International Journal of Innovation and Applied Studies
ISSN 2028-9324 Vol. 36 No. 2 May. 2022, pp. 609-618

http://www.ijias.issr-journals.org/

Assisted Natural Regeneration (RNA): An efficient practice for soil fertility management of cultivated tropical ferruginous soils in Niger

Dan Lamso Nomaou[1], Ado Maman Nassirou[2], and Guero Yadji[1]

[1]Faculty of Agronomy, Université Abdou Moumouni University, Niger

[2]Faculty of Agronomic Sciences, University of Tahoua, Niger

ABSTRACT: Assisted Natural Regeneration (RNA) is one of practices that small farmers adopted to restore vegetation cover and improve land productivity in cultivated areas in Niger. The present study, conducted in the main cultivation areas in Niger, aims to assess the effects of RNA trees on soil physicochemical characteristics of cultivated tropical ferruginous soil in order to assess their fertility. Composite soil samples were collected at 0-20 cm deep under and outside trees crowns of *Piliostigma reticulatum, Combretum glutinosum and Sclerocarya birrea* respectvily to determine physicochemical characteristics i.e soil particle size composition, pH, CEC, organic matter contents, assimilable phosphorus. The results showed that trees have no influence on particle size composition because there are no significant differences between area under crown and area outside crown on granulometric composition under all species. However, the presence of these trees (*Piliostigma reticulatum, Combretum glutinosum and Sclerocarya birrea)* significantly improves chemical soil fertility. Indeed, organic matter content was 26, 3.8 and 4.2 times higher respectively under crown of *P. reticulatum, C. glutinosum and S. birrea* than that outside crown of these species. Moreover, available phosphorus content, often very low in cultivated tropical ferruginous soils in Niger, was 2.5, 1.2 and 2.1 times higher in soil under crown than soil outside without crown of P. *reticulatum, C. glutinosum and S. birrea* respectively. Thus, RNA practice improves soil chemical fertility of cultivated tropical ferriginous soils through input organic matter and nutrients by biomass plant. However, further studies can be performed to determine effects of RNA ligneous plants on soil hydrostructural properties.

KEYWORDS: Assisted Natural Regeneration, soil fertility, soil restoration, Niger.

1. INTRODUCTION

In Sub-Saharan Africa, 95% of cultivated land is under rainfed agriculture, and an estimated 41% of the region's population lives in drought-prone dry lands [1]. In addition to the scarcity and unreliability of annual rainfall, the loss of rainwater through non-productive pathways also seriously limits rainfed agriculture in Sub-Saharan Africa [2]. Accordingly, more than 50% of the rainfall in dryland cropping systems may be lost non-productively. In Niger, small-scale farmers constitute the majority of agricultural food producers for whom rainfed agriculture is the mainstay. In Niger, soil degradation and irregular rainfall are the main constraints of the majority of agricultural areas leading to chronic food insecurity of population. In addition, demographic pressure on natural resources in this region accelerates the degradation of vegetation cover and lower soil fertility [3], [4], [5]. The consequences of this situation are the deterioration of agro-ecosystems and the low land agricultural productivity; thus leading to near-chronic food insecurity of population, particularly in rural zones [6]. The problem of low agricultural productivity is exaggerated by low input use and harsh climatic conditions. Thus, innovative low input technologies that concurrently replenish soil nutrients and organic matter as well as improving soil water availability can significantly increase crop production and reduce acute food shortages [7]. This situation prompted small-farmers to adopt and/or develop several strategies such as use of agroforestry practices [8], [9]. Indeed, in cultivated regions of Niger, in particular Maradi, Zinder, Tahoua, Dosso and Tillabéri, small-farmers protected and maintained trees in cultivated land. This practice, called Assisted Natural Regeneration (RNA), increased woody plants density in cultivated land with 60 to 150 individuals per hectare according to [10], [11] and [12]. Several studies showed interest of this RNA practice in restoring ecosystems and increasing soil fertility [13], [8], [14], increasing agricultural production [15], [16] and improve population living conditions [17]. Recently, similar studies have been conducted in Niger to assess woody species effect, especially in tuft form, on soil fertility and agricultural production [18], [19], [20]. However, these effects may change according to soil climate context, type and form of woody species. The objective of this study is to evaluate impacts of RNA ligneous trees species on physicochemical characteristics of cultivated tropical ferruginous soils in different agricultural zones in Niger. The aim is to assess fertility of cultivated tropical ferruginous soils under RNA trees influence.

2. MATERIAL AND METHOD

2.1. STUDY ZONES

The study was performed in five agricultural regions of Niger (Maradi, Zinder, Tahoua, Dosso and Tillabéri) (Figure 1) located between 300 and 800 mm isohyets in agricultural zone of Niger. The soil in their region is dominated by tropical ferruginous soils with two main particle size composition class: [21]:

- sandy-textured soil to sandy-loamy-textured soil which are very thicker and characterized by relatively high water storage capacity due to their great thickness. This soil is locally called "Jigawa";
- sandy-clay-textured soil relatively more fertile than the previous soil one but often compact, difficult to work and marked by significant runoff. This is called "Guéza".

In general, soils in study regions are characterized by acidic pH, low organic matter content (less than 1%), severe phosphorus deficiency and low cation exchange capacity (CEC).

