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Importance of the critical period for weedkilling millet (*Pennisetum glaucum* (L.) R. Br.) in eastern Southeast Niger

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Abstract

Weed infestation is, after the negative effects of climate variability and change, the second most important factor in grain reduction. The present study, carried out in the south-east of Niger, aims to determine the weeding period that can influence millet production. The experimental set-up used is a complete Fisher block, comprising 36 elementary plots divided into seven dates of manual weeding carried out with a hoe, and subjected to two series of early and late competitions. The study focused on determining the critical weeding period, the relative frequency, density and fresh biomass of weeds and the plot weight of millet. One-factor analysis of variance (ANOVA) and Duncan's test were used to compare yield obtained according to treatment type at $P \leq 0.05$. The results revealed that the best yields were obtained on the control plots (2268.75 Kg/ha), the mulched plots (1920 Kg/ha) and the plots maintained according to farmers' practice (1896 Kg/ha). Early, critical and late competition thresholds (21, 28 and 35 days after sowing respectively) were also determined. These results could help improve weed management in millet cultivation.

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Introduction

Millet [*Pennisetum glaucum* (L.) R. Br.] is the main staple food of Sahelian people and livestock (FAOSTAT, 2022). It is generally the best crop adapted to the hot temperatures, dry and infertile soils of arid and semi-arid tropical regions (Boubacar *et al.*, 2010 cited by Lawali, 2017).

Since the 1960s, cultivated areas in Niger have been steadily increasing. Areas sown to millet represent 6 million hectares (Ministère l'Agriculture et de l'Elevage du Niger, 2013) out of the 8 million cultivated annually under rainfed crops, i.e. 75% of cultivated areas (Amokou, 2013 cited by Lawali, 2017). However, millet production has low yields and is generally confined to subsistence cropping (Siaka *et al.*, 2004). Indeed, food security still remains a major challenge in the world and in Africa in particular (Niangado and Ouendeba, 1987). Promoting local cereal production at a level higher than population growth is a priority among food security initiatives (Ifeanyieze *et al.*, 2016). To achieve food security for growing populations, it is essential to focus on the factors that contribute to good cereal production, including production techniques (Traoré *et al.*, 2022).

In order to improve these techniques, it is necessary to take stock of producers' cropping habits, so as to better assess them and propose solutions to the difficulties encountered (Soumana, 2001). With this in mind, the present study was carried out in the Department of Illéla, part of Niger's agropastoral zone. The practice of millet cultivation is therefore propitious due to the favorable natural conditions (Médecins Du Monde, 2014). Despite these potentialities, millet production remains low due to the regular and accelerated decline in yields, one of the causes of which is weed pressure (Kadri *et al.*, 2019; Soumaila, 2024). Thus, weed control constraints occupy an important place among the factors that reduce yields and are often at the root of the very low productivity of certain crops. Average crop losses due to weeds are around 44.41%, and can reach 89.28% in maize crops (Mahamane, 2013). In the current context, where weed control is made difficult by unsuitable technical itineraries and the use of inefficient traditional tools, how can good crop weeding be achieved in order to improve yields? This study, which aims to improve millet yields, addresses this concern. The main objective of the study was to determine the critical period for the first weeding, and to compare the impact of weeding on the relative frequency, cover, density and fresh biomass of weeds and the plot weight of millet plants.

Materials and methods

Study area

This study was carried out in the Department of Illéla, one of the departments of the Tahoua region located in the east-southeast of Niger (Fig.1.). This department covers an area of 6933 km2 or 0.54% of the national territory (Dillo, 2020).

The population of Illéla Department is estimated at 366704 (Institut National de Statistique du Niger, 2011). It is an agro-pastoral zone with rainfall ranging from 300 to 600 mm (Kadri *et al.*, 2019). The vegetative growth period varies between 75 and 100 days. Soils planted with millet are essentially dune soils, poor in organic matter, phosphorus and nitrogen. They are leached, very poorly structured and do not facilitate good water retention for crops (Siaka *et al.*, 2004; Kadri *et al.*, 2019). Intercroping of pearl millet with cowpea constitue the dominant cropping system in the study area. Fallow land is tending to disappear. Farmers use almost no agricultural inputs (Médecins Du Monde report, 2014).

