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Restitution of fresh organic matter to the soil by woody plants in the fields of ANR in the Maradi region of central eastern Niger

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ABSTRACT

Niger, like other Sahelian countries, has experienced severe droughts that have led to the disappearance of vegetation cover in most regions and have led populations to adopt restoration techniques. This is the case of the practice of assisted natural regeneration (ANR) developed in the Maradi region. The objective of this study is therefore to quantify the fresh organic matter (FOM) of woody plants in ANR fields. The study fields were selected in two ANR terroirs (Boussaragui and Dan Saga). The direct method was used to quantify litter inputs from trees, shrubs and woody clumps that contribute to soil organic carbon stock (SOCS). Tree litter was quantified by a trap door and tussock litter by collection after clearing. The results of this work show that litterfall in the dry season occurs throughout the season, at different times depending on the terroir, with a shift in production peaks between plots in the same terroir. The average dry season litter production is 265.52 and 937.62 kg. ha^{-1} for Boussaragui and Dan Saga respectively. Trees and shrubs produce more litter and thus return more FOM to the soil than do tussocks. This study thus reveals that woody plants in ANR fields contribute significantly to improving the organic carbon stock of cultivated sandy soils.

Contribution/Originality: The study is unique in that it is one of the few in Niger that has estimated the amount of FOM returned to the soil by woody plants in the field, through the use of mosquito nets.

1. INTRODUCTION

In the Sahelian zone, the need to feed a growing population while preserving the environment, in particular the soil capital, is a major challenge, and there is a need, in many cases, to restore very degraded soils following continuous cultivation with low levels of mineral and organic fertilisation (Dan Lamso, 2002; Koné, Kassin, Ettien, Konaté, & Gnahoua, 2020; Soussana et al., 2019). Some agronomic studies have shown that mineral fertilisation alone does not allow, in the long term, a maintenance or an increase in crop yields due to a decrease in soil organic stocks and a degradation of all the physical, chemical and biological properties linked to them (Piéri, 1989). The

introduction of agroforestry practices in the form of assisted natural regeneration (ANR), which would allow both the production of wood or other products such as fruits, pods, and above all the restoration of fertility through organic matter that act on all biochemical cycles ; appears to be one of the promising alternatives for sustainable management of land fertility (Bayala et al., 2020). It is in this context that the present study is situated, which aims to assess the restitution of fresh organic matter (FOM) to the soil in ANR fields in central eastern Niger. It is true that studies have addressed the influence of woody vegetation on the improvement of soil organic matter by litter. However, it should be noted that some of these studies (Devineau, 1982; Gauquelin, Fromard, Badri, & Dagnac, 1992; Njoukam, Oliver, & Peltier, 1999) focused on forests in the tropical savannah zone and others (Agbahungba & Assa, 2000; Diallo et al., 2016; Konan, Yapo, Koné, N'Guessan, & Yao-Kouamé, 2021) on isolated individuals of dominant species. As for the present study, it will focus on the restitution of FOM from ANR in the Sahel.

2. METHOD OF COLLECTING LITTER

The study was carried out during the dry season (November 2021 to June 2022) in the Maradi region and consisted in determining the litter from the ANR trees that falls to the ground. Indeed, it is this litter that constitutes the main source of fresh organic matter (FOM) that the ANR returns to the soil. The choice of this period is justified by the fact that it is during this season that woody plant species, especially trees, lose their leaves and other organs (flowers, pods, branches, twigs).

The experiment was carried out in the field to monitor litterfall (leaves, twigs, flowers and fruits) under ANR using the direct method. Litter was assessed at two levels: crowned individuals (trees and saplings) and clumps. Plots of 625 m² in area (i.e. a square of 25 m sides) were delimited in the ANR fields before determining their dendrometric parameters. Three replicates per plot were carried out, making a total of six plots. Collection from trees and shrubs was carried out by means of a litter trap, which was placed under each ANR tree present in the delimited plot. A trap designed with a screen was used to collect the litter before it reached the ground as shown in Figure 1.