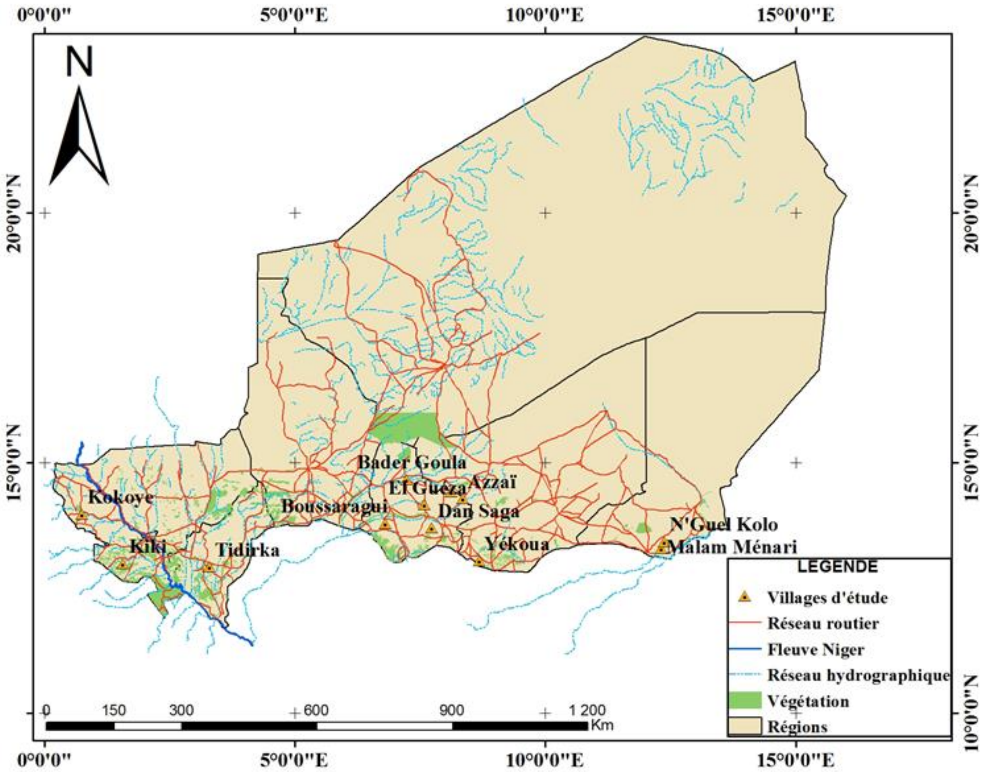

Fig. 1. Location of study sites

2.2. PLANT MATERIAL

The study was conducted in the fields of RNA practice. Three types of ligneous species were selected, namely *Piliostigma reticulatum, Sclerocarya birrea and Combretum glutinosum*. The criteria for choosing these species are essentially based on the local dominance of the species, plant age and economic interest of this species for local population. The age of chosen plant for each species was estimated between 5 and 7 years.

- *Piliostigma reticulatum* in tree form (Figure 2c), has a rounded bole, rarely straight and a rounded, bushy crown, and is about 8-9 m tall which can reach 10 m on fertile soils. It often retains a bushy growth habit with many suckers from the stump [22], [23]. *P. reticulatum* is also characterized by simple bilobed leaves; medium to small cluster or panicle flowers and indehiscent pods and deeply fissured to crevice bark [24], [25]. It forms small stands on moist or temporarily moist sandy soils and in fallows [26]. Its pods are eaten and its wood is very resistant to termites [27];
- *Sclerocarya birrea* is a rounded, relatively dense tree up to 12 m tall (Figure 2b). It has a bole 80 cm in diameter with a scaly bark, more or less silvery gray. Its leaves disappear during the dry season to save water [28]. Widely distributed in arid and semi-arid areas of Africa, S. birrea occurs on well-drained sandy and loamy soils [29];
- *Combretum glutinosum* is a small tree up to 10 m in height (Figure 2a). It is an evergreen Sudano-Sahelian species with an arborescent habit found on all types of soil. Its leaves are alternate and its inflorescences consist of compact axillary spikes with hairy yellow-cream flowers. The fruit has four yellowish wings, turning brown when ripe. Drought tolerant, *C. glutinosum* is left in fields to enhance soil fertility and provide wood for construction or used as household fuel [27], [30].