Population and socio-economic activities

The Department of Illéla is mainly populated by the Hausa (Médecins du Monde report, 2014). There are also Tuareg and Peulh. In addition to these populations, there are non-Nigerians from the Economic Community of West African States (ECOWAS), mainly Nigerians, Beninese, Togolese and Ghanaians. Agriculture is the main activity in this department (Dillo, 2020). There are food crops (millet, sorghum, cowpeas, beans, voandzou), vegetables (dolic, onions, potatoes, melons, okra, squash, lettuce, chillies, tomatoes, cabbage, peppers, carrots, etc.) and cash crops (groundnuts, mangoes, guava, sesame, etc.). In addition, there is livestock farming (cattle, sheep, goats, donkeys, camels, horses and poultry) and fishing, which is of little interest to the local population (Dillo, 2020).

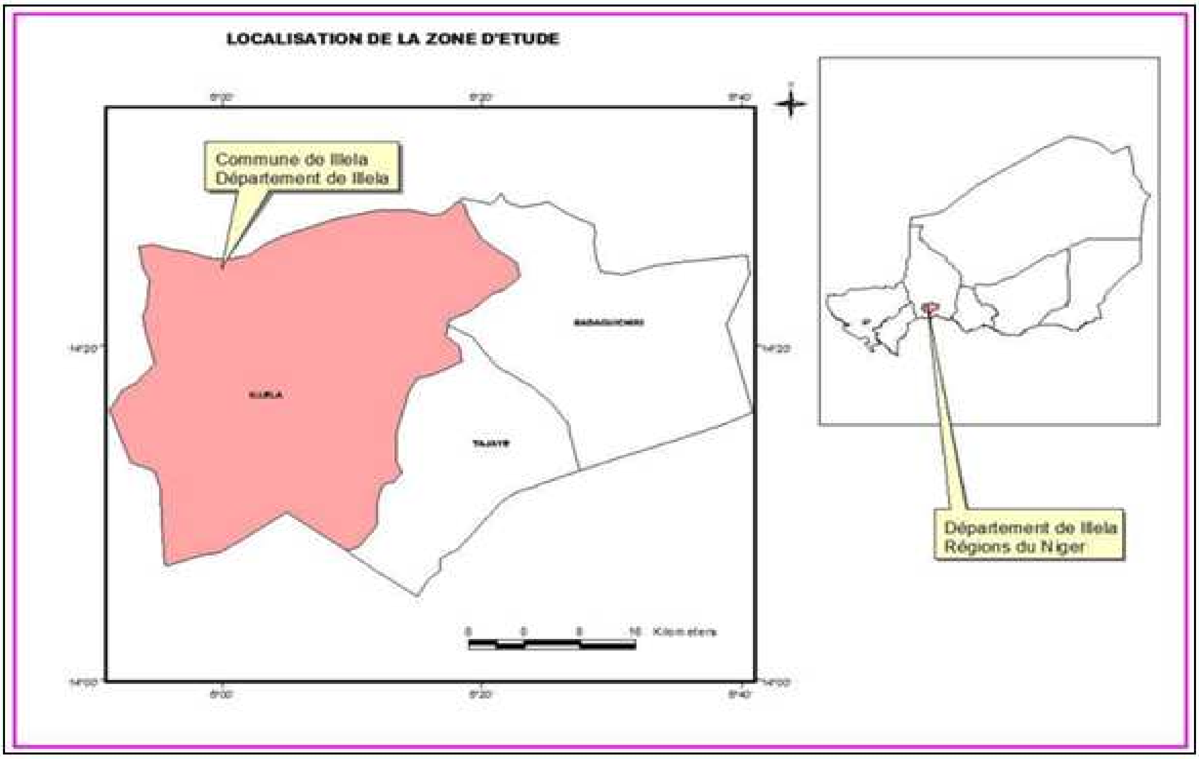

Fig. 1. Map of study area (MAG/EL, 2019).

Biological material

The biological material used for this work is millet seedlings of the early local variety (crop cycle 75 to 100 days) known in Hausa as "Guèrguéra", and weed seedlings.

Pearl millet is generally more tolerant of variability, climate change and water stress. The study focused on the local millet variety « Guèreguéra ». This variety is mainly cultivated by local populations. It is the staple food of the local population. This local variety of pearl millet is a subsistence crop. «Guèreguera » is cultivated by all farmers (there is no farmer without a field of millet in this locality).

