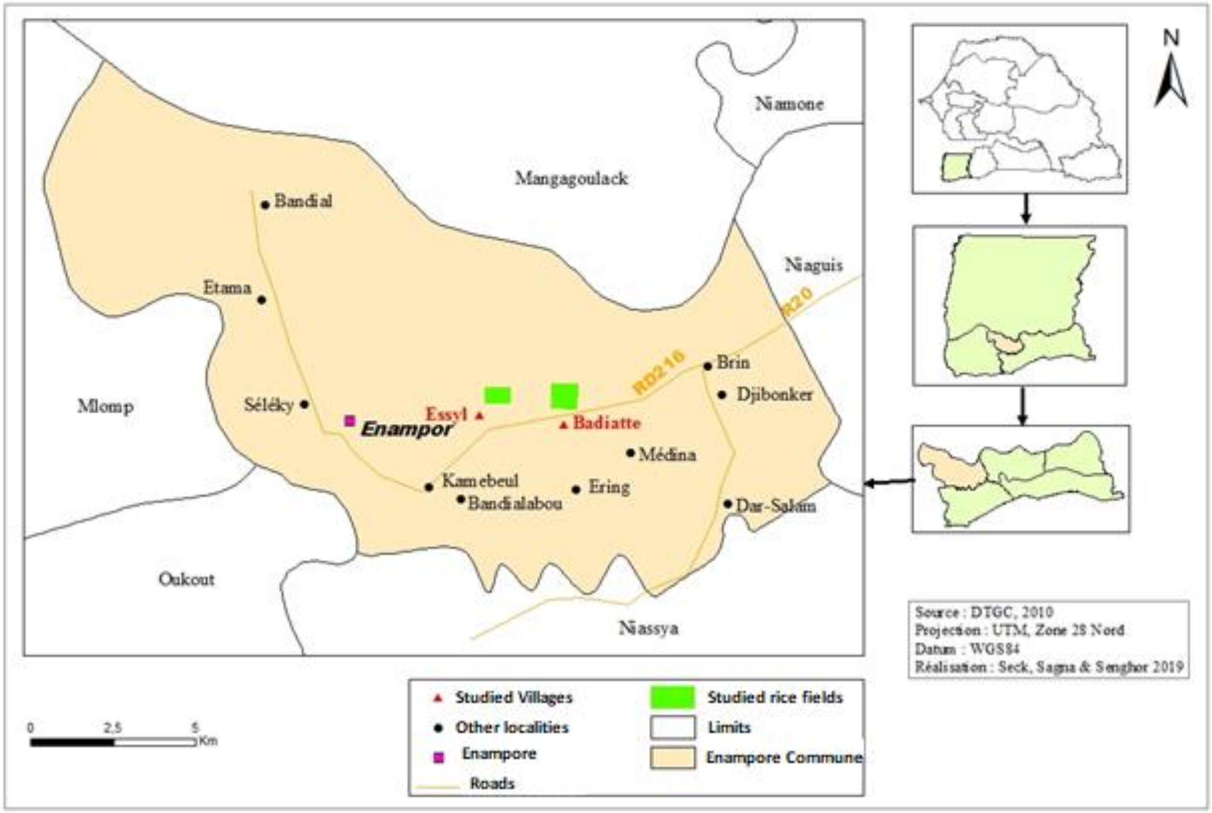

Figure 1. Location of study area

Data collection

Floristic inventory

The quadrant point method (Figure 2), developed by Levy and Madden (1933), was used to study herbaceous vegetation. In each quadrant, the floristic composition, the horizontal structure (cover) and vertical (height) of the vegetation were determined. The principle of the method was to carry out observations (presence) or measurements (counting the number of contacts) in the vegetation, at regular intervals along a line. The method was based on the fact that it was possible, when the number of observation or measurement points becomes high enough, to equate a frequency with a cover. The simplest protocol adapted by Daget and Poissonet (1971) was used in this study. These measurements are preferably made on days with low wind for more accuracy.

The work began 15 to 20 days after transplanting and was done over three times separated by periods of 15 days (Table 1).

Species were identified in the field by using Flowering Plants of Tropical Africa (Lebrun and Stork, 1991, 1992, 1995, and 1997), weeds in Rice Cultivation in West Africa (Johnson, 1997), Adventrop (Weeds of Sudano-Sahelian Africa) (Le Bourgeois and Merlier, 1995), and with the PLANTNET application. The data obtained with the quadrant point method were used to determine:

- **Contact Specific Contribution (CSC)**: The ratio of the number of contacts of one species to the sum of the contacts of all species (expressed as a percentage).

$$\mathrm{CSCi} = \frac{\mathrm{Ci} * 100}{\mathrm{Cn}} \qquad (1)$$

Ci = Number of contacts for species (i)

Cn = Total number of contacts.