Figure 1. Perceived view of litter traps. A. under *P. reticulatum* and B. under *C. glutinosum*.

The trap was set up two (2) m high around each ANR tree and positioned to intercept any loose leaves from the tree. In addition, the trap was pulled to the west side of the tree to minimise litter loss due to the east-west wind during this period. However, the litter from the clumps Figure 2, was evaluated at 10 days after clearing in the plots

by the producers. In view of the high number of clumps in the plots, 5 clumps per species were retained to determine the average per species.

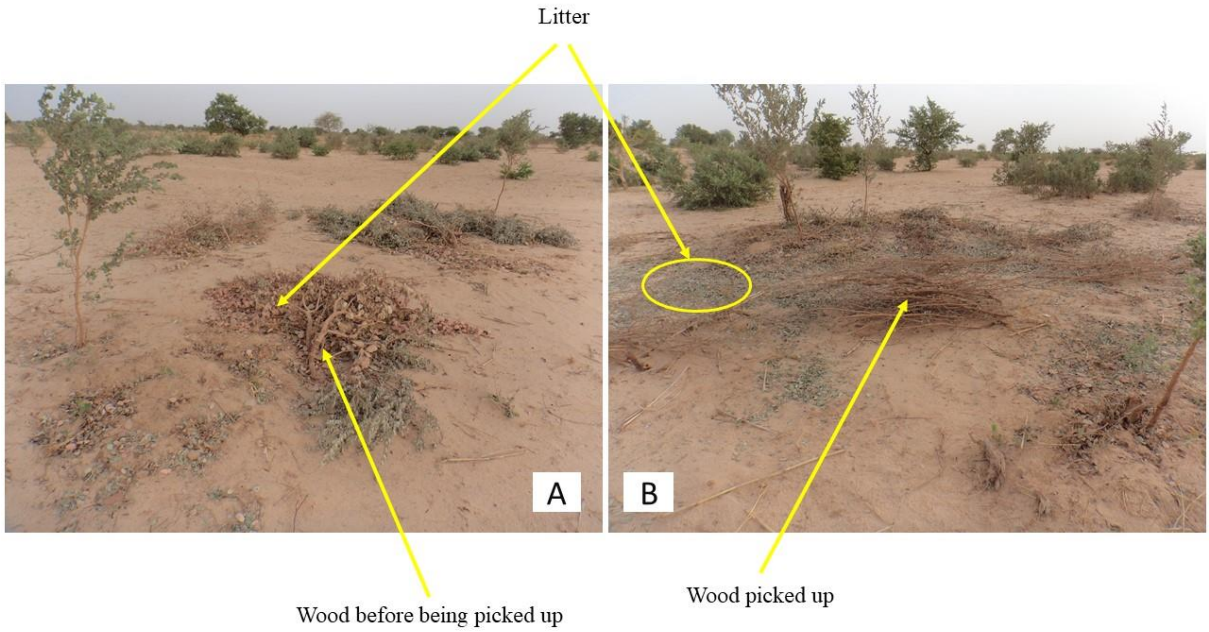

Figure 2. Clump litter (A. litter and twigs B. twigs separated from litter left on the ground).

Litter was collected and weighed at regular seven (7) day intervals throughout the monitoring period. All products (leaves, fruits, flowers, pods and twigs) constituting the litter from the woody plants under ANR were weighed using a precision electronic scale 0.0001.

Excel 2016 and SPSS version 20.1 were used for data analysis and processing.

3. RESULTS

3.1. Composition and Structure of the Woody Vegetation on the Study Plots

The surveys carried out in the six (6) plots made it possible to characterise the vegetation of each plot Table 1. Thus, the species recorded in the six (6) plots belong to four (4) families: *Annonaceae*, *Caesalpinaceae*, *Combretaceae* and *Mimosaceae*. The number of families and species varies from one plot to another depending on the soil. In fact, each family is represented by one (1) species, except for *Combretaceae* which is represented by two (2) species. The species common to the two (2) study sites are *Piliostigma reticulatum (P. reticulatum)* and *Gueira senegalensis (G. senegalensis)*. The species *P. reticulatum* dominates in all plots and in the two (2) terroirs. It is followed by *G. senegalensis* in Boussaragui. In Dan saga, on the other hand, *Combretum glutimosum* (*C. glutimosum*) and *G. senegalensis are dominant.*