Technical equipment

The technical equipment includes a GPS (Global Positioning System) to locate the experimental site, a balance to weigh the crops and software (Microsoft word, Microsoft Excel and R version 4.4.1) for data entry, processing and analysis.

Methodology

Choice of study site

The choice of the study site was guided by its accessibility thanks to the existence of a good road network and the prevailing social security.

Determining the critical period for first weeding

In this study, the method for determining the critical period of competition between weeds and crops, based on the work of Niéto, Peters, Wearer and Dawson cited by Caussanel (1989), was applied. It consists in using the results of a two-test study to analyze yield as a function of the duration of competition.

The first type of test consists in allowing weeds to develop for increasingly long periods after sowing before eliminating them, to determine early competition (Cp); the second type consists in keeping the crop clean from sowing until increasingly later dates to observe late competition (Ct).

Experimental design

The experimental design used is a randomized Fisher block design. It comprises four (4) replicates. Each elementary plot covers an area of 4 m² (2 m x 2 m) and is composed of two (2) crop lines, spaced one meter (1 m) apart. Each cultivation line is located 40 cm from the boundary of the elementary plot and comprises four (4) bunches 40 cm apart. Each plot contains five (5) millet plants. The distance between plots in the same block is one meter (1 m) and two meters (2 m) between blocks. On each elementary plot, there are forty (40) millet plants. Observations were made on ten millet plants belonging to the four central blocks per elementary plot. Work took place during the 2023 and 2024 crop years.

No fertilizer was applied to any of the plots. None of the plots were fertilized, in keeping with the growing conditions of pearl millet growers in the study area (few growers apply fertilizer here).

Treatments

On each elementary plot there were 40 millet plants. The different treatments for the two test types are defined in Fig.2. Plots for the early competition type (Cp) are weeded from the date shown in Fig.2. The following weeding period lasts 14 days until the crop has developed sufficiently. On the other hand, in the late competition type (Ct), plots are kept clean from sowing to the last weeding date shown in Fig.2. The first maintenance began 14 days after sowing, with a subsequent rhythm of two weeks. The clean control T15 (permanent maintenance) is weeded from the seventh day after sowing. Maintenance is carried out weekly. Maintenance is stopped when the millet reaches the heading stage. Treatment T16 (no maintenance) received no weeding throughout the millet vegetative cycle, while plot T17 (recommended maintenance) was weeded a first time on day 20 and again on day 40. Finally, plot T18 is covered with straw obtained after manual clearing. The quantity of grass used for mulching is 3 Kg per elementary plot (2 m x 2 m), i.e. 7500 Kg/ha. This work required 10 minutes per elementary plot, i.e. 417 h/ha (17 days/ha). Floristic surveys were carried out at each weeding operation. The relative frequency, cover, density and biomass of weeds were taken into account. Millet grain production by plot was also weighed.

Trial management

Early competition

Plots are kept clean from the first weeding date indicated.

Data collection

The growth and development of millet plants was monitored from sowing to harvesting.

Quantifying weediness depends on the study environment, the observation method and the study objectives (Le Bourgeois, 1993). The parameters frequently used to quantify weediness are Abundance, Density, Cover, and Abundance-Dominance (Guinochet, 1973; Le Bourgeois, 1993; Ipou, 2005). In the case of this work, cover, relative frequency, density and biomass of weeds and grain yield of millet were selected. These three parameters were used in a complementary manner.

Statistical analysis

Average weed densities, average weed fresh biomass and average millet grain weights were compared for each treatment. R software version 4.4.1 was used to analyze the data collected. To carry out the analysis of variance (ANOVA), the normality and equality of variances were first checked. When a significant difference was observed between treatments and the control, or between treatments, the ANOVA was completed by multiple comparisons using Duncan's test at the 5% threshold. This test is used to rank average densities, fresh biomass or average weights. The smallest significant difference between these parameters was set at $P \leq 0.05$.