- **Specific frequency (SF):** percentage of points where the species was encountered.

$$\mathrm{FS\%} = \frac{\mathrm{ni} * 100}{\mathrm{N}} \qquad (2)$$

ni= Number of samples where the species was recorded

N= Total samples

- **Specific contribution presence (SCP)**: The ratio of the specific frequency of a species to the sum of the specific frequencies of all species. It expresses the relative importance of species at different periods and reminds the index of abundance dominance.

$$SCP\% = \frac{SFi*100}{\sum SFi} \quad (3)$$

- Richness (S), diversity, and ecological distance were determined. Shannon diversity index (H') was determined by using the following formula :

$$\mathbf{H'} = -\sum_{i=1}^{S} p_i \ln(p_i) \quad (4)$$

H'= Shannon index

pi= relative abundance

Pielou evenness (J) was also calculated by using the following formula:

$$J = H'/lnS \quad (5)$$

Ecological distance of Jaccard (J') was determined:

$$\mathbf{J'} = 1 - \frac{\sum \min(ai,bi)}{\sum \max(ai,bi)} \quad (6)$$

a_i = Abundance of species i in site A

b_i = Abundance of species i in site B

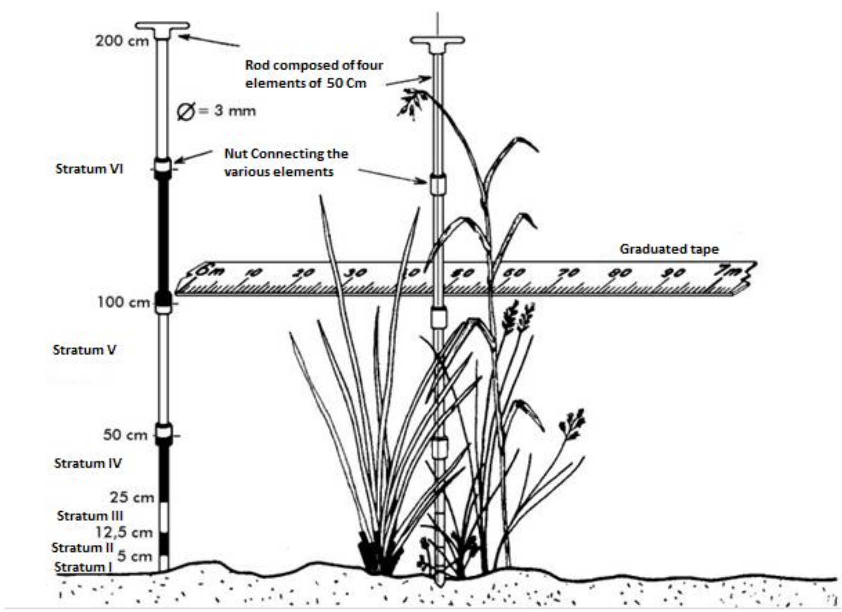

Figure 2. Illustrative diagram of the quadrant point method (Daget and Poissonet, 2010).

Table 1. Chronology of the inventories at the level of the fixed plots

Sites	Plots	Periods	Inventory date
Badiatte	1	1	23 september 2019
		2	08 october 2019
		3	23 octobre 2019
	2	1	24 september 2019
		2	09 october 2019
		3	24 october 2019
Essyl	1	1	25 september 2019
		2	10 october 2019
		3	25 october 2019
	2	1	25 september 2019
		2	10 october 2019
		3	25 october 2019

Soil samples

Soil sampling was collected in each experimental plot. Samples were taken along the diagonals of the plot. Each diagonal was divided into four parts and samples were taken from the 0-20 cm horizon by using an auger. These samples were mixed in pairs to form two composite samples per diagonal. The granulometric analysis was done in the laboratory of the Agroforestry Department of the Assane SECK University of Ziguinchor by using a granulometer.

The soil pH was measured on a solution suspension by the electrometric method with electrode pH meter (AFNOR, 1999). To do this, 10 g of soil sieved to 2 mm was added to 25 ml of distilled water and the solution was stirred and left to rest for 30 min and the pH was read with a pH meter calibrated at 7 and 4.

Data treatment and analysis

Sphinx software was utilized to process the survey data and the French classification to determine the rate of silt, clay, and sand. Data in community and environmental matrices were analyzed by BiodiversityR (3.0.3) to compare species richness, diversity, and ecological distance as spatial and temporal function of sampling by pooling increased numbers of samples within sites.