Analysis of the dendrometric parameters Table 2 shows that the density of individuals recorded per plot varies from 196 to 435 ind.ha^{-1} in the two study areas. All plots have an average density of more than 200 ind.ha^{-1} except for Plot 2 in Boussaragui (196 ind.ha^{-1}). In addition, all plots have a regeneration index (RI) of over 50%. In the plots the cover is less than 20% in Boussaragui and more than 20% in Dan Saga. The land area (LA) values highlight the trunk effect of the individuals on the soil. Thus, Basal area per plot (St) is higher in Dan Saga than in Boussaragui.

Table 1. Floristic composition of plots according to terroir.

Terroirs	Plots	Families	Species	En	CS
Boussaragui	P1	*Caesalpinaceae*	*Piliostigma reticulatum*	11	79
		Combretaceae	*Gueira senegalensis*	3	21
	Total P1	*2*	*2*	14	100
	P2	*Caesalpinaceae*	*Piliostigma reticulatum*	10	83
		Combretaceae	*Gueira senegalensis*	2	17
	Total P2	*2*	*2*	12	100
	P3	*Caesalpinaceae*	*Piliostigma reticulatum*	18	64
		Combretaceae	*Gueira senegalensis*	10	36
	Total P3	*2*	*2*	28	100
Dan saga	P1	*Annonaceae*	*Annona senegalensis*	3	18
		Caesalpinaceae	*Piliostigma reticulatum*	6	35
		Combretaceae	*Combretum glutimosum*	4	24
			Gueira senegalensis	3	18
		Mimosaceae	*Faidherbia albida*	1	6
	Total P1	*4*	*5*	17	100
	P2	*Caesalpinaceae*	*Piliostigma reticulatum*	7	44
		Combretaceae	*Combretum glutimosum*	4	25
			Gueira senegalensis	5	31
	Total P2	*2*	*3*	16	100
	P3	*Annonaceae*	*Annona senegalensis*	1	3
		Caesalpinaceae	*Piliostigma reticulatum*	18	58
		Combretaceae	*Combretum glutimosum*	6	19
			Gueira senegalensis	6	19
	Total 3	3	4	31	100

Note: Fr: Frequency; CF: Specific contribution in %.

Table 2. Dendrometric parameters of the study plots by terroir.

Terroirs	Plot numbers	D (ind/ha)	Dr.	Da	IR	Sr (m²)	R (%)	St (m²)	St (m²/ha)
Boussaragui	P1	205e	132	103	0.65c	106.5	16c	0.1815d	2.66
	P2	196f	146	81	0.75b	83.43	14c	0.1282f	2.08
	P3	435a	389	62	0.89a	53.3	8d	0.1537e	2.39
Dan saga	P1	238d	182	56	0.76b	160.63	22b	0.2508c	3.51
	P2	261c	130	130	0.50d	148.57	24a	0.3145b	5.12
	P3	366b	283	71	0.77b	211.57	25a	0.4395a	5.19

Note: Means with the same letter in the same column are not statistically different at the 5% threshold.

3.2. Seasonal Litter Production by Woody Plants

Figure 3 illustrates the monthly variations in litter quantities recorded. It appears that the production of litter takes place over a period of time with a shift in production peaks (February and March) in Boussaragui as shown in Figure 3A. However, at Dan Saga, production is done in two stages (November-March ; March-June) with a gap between peaks Figure 3B as in Boussaragui.