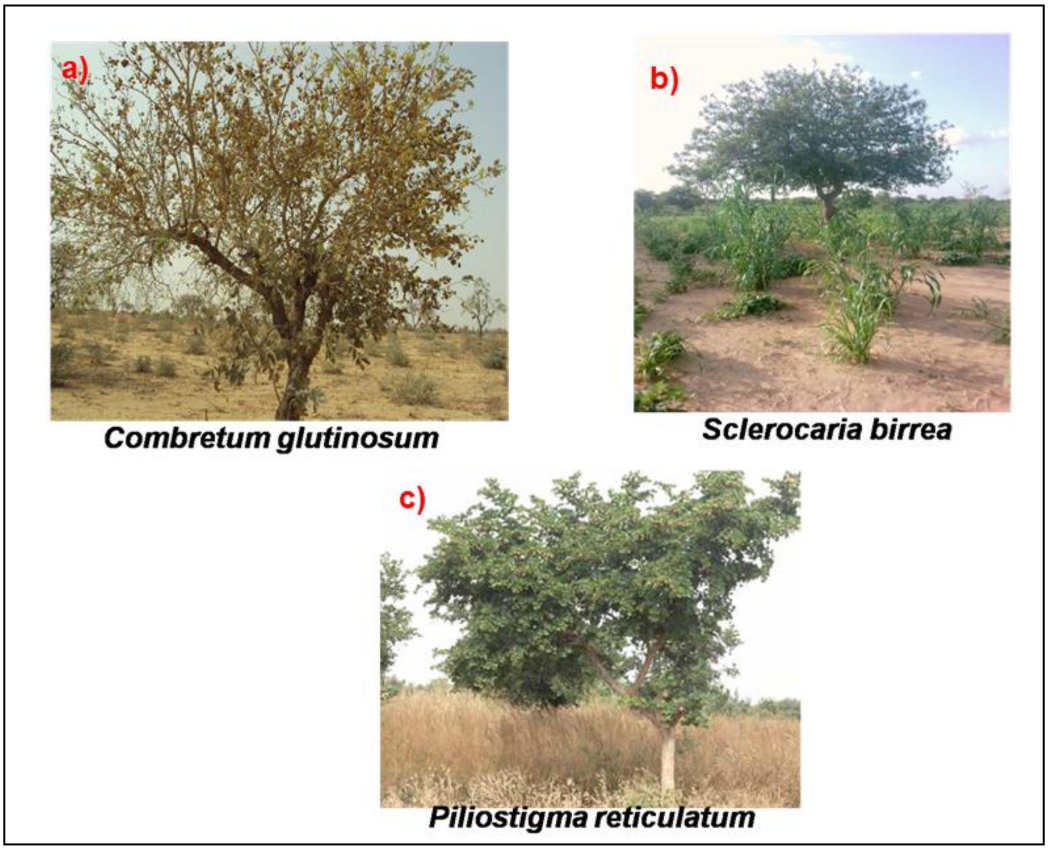

Fig. 2. Photographs of ligneous tree species of Combretum glutinosum (a), Sclerocaria birrea (b) and Piliostigma reticulatum (c)

2.3. SOIL SAMPLING AND LABORATORY ANALYSIS METHODS

For each species, 3 plants were selected and around each plant, the first aureole and the second aureole have been delimited corresponding respectively to zone under and outside plant crown (Figure 3). In each aureole, a composite soil sample was collected at 0-20 cm depth in 4 points respectively from 4 cardinal points. Thus, for each species 6 composite soil samples were taken, including 3 samples in aureole under crown and 3 samples in aureole outside crown plant, i.e. a total of 18 soil samples taken for the 3 species.

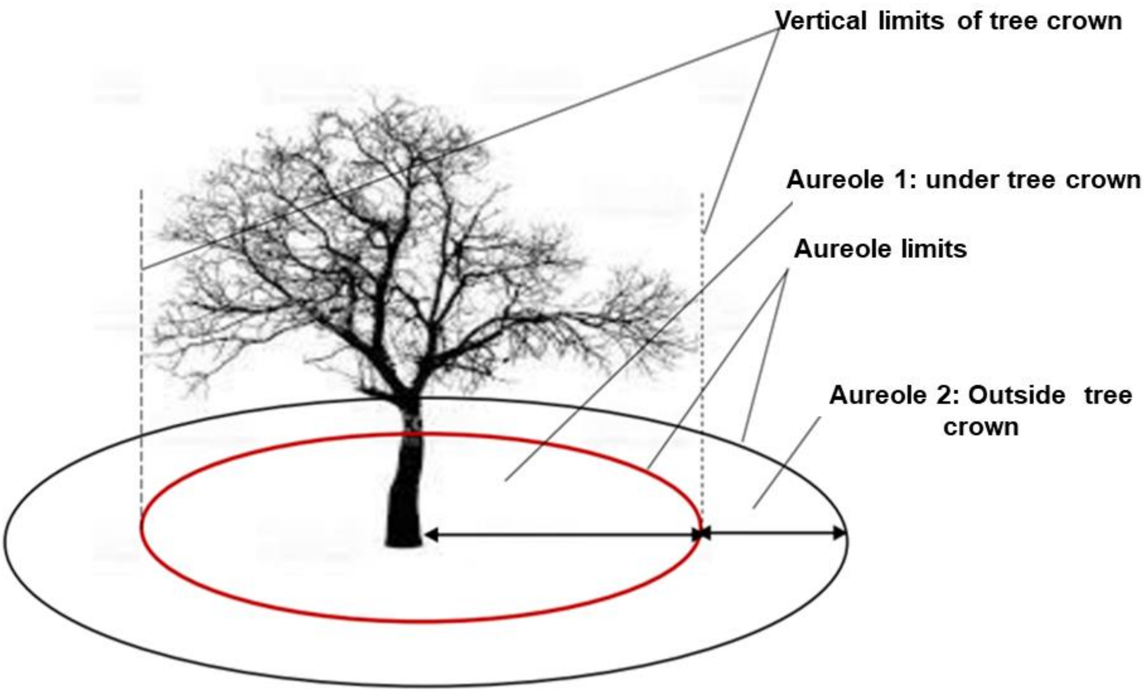

Fig. 3. Soil sampling design around tree plant

Soil samples taken were analyzed in the laboratory to determine soil physico-chemical properties notably pH, organic carbon, total nitrogen, phosphorus, CEC, exchangeable bases. Theses analyses were performed in soil science laboratory of agronomic faculty of University of Abdou Moumouni (Niger). The analysis methods were summarized in Table 1.

Table 1. Analysis methods of soil physico-chemical parameters in laboratory

Parameters	Analysis method
pH	pH-meter with soil/water ratio 1/2.5
Granulometry (6 fractions)	Pipette Robinson/sieving after oxidation of organic matter with hydrogen peroxide
Organic carbone	Method Walkley et Black (1934)
Total nitrogen	Kjeldahl
Phosphorus	Bray I
CEC and exchangeable bases	Ammonium acetate method pH=7

2.4. Data statistical analysis

The variance analysis (ANOVA) was performed using GenSTAT software to compare area under and outside plant crown for each species in changes of soil physicochemical characteristics. The Fisher's test (LSD test) at 5% threshold was performed to compare the means in pairs.

3. RESULTS AND DISCUSSION

3.1. RESULTS

3.1.1. CHANGES IN SOIL PARTICLES SIZE COMPOSITION (SOIL TEXTURE)

The figure 6 presents average proportions of different soil particles size fractions under and outside plant crown of three ligneous species. In general, soil granulometry under three plants species is dominated by sandy-textured soil with sand contents between 85 and 92%. Thus, the fine particles contents are very low between 6 and 12% for silts and between 1 and 4% for clays.