Results and Discussion

Taxonomic diversity

The herbaceous flora recorded in Essyl and Badiatte villages was composed of 11 families, 25 genera, and 31 species. The most abundant families were *Cyperaceae* (24.4%), *Fabaceae* (20.3%), *Amaranthaceae* (13.8%), *Sterculiaceae* (11.6%), and *Poaceae* (8.9%). The other families were poorly represented in the area. The most abundant species was *Desmodium triflorum* (L.) DC. Which was belonged to *Fabaceae*. The most represented genera were *Cyperus* (four species) and *Acrocera* (two species). This floristic composition is variable according to the period and the site. The diversity of the species varies according to the time. However, the species were more abundant during the third period (Table 2). The most important family were *Poaceae* and *Cyperaceae*. These two families were further dominant in the weed flora of food crops in the Groundnut Basin (Noba et al., 2004). This result was similar to that of several researchers in West Africa (Pocanam, 2003; Traore and Mangara, 2009; Kouamé and al., 2011; Diagne, 1995; Mballo, 2018), but different from those of Ka *et al.* (2020), for whom the Poaceae were the most important followed by Fabaceae and Malvaceae. On the other hand, the most frequent species was belonged to Fabaceae family. However, the Cyperaceae family was more abundant. The spatial distribution of species was different. *Nelsonia canescens* (Lam.) Spreng. was found in non-flooded areas. *Cyperus amabilis* Vahl, *Amaranthus viridis* L., and *Merremia tridentata* (L.) Hallier f. were generally found in submerged areas or very wet areas.

Table 2. Herbaceous floristic of composition by period and site

	Period 1				Period2				Period3				Total
	BP1	BP2	EP1	EP2	BP1	BP2	EP1	EP2	BP1	BP2	EP1	EP2	
Famillies	7	6	5	4	9	7	5	7	8	8	4	7	11
Genera	8	8	6	4	17	9	6	11	16	12	8	13	25
Species	9	8	6	4	19	9	6	12	21	14	8	15	31

Period 1, 2, and 3 were, respectively, the first, the second, and the third period of inventory; BP1 = Badiatte plot 1, BP2 = Badiatte plot 2, EP1 = Essyl plot 1, and EP2 = Essyl plot 2.

Richness and diversity

Species richness and diversity increased over time in the different plots. However, they were more important in the Badiatte plots. The evenness was different in Badiatte plots. In Essyl plots, evenness decreased over time (Tables 3 and 4). During the first two periods, the species abundance in the Badiatte fields was increased considerably, and then it was decreased significantly during the third period (Figures 3 and 4). In the Essyl plots, the species abundance was increased slightly over the time.

Table 3. Richness and diversity by site

Plots/Periods	Richness	Shannon index	Pielou index
BPR1	13	1,9098	0,7446
BPR2	22	2,3157	0,7491
BPR3	25	2,3571	0,7323
EPR1	8	1,6598	0,7982
EPR2	14	1,9041	0,7215
EPR3	15	1,8887	0,6975

Table 4. Richess and diversity according to periods

Plots/Periods	Richness	Shannon index	Pielou index
EP1R1	6	1,3696	0,7644
EP1R2	7	1,0608	0,5451
EP1R3	9	1,2195	0,5550
EP2R1	4	1,2570	0,9067
EP2R2	12	2,1055	0,8473
EP2R3	15	2,2289	0,8231
BP1R1	9	1,7081	0,7774
BP1R2	18	2,1594	0,7471
BP1R3	22	2,1383	0,6918
BP2R1	8	1,9702	0,9475
BP2R2	10	1,9481	0,8461
BP2R3	14	2,3092	0,8750