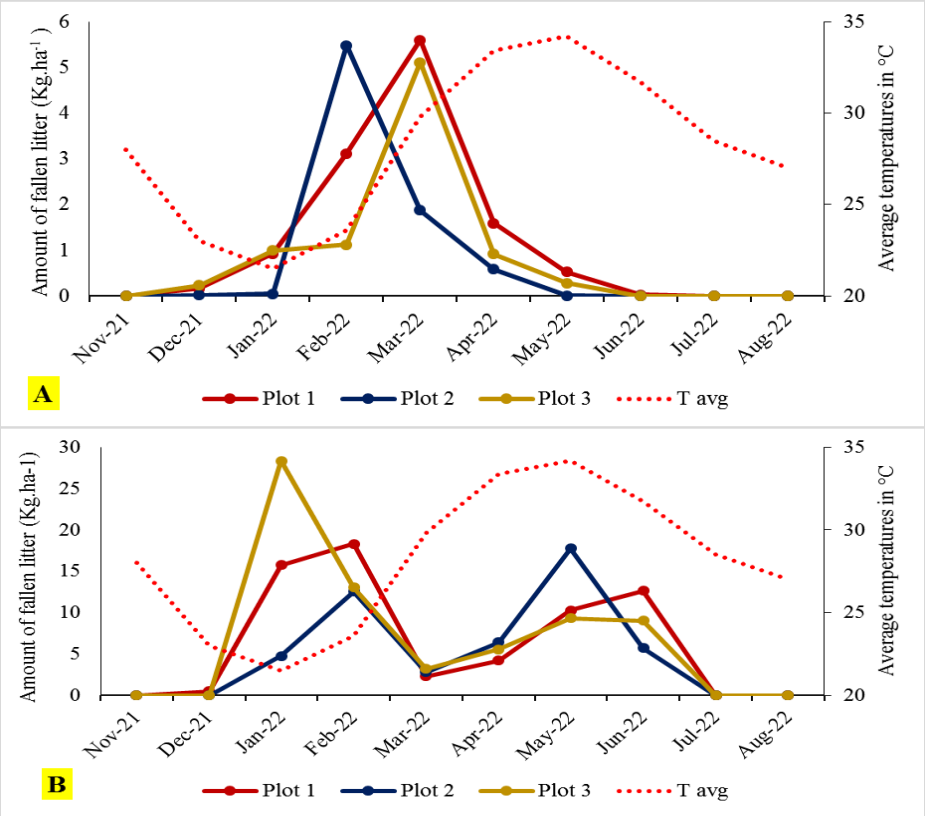

Figure 3. Monthly collection curves for ANR litter in the study areas (A. Boussaragui ; B. Dan Saga).

The difference in production time observed between the two terroirs can be attributed to the species, the age of the ANR and the climatic variations of the two terroirs. However, the difference in peak production between the two sites may be related to species dominance. Figure 4 illustrates the appearance of ANR woody plants before and after leaf loss.

Figure 4. Views of a study plot A. litter trap at the beginning of collection with leafy trees; B. trap at the moment when the woody plants are losing their leaves.

Figure 5 presents the quantities of litter recorded in the three plots by terroir. It can be seen that the quantities of FOM returned to the soil under ANR vary between the terroirs and plots. The quantities harvested in Dan Saga are four times higher than those recorded in Boussaragui. In fact, they are on average 937.62 kg.ha^{-1} in Dan Saga and 265.52 kg.ha^{-1} in Boussaragui. As for the quantities harvested per plot, they vary from 191.61 kg.ha^{-1} to 400.85 kg.ha^{-1} in Boussaragui. On the other hand, they varied between 853.75 and 983.91 kg.ha^{-1} in Dan Saga.