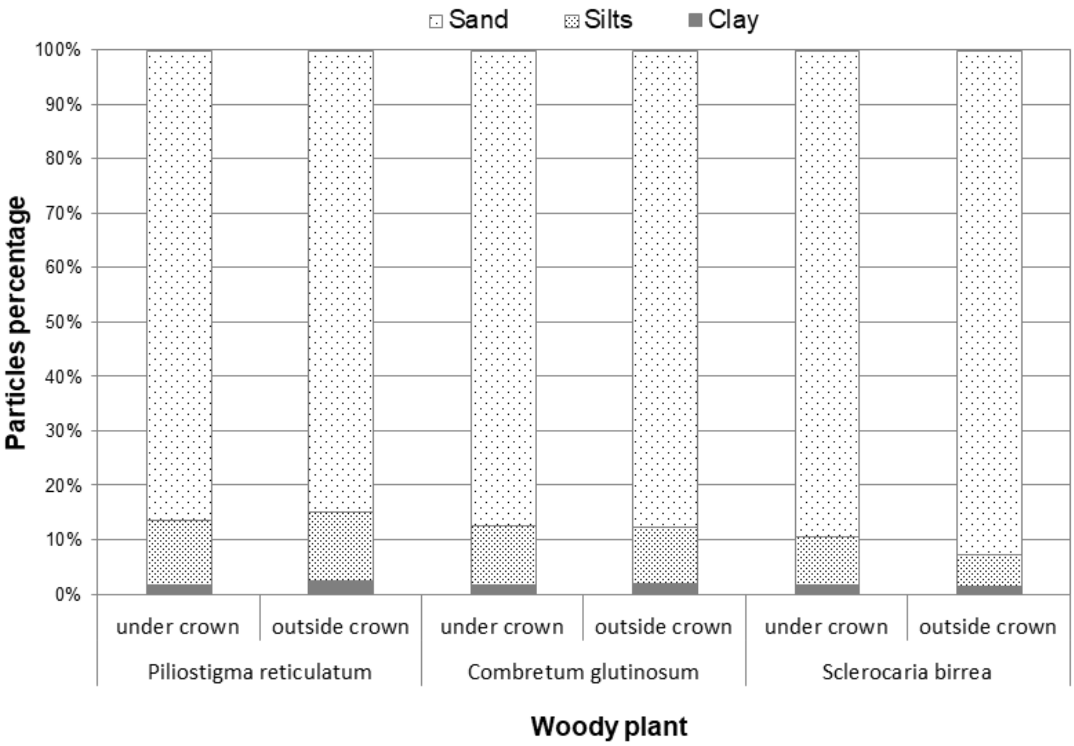

Fig. 4. Soil particle size distribution under and outside plant crown of Piliostigma reticulatum, Combretum glutinosum et Sclerocarya birrea

3.1.2. CHANGES IN SOIL CHEMICAL CHARACTERISTICS

3.1.2.1. CHANGES IN SOIL PH

In general, soil pH values were between 5.5 and 6.5 under all trees species (Figure 5), with slightly lower values under *C. glutinosum* (5.6) and higher values under *S. birrea* (6.1-6.4), confirming acid character of cultivated tropical ferruginous soils in Niger. These pH values correspond to limit threshold for normal development of most rainfed crops cultivated in Niger. However, the presence of RNA ligneous plant influences soil pH. Indeed, the soil pH under crown of *P. reticulatum* and *S. birrea* respectively is significantly higher than that outside crown of these species. Thus, the presence of *P. reticulatum* and *S. birrea* increases soil pH by 18.2 and 4.9% respectively. However, the presence of *C. glutinosum plant* has no significant effect in changes of soil pH because soil pH value is similar (5.6) between soil under and outside plant crown of this species.

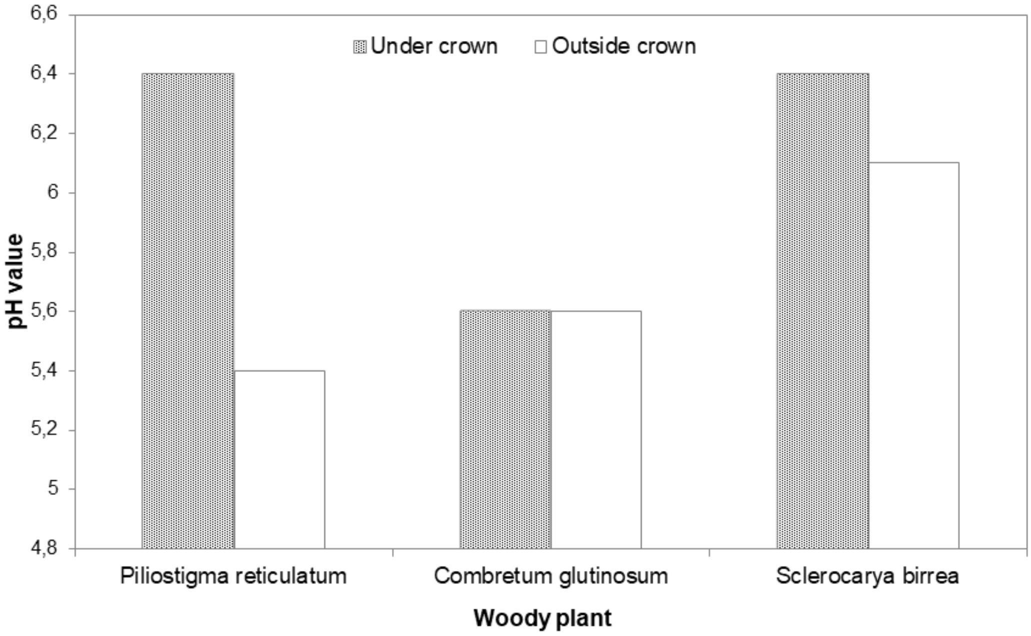

Fig. 5. Changes in soil pH under and outside plant crown of Piliostigma reticulatum, Combretum glutinosum et Sclerocarya birrea

3.1.2.2. CHANGES IN SOIL ORGANIC MATTER CONTENT

The figure 6 present variations in soil organic matter content under and outside plant crown of three species. In general, soil organic matter levels are low to average under tree crowns (between 1.21 and 1.85%) and very low outside tree crowns (< 0.5%). Thus, the presence of RNA trees species significantly increases organic matter content of soils under plant crown of all ligneous species studied. The organic matter contents are 1.85, 1.56 and 1.21% respectively under plant crown of *P. reticulatum*, *C. glutinosum* and *S. birrea*, i.e. 26, 3.8 and 4.2 times higher than that of soils outside plant crown of these ligneous species.