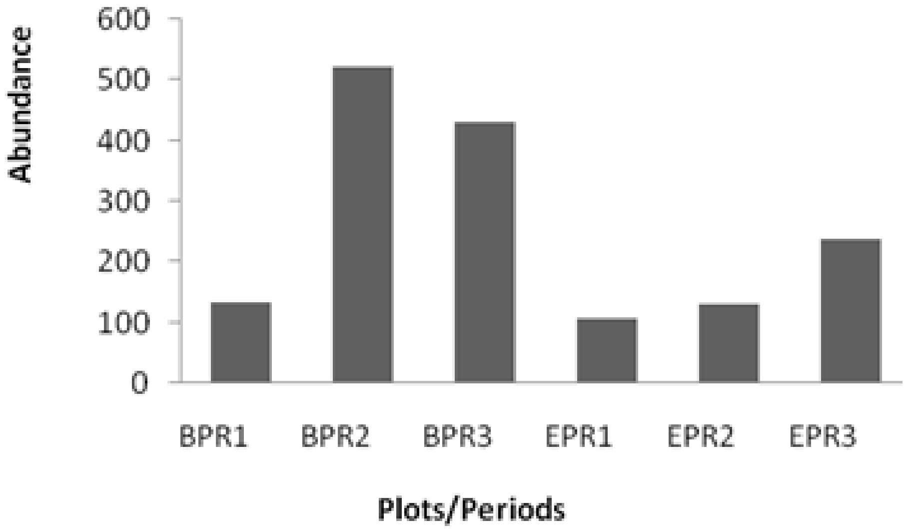

Figure 3. Abundance of species between periods and plots

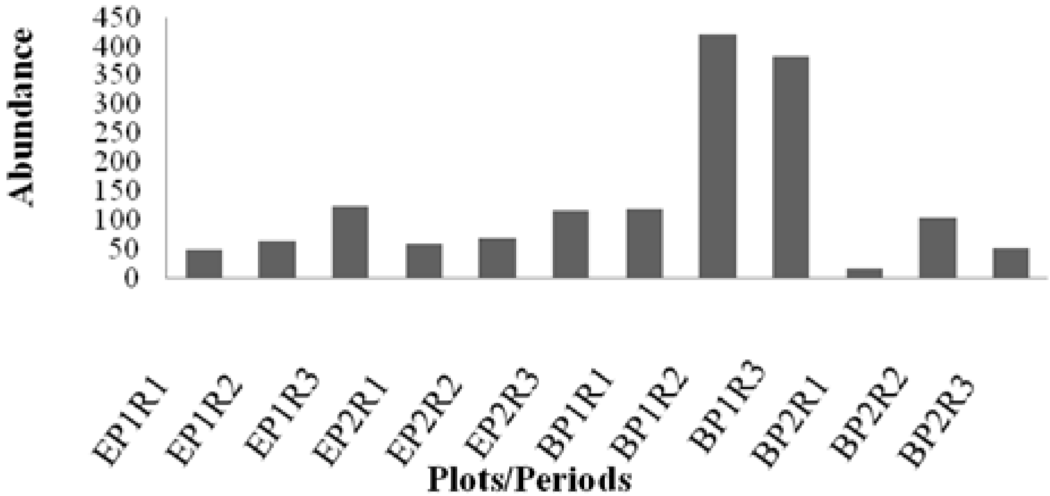

Figure 4. Abundance of species according to plots and periods

Several rice varieties were grown in the study area. The varieties grown in the experimental plots were NERICA, Sahel-108, and Tox-728-1. For ploughing, people used tractors, “kadiandou”, or a combination of the two. The crops were either not maintained, or maintained with weeding and fertilization. The types of variety, ploughing, maintenance, and soil pH influenced the richness, diversity, and abundance of weeds. In the plots cultivated with the Sahel 108 variety, there were fewer species and individuals than in the other plots. However, the highest Shannon and Pielou indices were recorded in the second plots of Badiatte and Essyl (Table 5). The low abundance was recorded in the plot cultivated with "kadiandou" and not maintained. In not maintained plot cultivated with "kadiandou and tractor", there were many more species and a greater abundance than in the plots cultivated with tractor and kadiandou or tractor only. High species richness and abundance were recorded in the plots with high pH. Research has shown that rice cultivation is the main activity during the rainy season. Farmers have begun to change their production patterns. According to Akintayo *et al.* (2008), traditional cropping systems are partly responsible for soil erosion, fertility deterioration, and water deficit in tropical rainfed rice growing areas. The major problem for farmers is the weed invasion. During three periods, many species of weed were recorded in the study area. The factors determining the heterogeneity of this herbaceous vegetation in this area was abiotic factors mainly water, soil type, and topography (Diallo, 2011). In the Badiatte plots, the abundance of species was increased over time. However, there were few individuals on the second plot in Badiatte. The weeds abundance in the first plot of Badiatte was due to the fact that the plot was plowed with tractor and kadiandou. Indeed, during this plowing, the reproductive parts of the weeds were brought to the surface, thus causing their regeneration. This combined with the absence of weeding could explain the appearance of new species during the different periods. According to Le Bourgeois and Merlier (1995), shallow plowing (12 cm deep) and deep motorized plowing (20 cm deep) provide the best burial but bring up the seeds located deep in the soil. A soil with a high percentage of fine sand and silt-clay had more water retention and therefore fewer weeds. However, clay soil was not good for weeds or for crops because water infiltration was limited. The clay content also influenced the capacity of the soil to fix organic matter, and thus the fertility and pH (Le Bourgeois and Merlier, 1995). Weed growth was less significant in the first Essyl plot during different periods. The specific richness was lower in the plots where the soil pH is very acid. According to Zingore *et al.* (2014), if the pH is acid, there is a risk of aluminium toxicity and low phosphorus availability. Indeed, in hydromorphic soils poor in phosphorus, *Cyperaceae* are more adapted than Grasses (Cirad-ES, 2014).