Results

Evolution of the floristic richness of the test plots

Table 1 shows the number of weeds observed on the test site. Before weeding, the number of weeds observed differed from plot to plot. The number of individuals per species decreased from 14 days after sowing (DAS) to 42 DAS. Species such as *Leucas aspera* (88% at 14 DAS and 16% at 42 DAS); *Cassia mimosoides* (86.50% at 14 DAS and 17% at 42 DAS); *Eragrostis tremula* (32% at 14 DAS and 8% at 42 DAS); *Cenchrus biflorus* (28% at 14 DAS and 10% at 42 DAS); *Alysicarpus ovalifolius* (26% o 14 DAS and 2% at 42 DAS) and *Phyllanthus pentandrus* (21% o 14 DAS and 4% at 42 JAS) showed the highest relative frequencies at 14 DAS. Most species had mean cover scores below 15% at 42 DAS (Table 1). This was the case for *Commelina diffusa* (1%), *Ceratotheca sesamoides* (1%), *Mitracarpus scaber* (1%), *Zornia glochidiata* (1%), *Gisekia pharnacioides* (1%), *Corchorus tridens* (1%), *Alysicarpus ovalifolius* (7%), *Cenchrus biflous* (7%) and *Eragrostis tremula* (7%). On the other hand, *Cassia mimosoides* (30%) and *Leucas aspera* (30%) showed mean cover scores above 15% at 42 DAS. *Cassia mimosoides* and *Leucas aspera* were present and abundant in all elementary plots, with varying frequencies.

Table 1. Floristic richness of test plots.

Relative frequencies						
Species	Period (DAS)			Average cover scores		
	14	28	42	14	28	42
Commelina diffusa Brum.f.	3	2	2	15	1	1
Ceratotheca sesamoides Endl.	3	1	1	7	1	1
Mitracarpus scaber Zucc. InSchhultes & schultes f.	3	1	1	1	1	1
Corchorus tridens L.	10	6	2	30	7	1
Zornia glochidiata Rchb.Ex DC.	8	3	1	15	1	1
Gisekia pharnacioides L.	10	4	2	7	1	1
Phyllanthus pentandrus Schumach. & Thonn.	21	16	4	30	7	1
Alysicarpus ovalifolius (Schumach.) J. Léonard	26	16	4	30	7	1
Cassia mimosoides L.	86.50	30	17	70	50	30
Leucas aspera (Wild.) Link	88	24	16	70	50	30
Eragrostis tremula Steud	32	20	8	30	15	7
Cenchrus biflorus Roxb.	28	12	10	30	15	7

DAS : days after sowing.

Density and fresh biomass

In order to compare the level of grass cover between plots, it is important to evaluate the effectiveness of the treatments. To this end, density and biomass were determined for each individual plot. Table 2 and Table 3 show the average weed density and average weed biomass, respectively.

Analysis of variance and Duncan's test at the 5% threshold for the results reported in Tables 2 and 3 indicate that there is a highly significant difference between the various weed densities and mean fresh biomasses, with *p-value* = 0.0001. The highest average density at 14 DAS (183.66 Kg/ha) was obtained for *Leucas aspera*; this weed obtained (3.66 Kg/ha) at 42 DAS. This weed is the most sensitive to weeding. On the other hand, *Eragrostis tremula* (120.91 Kg/ha at 14 days a week and 127.91 Kg/ha at 42 days a week) and *Cenchrus biflorus* (125.16 Kg/ha at 14 days a week and 126.66 Kg/ha at 42 days a week) were the weeds least affected by weed control.

The highest average fresh biomass at 14 days a week (99.41 Kg/ha) was obtained for *Leucas aspera* and *Cassia mimosoides*; these weeds were the most sensitive to weed control at 42 days a week, with 20.41 Kg/ha for *Leucas aspera* and 25.16 Kg/ha for *Cassia mimosoides*. Weeds such as *Eragrostis tremula* (66.41 Kg/ha) and *Cenchrus biflorus* (47.16 Kg/ha) were less affected by weed control.

Table 2. Comparison of average weed densities at 14 DAS and 42 DAS.

Average weed density (plants/m²)		
Species	Periods (DAS)	
	14	42
Leucas aspera	183. 66 ± 0.33c	3.66 ± 0.33a
Cassia mimosoides	180. 66 ± 0.30c	23.42 ± 0.33b
Eragrostis tremula	120.91 ± 0.30 a	127.91 ± 0.33c
Cenchus biflorus	125.16 ± 0.30b	126. 66 ± 0.33c
ddl	3	3
F	12957.40	39401.80
p-value	< 0.0001	< 0.0001

Effect of weeding period on millet yield

The average yield for each elementary plot was obtained by weighing the dry grains. Table 4 shows the average yield in kilograms per hectare for each elementary plot. The mean yields for each treatment were significantly different (P < 0.0001). Analysis of variance and Duncan's test at the 5% threshold revealed that unweeded plots (unweeded control, never maintained) produced the lowest average yield (107.50 Kg/ha); these plots are the best weeded and the most subject to competition from weeds. Plots weeded at 56 DAS (2100 Kg/ha) produced higher yields than those weeded at 14 DAS (1800 kg/ha).