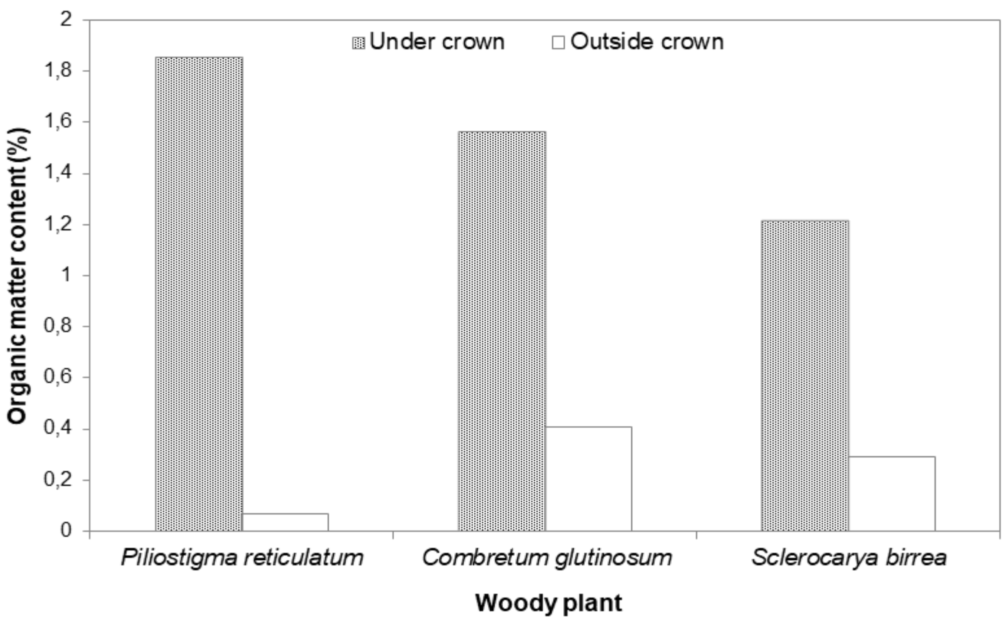

Fig. 6. Changes in soil organic matter content under and outside plant crown of Piliostigma reticulatum, Combretum glutinosum et Sclerocarya birrea

3.1.2.3. Changes in soil assimilable phosphorus content

The figure 7 present soil assimilable phosphorus contents under and outside of plant crown of RNA ligneous three. The assimilable phosphorus contents are less than 10 ppm outside of plant crown of all trees except to soil under plant crown of *C. glutinosum* which assimilable phosphorus content is 72.98 ppm. This assimilable phosphorus content is 2.5, 1.2 and 2.1 times higher under plant crown than outside plant crown of *P. reticulatum, C. glutinosum* and *S. birrea* respectively.

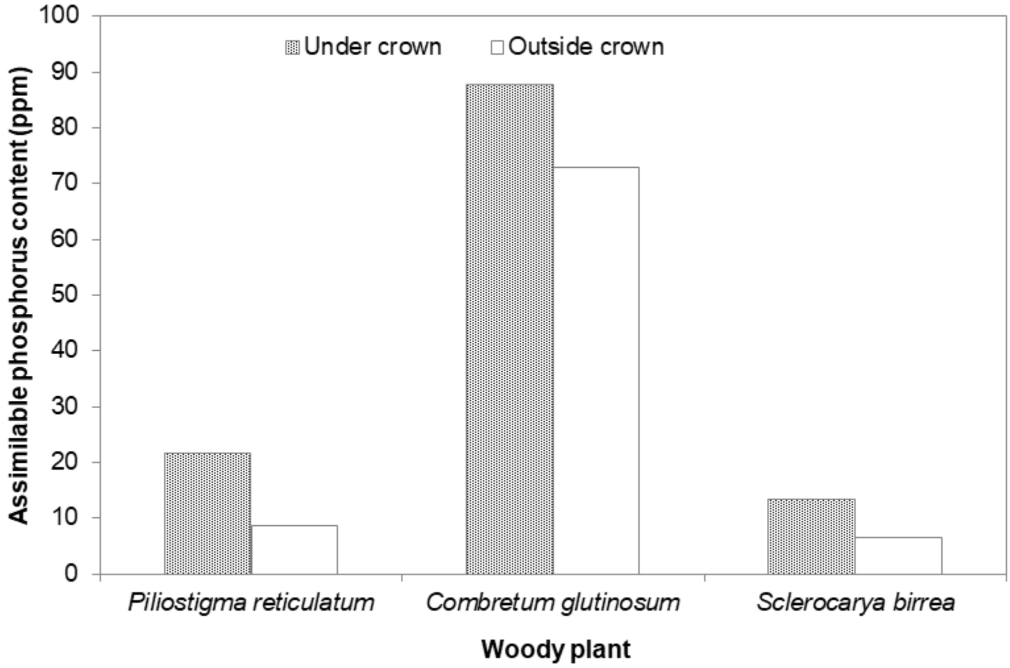

Fig. 7. ***Changes in soil assimilable phosphorus content under and outside plant crown of Piliostigma reticulatum, Combretum glutinosum et Sclerocarya birrea***

3.1.2.4. Variation of cation exchange capacity (CEC)

Figure 8 presents soil cations exchange capacity (CEC) values under and outside plant crown of three ligneous trees. In general, soil CEC value is between 10 and 12.5 under tree cover and between 7.5 and 10.0 outside plant crowns, confirming the low CEC values of cultivated tropical ferruginous soils. However, CEC value is slightly higher under plant crown than that outside plant crown for all ligneous species.