Table 5. Environmental factors influencing abundance, richness, and diversity of weeds

Plots	pH	Varieties	Tools	Maintenance	Richness	Shannon	Pielou	Abundance
BP1	4,34	NERICA	T+K	NON	23	2,2328	0,7121	919
BP2	4,12	Sahel-108	K	NON	17	2,4306	0,8579	167
EP1	3,50	Sahel-108	T+K	W+F	15	1,5483	0,5717	234
EP2	4,00	Tox-728-1	T	D	17	2,2443	0,7921	242

T= tractor, K= kadiandou, NON= non maintenance, W= weeding, and F= fertilisation.

Ecological distance

The floristic composition of weeds varies with plot and time. When comparing the ecological distance between plots, the dissimilarity varies from plot to plot. Dissimilarity between plots is quite high ranging from 56 to 94%. The highest dissimilarity (90 to 94%) was noted between Badiatte plot 1 and Essyl plots as well as between Essyl plot 3 and Badiatte plots (Table 6). The dissimilarity between periods ranged from 50 to 99%. The high dissimilarities (90 and 99%) were noted between the three periods of Badiatte and Essyl plots (Table 7).

Table 6. Dissimilarity between plots

	BR1	BR2	BR3	ER1	ER2
BR2	0,7571				
BR3	0,7522	0,5712			
ER1	0,7680	0,9021	0,8647		
ER2	0,8771	0,9190	0,8960	0,6243	
ER3	0,9400	0,9444	0,9122	0,7306	0,5659

Table 7. Dissimilarity between periods

	EP1R1	EPR2	EP1R3	EP2R1	EP2R2	EP2R3	BP1R1	BP1R2	BP1R3	BP2R1	BP2R2
EP1R2	0,6341										
EP1R3	0,7872	0,5878									
EP2R1	0,8222	0,8889	0,9151								
EP2R2	0,7446	0,7547	0,8210	0,6596							
EP2R3	0,7404	0,7394	0,6244	0,7279	0,5659						
BP1R1	0,9161	0,9357	0,9874	0,8188	0,9195	0,9318					
BP1R2	0,9600	0,9657	0,9812	0,9399	0,9322	0,9530	0,7221				
BP1R3	0,9512	0,9698	0,9797	0,9265	0,9362	0,9357	0,7469	0,4962			
BP2R1	0,8750	0,9733	0,9925	0,9242	0,8933	0,9430	0,9527	0,9788	0,9767		
BP2R2	0,8905	0,9625	0,9955	0,7302	0,8831	0,8826	0,6706	0,8296	0,8718	0,9065	
BP2R3	0,7625	0,8105	0,8974	0,8369	0,7604	0,7883	0,9167	0,9601	0,9436	0,8965	0,9149

Structure and Dynamics of weeds

In the first plot of Badiatte, a variation in structure was noted over time. First, the weeds were characterized by species not exceeding 40 cm in height. The species that were found at the ground level were important. There were mainly *Desmodium triflorum*, *Melochia nodiflora* Sw, *Amaranthus viridis*, and *Cyperus esculentus* L. Then, some species (*Digitaria horizontalis* Willd. and *Paspalum vaginatum* Sw.) were evolved to reach a height between 60 and 70 cm. There were less species (*Desmodium triflorum* and *Melochia nodiflora*) at the ground level. Finally, the number of species at ground level increased during the third measurement period. 18% of the species had a height between 10 and 20 cm. Only 2% of the species (*Cyperus rotundus* L.) had a height between 40 and 50 cm (Figure 5).