The highest average yields (2268.75 Kg/ha) were observed in plots T15 (clean control maintained throughout the crop cycle). These plots were the most weeded and the least weed-competitive.

Table 3. Comparison of average weed fresh biomass at 14 DAS and 42 DAS.

Fresh biomass (Kg/ha)		
Species	Periods (DAS)	
	14	42
Leucas aspera	107. 91 ± 0.33c	20.41 ± 0.33a
Cassia mimosoides	105.41 ± 0.30b	
Eragrostis tremula	99.41 ± 0.30 a	66.41 ± 0.33d
Cenchrus biflorus	99.41 ± 0.30a	47.16 ± 0.33c
ddl	3	3
F	25.61	4057.68
p-value	< 0.0001	< 0.0001

DAS : days after sowing, ddl: degree of freedom, F: value of the ratio of variances, *p*-value: probability value.

The difference in average millet yield between control and treatments is 995.10 kg/ha. The difference in average millet yield between the control and T1 treatment is 348.75 kg/ha, and between the control and T10 treatment is 2161.25 kg/ha.

Determining the critical period for first weeding

Fig.3. shows the critical period for the first weeding of millet according to plot weights and weeding dates. This figure shows that yields decreased from T1 (1800 Kg/ha) at 14 DAS to T7 (745 Kg/ha) at 56 DAS for early competition. In contrast, yields for late competition increased from T8 (1000 Kg/ha) at 14 DAS to T14 (2100 Kg/ha) at 56 DAS. In addition, this figure indicated that the dates of early, critical and late competition were 21, 28 and 35 DAS respectively. The corresponding yield thresholds were 1629 Kg/ha, 1500 Kg/ha and 1300 Kg/ha respectively. Fig.3. also shows a loss of yield for early competition dates. Indeed, the higher the early competition date, the greater the yield loss compared with the clean control (14 DAS = 20.66% vs. 56 DAS = 67.16%).

Table 4. Average yield obtained by individual plot.

Treatments	Periods	Type of competition	Yield (K/ha)	Yield compared with clean control (%)
T1	14		1800 c ± 108.01	20.66
T2	21		1629 de ± 68.05	28.19
T3	28		1500 ef ± 108.01	33.88
T4	35	Early Competition	1300 gh ± 108.01	42.69
T5	42		1100 ij ± 108.01	51.51
T6	49		911 k ± 76.03	59.84
T7	56		745 l ± 108.01	67.16
T8	14		1000 jk ± 108.01	55.92
T9	21		1205.25 hi ± 55.25	46.87
T10	28		1398.25 fg ± 98.21	38.36
T11	35	Late competition	1769 cd ± 58.61	22.02
T12	42		1850 c ± 108.01	18.45
T13	43		1890 c ± 108.01	16.69
T14	56		2100 b ± 108.01	7.43
T15			2268.75 a ± 140.26	100
T16			107.50 m ± 49.44	95.26
T17			1896 c ± 128.23	16.42
T18			1920 c ± 160.20	15.37
Average			1466.09	
Standard deviation			100.35	
P-value			< 0.001	

a, b, c, cd, de, ef, gh, hi, ij, jk, k, l, m: means followed by the same letter in a given column, are not significantly different according to Duncan's 5% test.

In addition, yield loss compared with the clean control is inversely proportional to the late competition date (14 DAS = 55.92% vs. 56 DAS = 7.43%)

Discussion

Evolution of floristic richness and cover

The high relative frequency and cover of *Leucas aspera* and *Cassia mimosoides* in the test plots can be explained by the superficial manual weeding of the soil with a hoe. This type of weeding brought superficially buried seeds to the soil surface and favoured their germination. Manual weeding with a hoe did not completely eliminate *Leucas aspera* and *Cassia mimosoides* plants. It left residues of the stumps of these weeds, which reappeared a few days after weeding. What's more, the uprooted plants, left in place, grew back when soil moisture became favourable. These results are similar to those of Le Bourgeois and Merlier (1995) ; Téhia (2013) and Bello *et al.*, 2019.