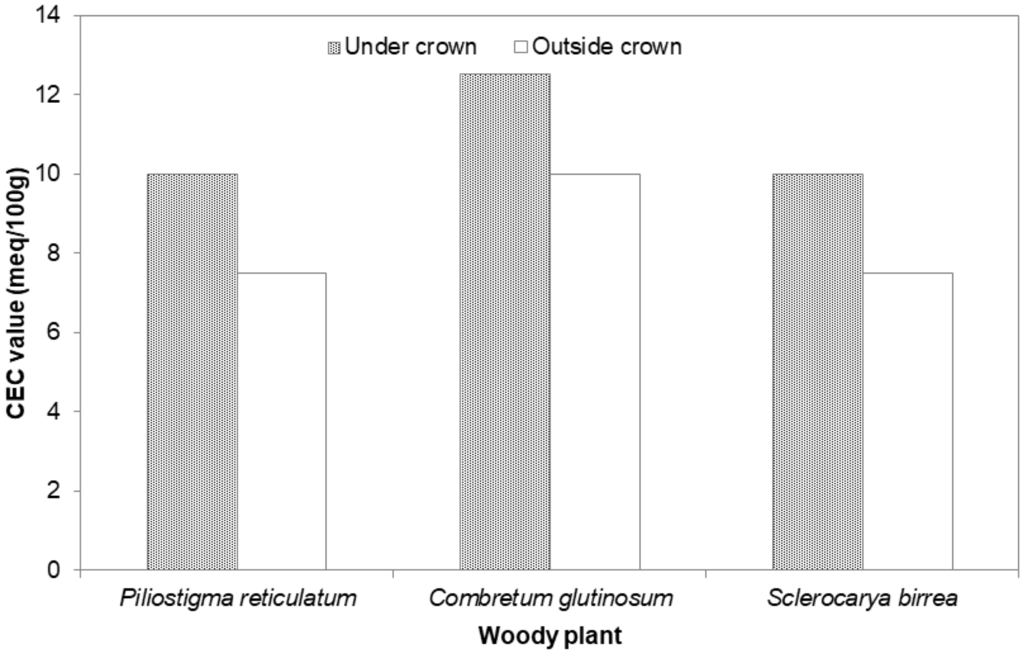

Fig. 8. Changes in soil CEC under and outside plant crown of Piliostigma reticulatum, Combretum glutinosum et Sclerocarya birrea

3.2. DISCUSSION

3.2.1. EFFECT OF RNA TREES ON SOIL PARTICULES SIZE DISTRIBUTION

The results of this study showed that soil in studies zones is dominated by sandy-textured soil with very low clay fraction (<5%), confirming the classification of ferruginous soil in study area [21]. Furthermore, this study showed that there are no significant differences between zone under and outside plant crown of *Piliostigma reticulatum, Combretum glutinosum* and *Sclerocarya birrea* on soil particle sizes distribution; showing that presence of these RNA trees has no effect on soil particle size distribution. This same observation has been reported by several authors showing that trees have no influence on soil texture [31], [32], [14]. However, reference [14] showed that the presence of tufts of *Hyphaene thebaica* and *Guiera senegalensis* significantly favor fine particles fractions (clays and silts) because of the trapping role that these tufts perform at soil surface. Therefore, the height of ligneous species in tree form is not favorable to capture fine particles at the soil surface to influence soil particle size distribution.

3.2.2. INFLUENCE OF RNA TREES ON SOILS CHIMICAL COMPOSITION

This study showed that the presence of RNA trees significantly improves soil chemical characteristics and consequently chemical fertility of these soils. Indeed, soil organic matter contents are 1.85, 1.56 and 1.21 % respectively under plant crown of *P. reticulatum, C. glutinosum* and *S. birrea*, i.e. 26, 3.8 and 4.2 times higher than those of bare soil outside plant crown of these species. This increase in soil organic matter content under RNA tree crowns is attributed to decomposition of aboveground and root biomass residues of these trees; confirming the observation of several authors [33], [34], [35], [36]. In addition, the presence of RNA trees improves soil pH. Indeed, pH of bare soils outside tree crowns is significantly more acidic than that of soils under tree crowns, in particular *P. reticulatum* and *S. birrea*. Several studies carried on effect of ligneous trees on soil chemical properties [37], [32]. Reference [14] showed positive effect of trees on improving soil pH. This improvement in soil pH was attributed to decomposition of organic matter of foliage and roots biomass of tree plant which releases exchangeable bases; thus replacing H^+ protons of soil humus-clayed complex [38]. Furthermore, presence of RNA trees improves soil assimilable phosphorus content, which is most often very low on tropical ferruginous soils. Indeed, soil assimilable phosphorus content is 2.5, 1.2 and 2.1 times higher under tree crown than that bare soil outside plant crown of *P. reticulatum, C. glutinosum* and *S. birrea* respectively. This improvement of soil phosphorus content by RNA trees is accorded to phosphorus recycling, decomposition of organic matter and root symbiosis with mycorrhizal fungi as indicated by several authors [14], [39]. Thus, RNA ligneous species of *P. recticulatum, C. glutinosum* and *S. birrea* contribute to reducing very frequent phosphorus deficiencies in ferruginous cultivated soils of Niger.