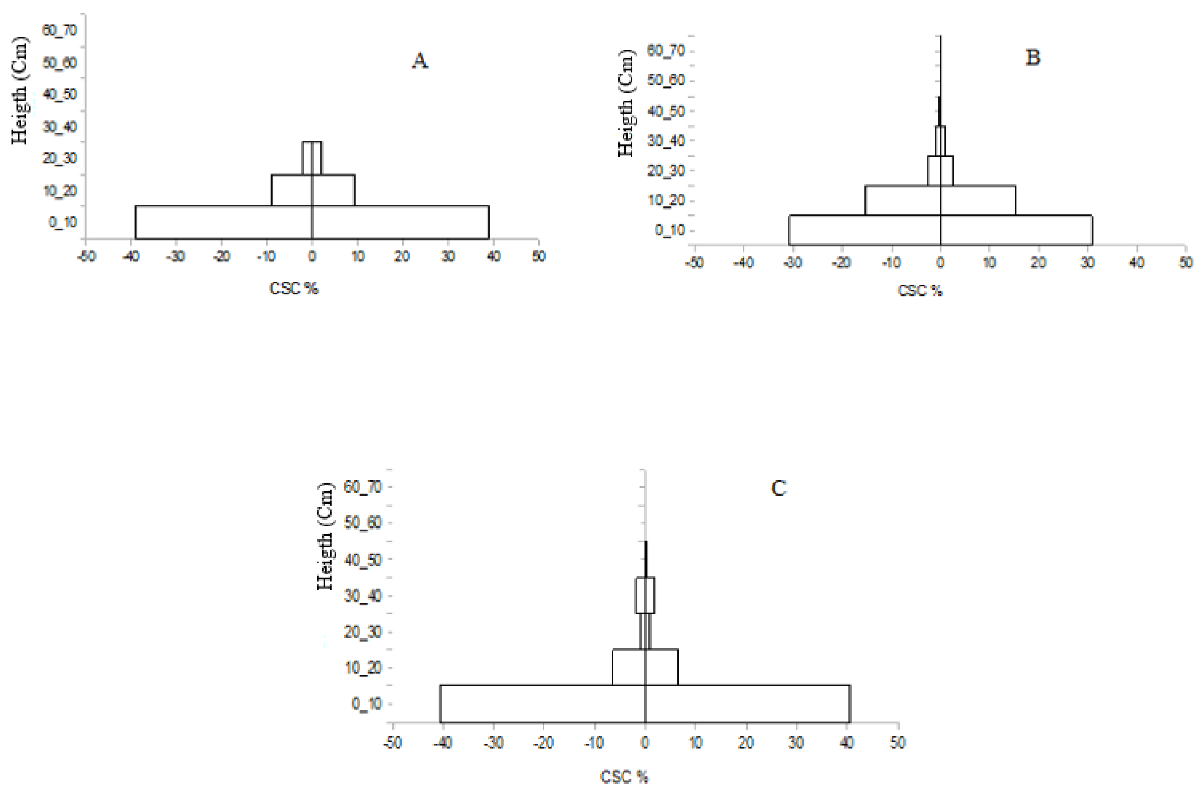

Figure 5. Weed stratification of the first plot of Badiatte according to the first (A), the second (B), and the third (C) period

In the second plot at Badiatte, a change in the vertical structure of weeds from the first to the third survey period was noted. At the beginning, the species are mostly at the ground level. Only *Acroceras amplectens* Stapf exceeded 10 cm. However, in the second period, many individuals (95%) had a height between 0 and 10 cm. Only *Melochia nodiflora* and *Acrocera amplectens* reached a height between 20 and 30 cm. In the third period, the number of species at the ground level was decreased considerably. 72% of the species (*Amaranthus viridis and Cyperus amabilis Vahl*) had a height between 0 and 10 cm, 20% a height between 10 and 20 cm, and 8% (*Calopogonium mucunoides* Desv. and *Spermacoce verticilata* L.) with a height between 20 and 40 cm (Figure 6).

In the first plot of Essyl, the species were mostly at ground level. 98% of the individuals had a height between 0 and 10 cm. In the second period, the height of the weeds was characterized by the species presence with a height between 0 and 20 cm. The number of species was decreased at the ground level. In the third period, the number of species at the ground level was increased considerably, as compared with the second period. *Spermacoce verticilata* was the most frequently recorded species (Figure 7).