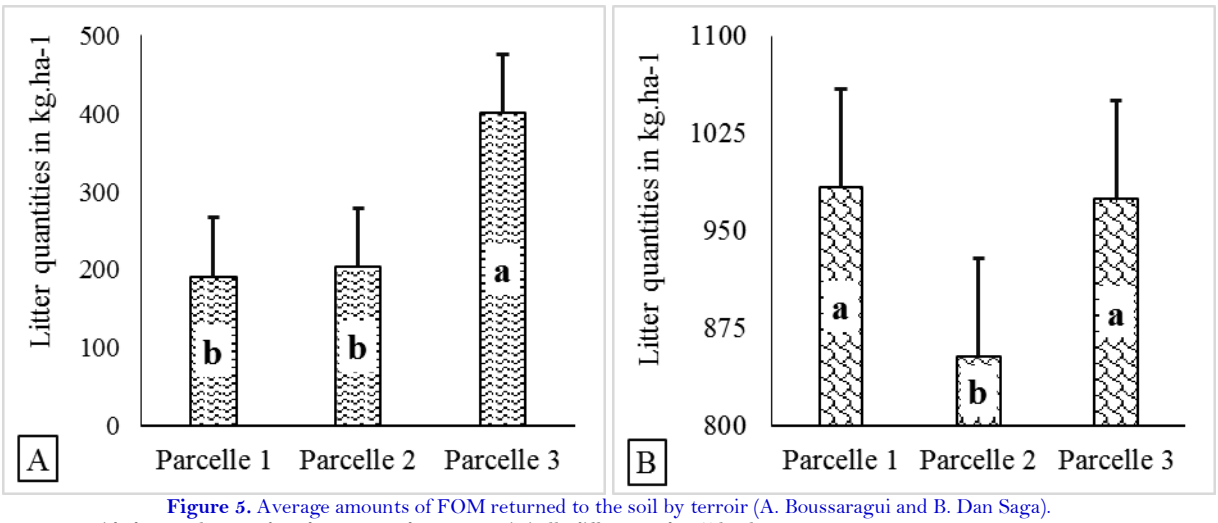

Figure 5. Average amounts of FOM returned to the soil by terroir (A. Boussaragui and B. Dan Saga).

Note: Bars with the same letter and on the same graph are not statistically different at the 5% level.

The statistical analysis between terroirs shows a difference in FOM production under ANR. This difference in production may be due to the age of the ANR. For the intra-terroir analysis, differences in FOM were also observed between plots. This result can be explained by the density and types of individuals as shown in Figure 6.

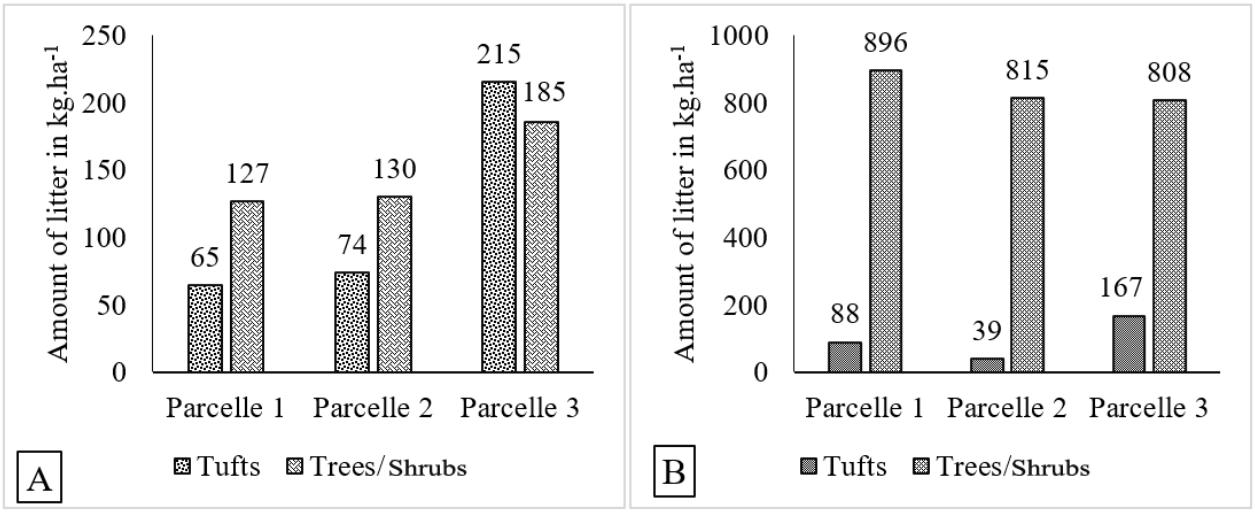

Figure 6. Average amount of FOM produced by type of individuals in the plots (A: Boussaragui and B: Dan saga).