4. Conclusion

This study showed that the presence of RNA trees improves physico-chemical properties of cultivated tropical ferruginous soils. Indeed, presence of trees of *P. reticulatum, C. glutinosum* and *S. birrea* allowed to i) reduce soil acidity and ii) significantly increase soil organic matter content and soil assimilable phosphorus content of cultivated tropical ferruginous soils. This improvement in soil chemical fertility by RNA trees is essentially linked to decomposition of residues aboveground and root biomass of plant trees in soil. Thus, ligneous plants in trees form recycle nutrients in soil and input fresh organic matter to soil which improves exchange complex. In addition to its importance in the production of firewood and service wood, RNA is a promising practice for improvement and maintenance of fertility of tropical ferruginous soils which are naturally soils poor in nutrients. However, future research studies can be considered to complete this study, particularly concerning impact of RNA ligneous plants on soil water properties and interaction between crops and trees on mineral elements and light.

References

[1] M. Svendsen, M. Ewing, S. Msangi, “Measuring irrigation performance in Africa. IFPRI Discussion Paper, International Food Policy Research Institute”. Tabor, J.A., 1995. Improving crop yields in the Sahel by means of water-harvesting. J. Arid Environ. 30: 83–106, 2009.

[2] B. Biazin, G. Sterk, M. Temesgen, A. Abdulkedir, L. Stroosnijder, “Rainwater harvesting and management in rainfed agricultural systems in sub-Saharan Africa–a review, ” Physics and Chemistry of the Earth, Parts A/B/C, 47, 139-151, 2012.

[3] E. Roose, 1974. “Introduction à la gestion conservatoire de l’eau, de la biomasse et de la fertilité des sols (GCES), ” Bull. Pédol. FAO, Rome, 70, 1974.

[4] N. Dan Lamso, “Valorisation des eaux de ruissellement par des techniques traditionnelles d’aménagement des sols: Expériences en zones arides et semi-arides méditerranéennes et sahéliennes et exemple d’efficacité au Niger, ” Thèse de Doctorat. Université Abdou Moumouni de Niamey/Université de Tunis II, 2002.

[5] E. Roose, “Restauration de la productivité des sols tropicaux et méditerranéens. Contribution à Agroécologie, ” Edition IRD, 2017.

[6] J. Strebelle, B. Boubacar, “Sécurité alimentaire et organisations intermédiaires, “Evaluation et identification des besoins de renforcement des capacités des organisations paysannes dans six pays de l’UEMOA et de la CEDEAO, ” Participation des organisations paysannes et leurs faîtières à la sécurité alimentaire et aux flux commerciaux dans les marchés des produits de base. Rapport pays: Niger. Projet WAF/6349. Collectif Stratégies Alimentaires, Bruxelles – Belgique, 2011.

[7] M. Evequoz, Y. Guéro, “Conservation et Gestion des eaux et des sols: Durabilité des systèmes de production nord sahélien, ” University Abdou Moumouni (Niamey) and Ecole Polytechnique de Zurich, 2000.

[8] M. Larwanou, M. Saadou, S. Hamadou, “Les arbres dans les systèmes agraires en zone sahélienne du Niger: mode de gestion, atouts et contraintes, ” Tropicultura, 24 (1): 14–18, 2006.

[9] B.A. Bationo, A. Kalinganiré, J. Bayala, “Potentialités des ligneux dans la pratique de l’agriculture de conservation dans les zones arides et semi arides de l’Afrique de l’Ouest: Aperçu de quelques systèmes candidats, ” ICRAF Technical Manual n° 17 Nairobi: World Agroforestry Centre, 32P, 2012.

[10] A. Salissou, 2004. “Valorisation des produits et sous-produits ligneux dans la partie Nord du département d’Aguié: cas du terroir villageois de Dan Saga, ” Mémoire de fin d’études, Faculté d’Agronomie, Université Abdou Moumouni de Niamey, 66 p, 2004.

[11] A. Hamissou, “Étude de faisabilité technique, économique et organisationnelle d’un marché à bois issu de la RNA dans la grappe de Dan Saga, ” Mémoire de fin d’étude, Faculté d’Agronomie, Université Abdou Moumouni de Niamey, 71 p, 2005.

[12] A. Moustapha, “Étude de faisabilité technique, économique et organisationnelle d’un marché à bois issu de la RNA dans la grappe de Dan Saga, ” Mémoire ITA, Faculté d’Agronomie / Université Abdou Moumouni de Niamey, Niger. 67 p, 2005.

[13] ; Baumer M., 1987. “Le rôle de l’agroforesterie dans la lutte contre la désertification et la dégradation de l’environnement, ” ICRAF / CTA: Washington. 260 p, 1987.

[14] M.M Abdou, Z. M. Alzouma, A. Kadri, J.M.K Ambouta, N. Dan Lamso, “Effet de l’arbre Acacia senegal sur la fertilité des sols de gommeraies du Niger, ” Int. J. Biol. Chemi. Sci., 7 (6): 2328-2337, 2013.

[15] B. A. Camara, M. Drame, D. Sanogo, D. Ngom, M. Badji, M. Diop, “Régénération Naturelle Assistée, perceptions paysannes et effets agro-écologiques sur le rendement du mil (Pennisetum glaucum (L.) R. Br.) dans le bassin arachidier au Sénégal, ” Journal of Applied Biosciences 112: 11025-11034, 2017.

[16] C.S.F. Zounon, A. T. Abasse, M. Moussa, H. Rabiou, V. Bado, D. Tidjani, J.M.K. Ambouta, “Effet de la combinaison régénération naturelle assistée (RNA) et microdose d’engrais sur la production du mil (Pennisetum glaucum) dans les zones agro-écologiques du centre-sud du Niger, ” European Scientific Journal, 16 (6): 52-62, 2020.