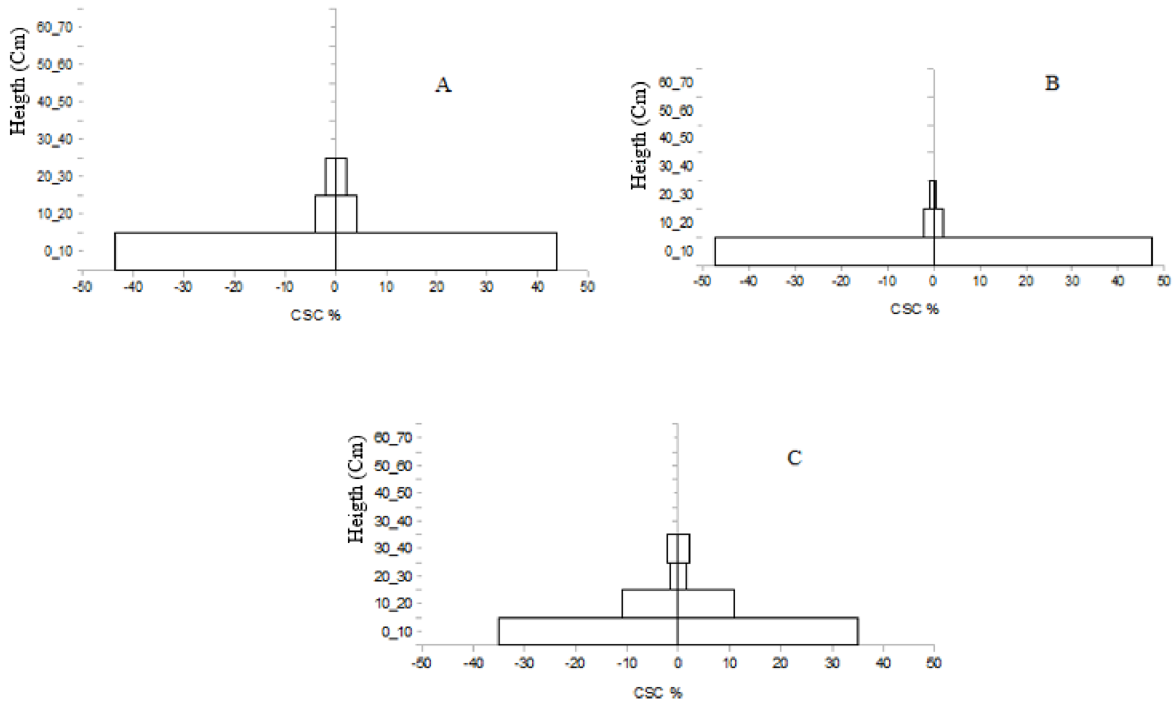

Figure 6. Weed stratification of the second Badiatte plot according to the first (A), the second (B), and the third (C) period

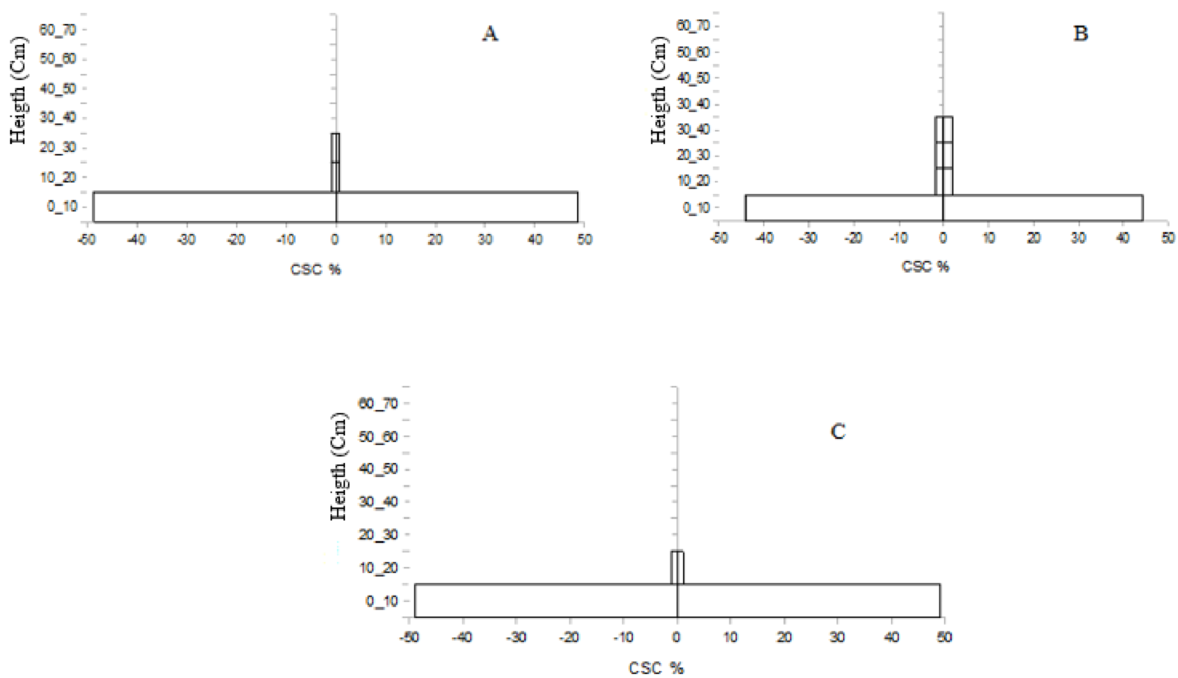

Figure 7. Weed stratification of the first Essyl plot according to the first (A), the second (B), and the third (C) period