The analysis of the results Figure 5 and Figure 6 shows that the higher the density and age of the ANR, the higher the amount of FOM returned to the soil.

3.3. Litter Production by Species

Figure 7 records the monthly variations in FOM arriving on the ground according to the main species found in the study plots. This figure is based on the total amount of FOM in the plots by species.

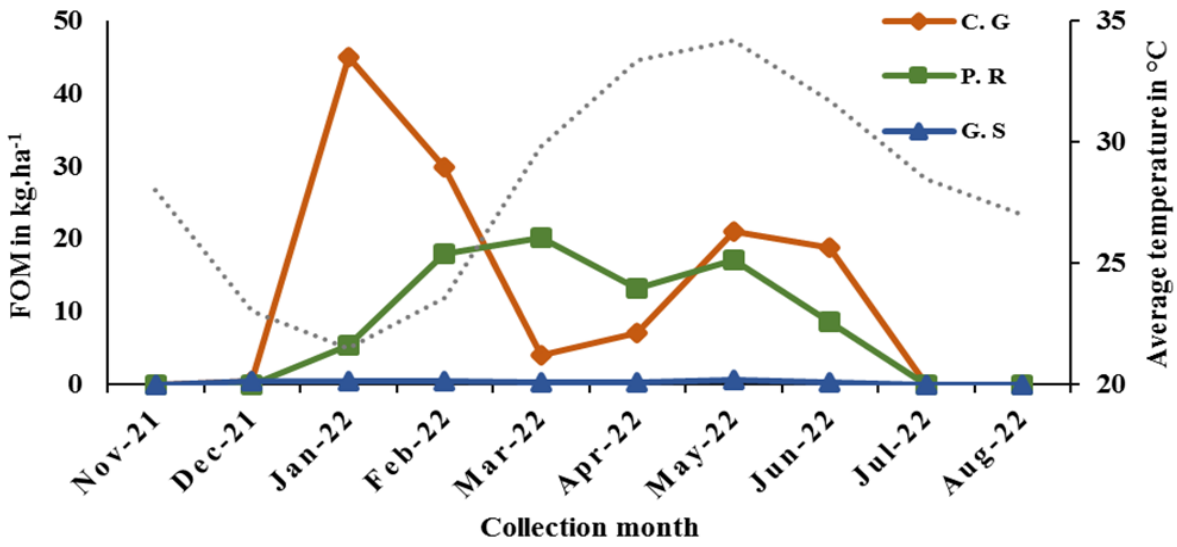

Figure 7. Litterfall curves by species.
Source: C.G: Combretum glutimosum; P.R: Piliostigma reticulatum; G. S: Guiera senegalensis; T. moy: Mean temperature.

Analysis of Figure 7 shows that *C. glutimosum* and *P. reticulatum* have two peaks in litter production. It can be seen that the amount released by *G. senegalensis* is very small and almost constant. This may be due to the resistance of this species to climatic variations (drop in temperature, wind and water stress).

4. DISCUSSIONS

4.1. Woody Cover on the Study Plots

The study of the woody vegetation of the study plots not only highlighted the floristic diversity, but also the important dendrometric parameters characterising these plots. Woody species richness and dendrometric characteristics are higher in Dan Saga than in Boussaragui. The difference in diversity may be related to the potential of the agro-ecological zone of the two areas. These results corroborate those of Zounon (2021) and Kiema (2007) who reported that agroecological zones influence floristic diversity. In addition, differences in dendrometric parameters can be explained firstly by the age of the ANR and secondly by the level of involvement of producers in scaling up the ANR in their fields under ANR. Similar results have already been obtained by Lawali et al. (2018) and Zarafi, Abasse, Bokar, Niang, and Traore (2002) who also demonstrated that the age of the ANR associated with socio-economic characteristics and benefits derived by the farmers; are among the relevant variables underlying the success of ANR in the same study area. Similar results were also reported by Zona, Tarama, and Kiema (2022) in Burkina Faso. Indeed, they report that the high adaptation rates of ANR (95% of farmers) reveal the willingness of farmers to diversify the species in the fields under ANR.