Influence of weeding period on weed density and fresh biomass

Leucas aspera and *Cassia mimosoides* were the two weeds with the highest relative frequency. According to the local population, these two weeds are among the most harmful major weeds in the area. According to the local population, these two weeds cause enormous yield losses every year. They have often been responsible for the abandonment of several fields. At 42 DAS, the density of *Leucas aspera* has become the lowest. This weed is very sensitive to drought and weeding.

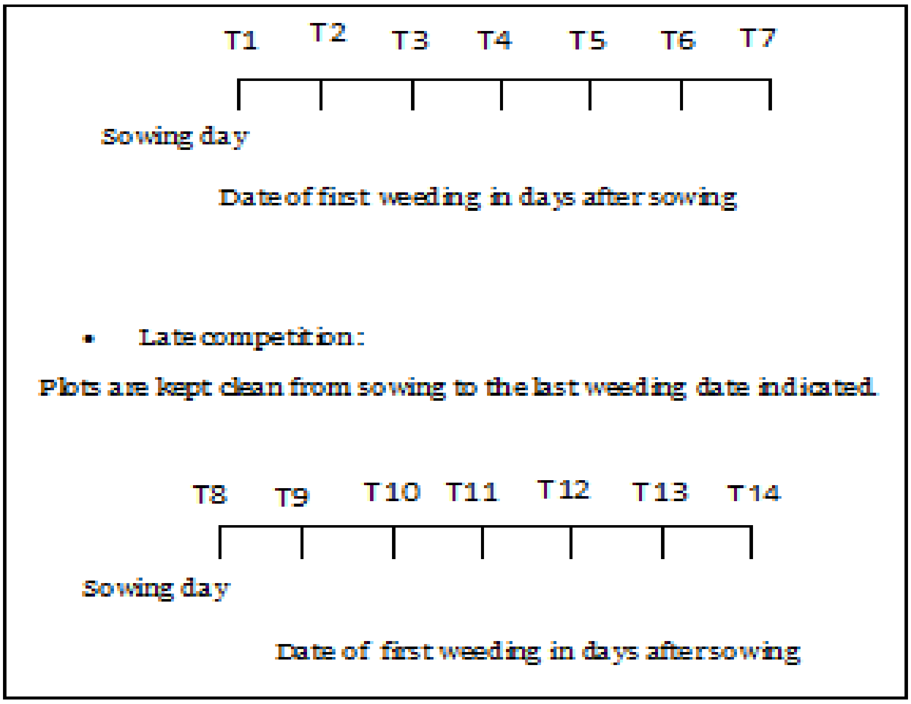

Fig. 2. Test plots and weeding dates.

This could explain the reduction in individuals of this weed in the test plots. On the other hand, the density and biomass of species such as *Eragrostis tremula* and *Cenchrus biflorus* increased at 42 DAS. These weeds have highly regenerative roots, so even when uprooted and piled up, they can resume their life cycle as soon as conditions become favourable again. These species are also difficult to uproot completely, often leaving behind stumps that could later reconstitute the entire plant.

Impact of weeding period on millet yield

Weeding following the early, critical and late competition thresholds increases the effectiveness of weed control. The number of weedings in this process makes it possible to obtain high yields of millet and even other crops. Weed infestation leads to wilting and early death of millet plants in plots that are not weeded at the appropriate times. Competition between millet plants and weeds reduces yields by an average of 35-37%. The yield reduction in plots T16 (never weeded) compared with the clean control was 95.26%. It was 15.37% for straw-covered plots and 16.42% for plots weeded on days 20 and 40 after sowing. This showed that superficial manual weeding increased plot weediness. It should be noted that these results were similar to those of Beuret (1980) and Traoré (1991). As for the straw-covered plots, it is noted that under the tufted mulch, the soil retained moisture and lacked sunlight. The weed species found there did not develop, and others were unable to grow. Weeds were scarce on these straw-covered plots. This seems to hinder the germination of new weeds. These results confirmed those of (Kamara *et al.*, 2000; Smith and Alli, 2007).

The low millet yield obtained in our study would also be due to pockets of drought during the millet development cycle, the early cessation of rains (2023 cropping season) and attacks by animal pests (worms, insects and birds) and fungi.

Determining the critical period for the first weeding operation

The critical period for weed competition was identified around 28 days after sowing millet in Niger. The effect of early weed competition increases with time. This could explain the abrupt yield loss recorded in the case of early competition, characterized by weed interference on the millet plants, and a small loss in the case of late competition.