In the second plot in Essyl, species recorded in ground level were more abundant during the first survey period. Species such as *Echinochloa stagnina* (Retz.), P. Beauv., and *Amaranthus viridis* had a height between 10 and 20 cm. In the second period, the number of species at the ground level was decreased considerably, as compared with the first period. 46% of the individuals had a height between 0 and 10 cm, 34% between 10 and 20 cm, 8% between 20 and 30 cm, and 12% between 30 and 40 cm. *Digitaria horizontalis*, *Echinochloa stagnina*, and *Pycreus macrostachyos* Lam recorded the greatest heights. Some species reached 50 cm during the third measurement period. The most frequent species were *Spermacoce verticilata* and *Cyperus amabilis* Vahl (Figure 8). The species at the ground level had a higher contact contribution than the tall species in the surveys of the first plot of Essyl. Few species that growed up overtime were *Pycreus macrostachyos*, *Echinochloa stagnina*, and *Digitaria horizontalis*. As the weeding was done manually, species such as *Pycreus macrostachyos* Lam. were difficult to be removed because of their strong stems. As in the Badiatte plot, the weeds abundance is favoured by the double tillage. During the first period, almost all species in the second Essyl plot were low to the ground. This would be due to the fact that the plot was 60% submerged in water. According to Johnson (1997), rice grew well in the flooded soils, and standing under a 10 cm high water table prevented germination and destroyed the seedlings of most weeds. These similar facts are observed during the third period. However, the number of tall species decreased due to partial weeding (Soro et al., 2018). The difference observed in weed dynamics and structure between the two plots in Essyl and Badiatte can be explained by the difference in soil texture composition. Indeed, soil texture conditioned water availability for vegetation and contributed to the expression of soil climate, which was sometimes more important for plants than climate itself (Le Bourgeois and Merlier, 1995).

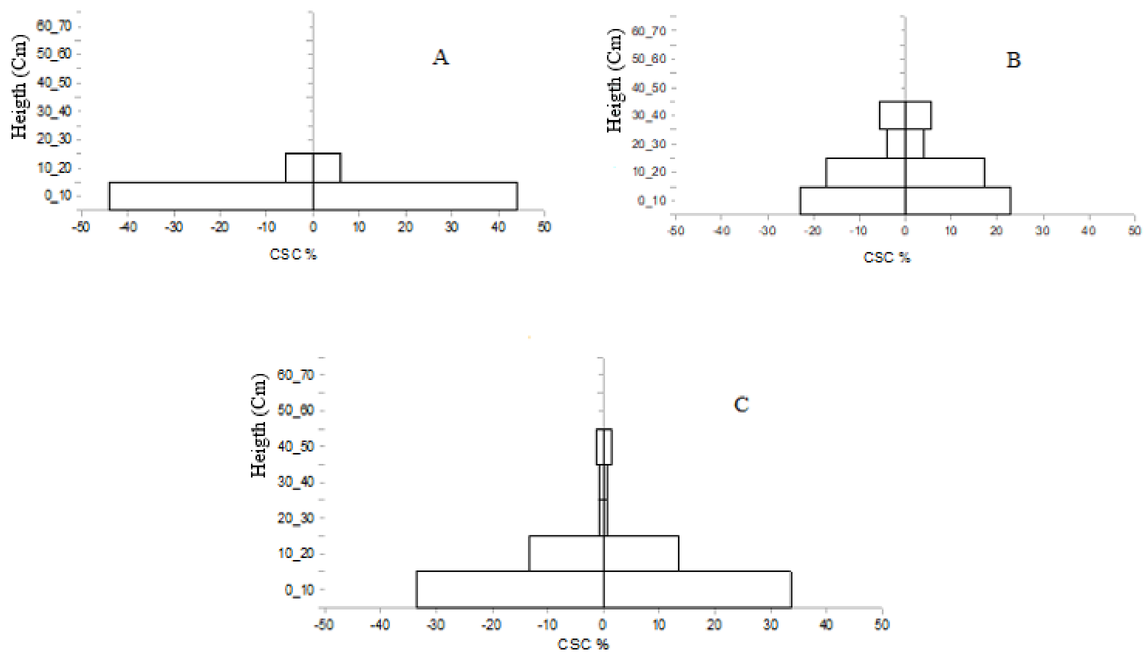

Figure 8. Weed stratification of the second Essyl plot according to the first (A), the second (B), and the third (C) period

Conclusion

The study area was rich and diversified in weed species. 31 species of weeds were recorded in the two studied sites. The highest species richness was observed in the first plot of Badiatte. The species are more diversified in the second plot of Badiatte. The *Cyperaceae* family is more abundant in both fields. The spatial and temporal distribution of weeds was influenced by the agricultural practices and the environmental factors including soil pH and humidity, which favoured the germination of several weeds. Poor tillage practices combined with high soil moisture accentuate the weeds abundance in the plots. Plowed soils recorded fewer weeds than other soils. Thus, to control these weeds, a good plowing and water management are necessary.

Conflict of interest

The authors certify that they have no affiliations with or involvement in any organization or entity with any financial interest (such as honoraria, educational grants, participation in speakers' bureaus, membership, employment, consultancies, stock ownership, or other equity interest, and expert testimony, or patent-licensing arrangements), or non-financial interest (such as personal or professional relationships, affiliations, knowledge, or beliefs) in the subject matter or materials discussed in this manuscript.

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