4.2. Restitution of the AFM by the NAS

The study identified the periods of high litter production and the amount of FOM returned to the soil by the woody plants. The results of the study indicate that the fall during the dry season shows two peaks of litter production depending on the species. The first peaks would be due to the decrease in temperature and wind speeds during this period as mentioned and explained by Agnusdei (1999) and Guyot (2015). The latter, on the other hand, can be explained by the physiology of the species (Gnahoua, Oliver, Nguessan, & Balle, 2013; Zhang, Yuan, Dong, & Liu, 2014) reacting to the water stress that set in during this period (April-May) of high decline in the useful water reserve of the soil, accentuated by the high temperatures of this period. According to D'Annunzio (2008) litterfall during the dry season is due to water stress leading to cavitation, embolism and abscission of tree leaves and to a replacement mechanism of old leaves concomitant with the development of new ones. Leaves constitute the major part of the total litter production as found by other authors (Lugo, Wang, & Bormann, 1990; Morellato &

Patricia, 1992). The total loss of litter observed between May and June may be related to the fact that the dried organs (leaves, flowers, pods, etc.) of the trees do not withstand the strong winds that accompany the first rains (Njoukam et al., 1999).

The major constraints to SOCS restitution are the transport of crop residues from the fields to the villages and the low inputs of manure. According to Malam Abdou, Issa, Mani, and Sawadogo (2016) the amount of manure brought and spread in the field by farmers in Maradi is 1.7 t.ha-1. However, there is hope for these farmers, with the return of litter to the soil through ANR. Indeed, the seasonal quantities of litter that fall to the ground vary from 265.52 to 937.62 kg.ha^{-1} .ss^{-1} , depending on the age and density of the ANR. The results of the quantities obtained in this study are lower than those reported by Konan et al. (2021) in the Lamto reserve (Ivoiry Cost), which are 1.85 to 2 t.ha^{-1} . year^{-1}. These results are also lower than those obtained (8293 and 9867 kg.ha^{-1} .ss^{-1}) by Njoukam et al. (1999) The differences could be explained by the collection systems adopted on the one hand and on the other hand the fact that these authors conducted their study over a whole year in savannah forest formations. The results of the study also show that litter production varies according to species. Indeed, it appeared that the species *C. glutimosum* produced more litter followed by *P. reticulatum* and *G. senegalensis* respectively. Similar results were reported by Diallo et al. (2016) who showed that the amounts of litter collected under *Boscia senegalensis* (39.3 t. ha^{-1}) were significantly higher than those of the woody species *Acacia senegal*, *Acacia tortilis*, *Balanites aegyptiaca and Sclerocarya birrea*. The differences in litter production by the species may be related to their foliage which is very dense in some and less so in others.

5. CONCLUSION

From this study, it can be concluded that the practice of ANR through woody plants increases the level of fresh organic matter in the farmers' fields. In addition, this increase is due to the loss of litter from woody plants during the dry season as a result of climatic variations and the physiology of these plants. The results show that, depending on the age of the ANR, quantities of litter close to one ton can be returned to the soil, which is not negligible compared to the regional average of 1.7 t.ha of manure input^{-1} . It is clear that ANR is an alternative for small-scale farmers to solve the problem of organic matter input to the fields in a sustainable way and at lower cost. The combination of ANR and manure inputs by farmers would allow them to achieve satisfactory levels of soil organic matter that would help farmers increase their agricultural production, which is a guarantee of their food security.

List of Abbreviation:

ANR. Assisted Natural Regeneration; SOCS. Soil Organic Carbon Stock; FOM. Fresh Organic Matter; D. Density (feet/ha); Dr. Density of young individuals; Da. Density of adult individuals; IR. Regeneration index; Sc. Covered area; R. Recovery; St. Basal area per plot; Fr: Frequency; CF: Specific contribution in %.

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Authors' Contributions: All authors contributed equally to the conception and design of the study.

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