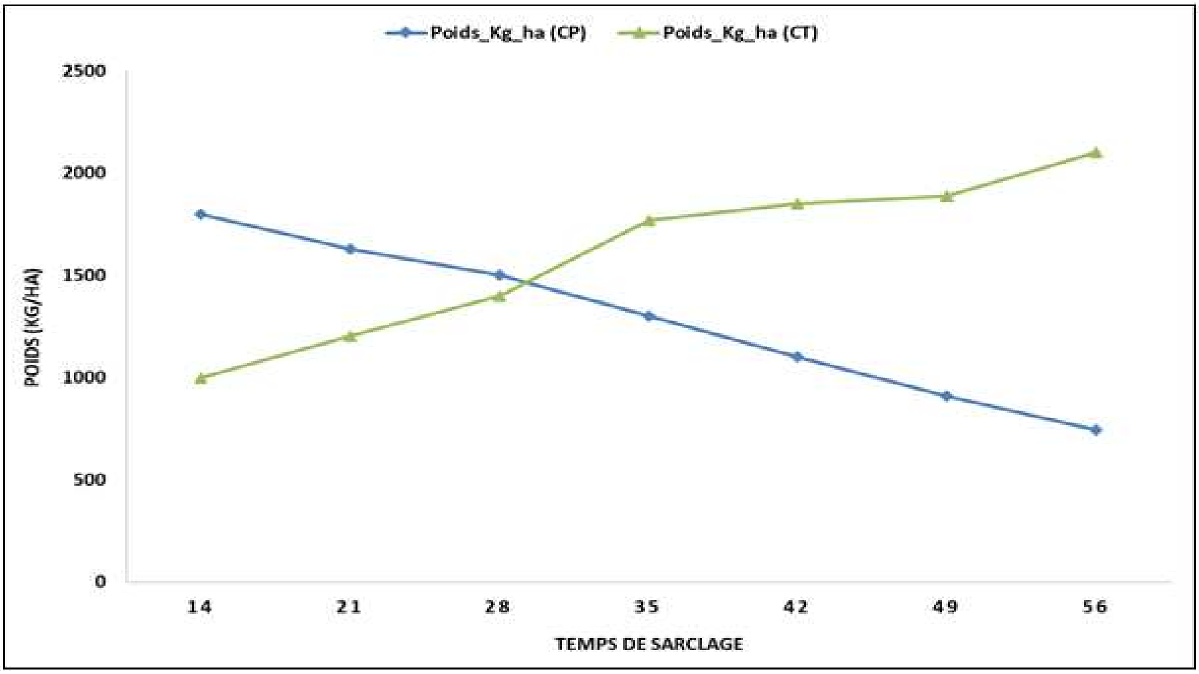

Fig. 3. Determination of the critical period for the first weeding according to the weights of plots subject to early competition (SCP) and plots subject to late competition (CT).

The critical period of competition varies according to the crop and weeds present. According to Mahamane (2013), this critical period occurs in the third week of maize cultivation in central-eastern Côte d'Ivoire.

For onions, the critical period is determined at 45 days after transplanting in northeastern Benin (Bello *et al.*, 2019). For soybean, it was between 9 and 19 days after emergence, depending on sowing density (Knezevic *et al.*, 2003). For cotton, this period was between 2 and 4 weeks after emergence under irrigated conditions, and between 6 and 8 weeks under rain-fed conditions (Schwerzel and Thomas, 1971). In Togo, it is between 28 and 42 days after sowing for cotton crops (Douti and Djagni, 1995). The difference observed between the results of the different authors' work could be due to the nature of the weeds, the nature of the crop, eco-climatic conditions and the type of experiment.

Conclusion

This study has enabled us to understand the influence of the weeding period on millet cultivation of the early local variety called "Guèreguéra" in Haoussa, under the eco-climatic conditions of the study site. Weed competition on millet plants is not very effective for sowing dates corresponding to early competition. The critical period for competition was approximately 28 days after sowing. This period can be used as a reference for making weed control decisions. The importance of the weed control period is most striking in terms of millet yield losses, where the average production loss obtained was 35.37% compared with the clean control. The local variety (Guèreguéra) used in this study is sensitive to competition from weeds. These results could help to improve weed control techniques in weedy millet fields.

Thanks

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Declaration of interests

All authors have declared that there is no conflict of interest.

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