[17] S. Lawali, A. Diouf, B. Morou, K.A. Kona, L. Saidou, C. Guero, A. Mahamane, "Régénération Naturelle Assistée (RNA): outil d'adaptation et résilience des ménages ruraux d'Aguié au Niger, " International Journal of Biological and Chemical Sciences, 12 (1): 75-89, 2018.
[18] N. Dan Lamso, Y. Guéro, A. Tankar Dan-Badjo, R. Lahmar, B.B André, D. Patrice, A.D. Tidjani, M.N. Ado, J.M.K Ambouta, "Variations texturales et chimiques autour des touffes d'Hyphaene thebaica (MART) des sols dans la région de Maradi (Niger), " Algerian journal of arid environment 5 (1): 40-55, 2015.
[19] N. Dan Lamso, Y. Guéro, A. Tankari Dan-Badjo, R. Lahmar, B.B. André, D. Patrice, A.D. Tidjani, M.N. Ado, J.M.K Ambouta, "Effet des touffes de Hyphaene thebaica sur la production du mil dans la région de Maradi (Niger), " Int. J. Biol. Chem. Sci., Octobre, Volume 9, Number 5: 2477-2487, 2015.
[20] N. Dan Lamso, Y. Guéro, A. Tankari Dan-Badjo, R Lahmar, B.B. André, D. Patrice, A.D. Tidjani, M.N. Ado, J.M.K Ambouta, "Effet des touffes de Guiera senegalensis (J.F. Gmel) sur la fertilité des sols dans la région de Maradi (Niger), ". Journal of Applied Biosciences 94: 8844-8857, 2015.
[21] J.M.K Ambouta, A. Issaka, S. Issa, "Gestion de la fertilité des sols et évolution des sols de Gakudi (Maradi, Niger), " Cahiers Agricultures 7: 395-400, 1998.
[22] P.L. Giffard, "L'arbre dans le paysage sénégalais. Sylviculture en zone tropicale sèche, " 431 p, 1974.
[23] M. Arbonnier, "Arbres, arbustes et lianes des zones sèches d'Afrique de l'Ouest, CIRAD - MNHN - UICN, Montpellier (France) ", 541 p, 2000.
[24] M. Traoré, "Etude de la phénologie, de la régénération naturelle et des usages de Piliostigma reticulatum (DC) Hochst en zone Nord soudanienne du Burkina Faso, " Mémoire de fin de cycle, Institut du Développement Rural/Université Polytechnique de Bobo Dioulasso, Burkina Faso, 68p, 2000.
[25] M.C. Dao, "Biologie et écologie de la reproduction sexuée d'une Caesalpinioideae (Leguminoseae): Piliostigma reticulatum (D.C.) Hochst, " Thèse de Doctorat Unique Université Polytechnique de Bobo-Dioulasso (UPB), 107 p, 2012.
[26] B. Yélémou, "Biologie et productivité de Piliostigma reticulatum (D.C.), Hochst., sur sol ferrugineux tropical de la station de recherche expérimentale de Saria (Zone phytogéographique nord soudanienne du Burkina Faso), " Mémoire de DEA, Université de Ouagadougou, 2006.
[27] A. Michael "Arbres, arbustes et lianes de l'Afrique de l'ouest, " 547p, 2000.
[28] A. Michel "Arbres, arbustes et lianes des zones sèches d'Afrique de l'Ouest, " Manuel technique, 573p, 2002.
[29] J. B. Hall, "Sclerocarya birrea (A.Rich.) Hochst., " Fiche technique Protabase sur le site http://database.prota.org/search.htm, 2002.
[30] B. Yamba, 1993. "Ressources ligneuses et problèmes d'aménagement forestier dans la zone agricole au Niger, " Thèse de doctorat, 383p, 1993.
[31] H. Moussa, "Germination du palmier doum (Hyphaene thebaica Mart.) et analyse de son interaction avec le mil (Pennisetum glaucum L, R, Br.) en zone semi-aride du Niger, " Thèse, Université Laval/ Canada, 178 p, 1997.
[32] A. Kadadé, "Système des productions et gestion de la fertilité des sols dans la rôneraie de Gaya: cas du terroir de Bana, " Mémoire de fin d'étude CRESA/FA, 68 p, 1999.
[33] A.A Maï Moussa, "Environnement de Faidherbia albida Del; caractérisation; exploitation et perspectives d'optimisation dans les zones soudano-sahéliennes de l'Afrique de l'Ouest, " Thèse de Doctorat, Université de Cocody / Cote d'Ivoire 137 p, 1996.
[34] A. Wezel, J.L. Rajot, C. Herbrig, "Influence of shrubs on soil characteristics and their function in Sahelian agro-ecosystems in semi-arid Niger, " Journ. Arid Environ, 44: 383-398, 2000.
[35] R. Lahmar, B.A Bationo, N. Dan Lamso, Y. Guéro, P. Tittonell, "Tailoring conservation agriculture technologies to West Africa semiarid zones: building on traditional local practices for soil restoration, " Field Crop Res., 2011.
[36] R. Lahmar, H. Yacouba, 2012. "Zaï et potentiel de l'association cultures annuelles-arbustes natifs. In: Dia Abdoulaye (ed.), Duponnois Robin (ed.). La grande muraille verte: capitalisation des recherches et valorisation des savoirs locaux, " Marseille: IRD p.203-223, 2012.
[37] K.A. Maï Moussa, J.H. Williams, J.C.W. Odongo, "Diversification des cultures sous Faidherbia albida en milieu paysan dans la zone semi-aride de l'Afrique de l'ouest. In: G. Renard, A. Neef, K. Beckert and M. von Oppen (eds.): Soil fertility management in west African land use systems, " Proceedings of the regional workshop. Niamey, Niger 4-9 March 1997. p. 299-303. 1997.
[38] M.G. Hagos, G.N. Smit, "Soil enrichment by Acacia mellifera subsp. Detinens on nutrient poor sandy soil in a semi-arid southern African savanna, " Journal of Arid Environments 61: 47–59.
[39] S. Boureima, M. Ibrahim, D. Ibrahim, S. Lawali, "Les pratiques paysannes de Régénération Naturelle Assistée des arbustes favorisent le développement des champignons mycorhiziens arbusculaires " 2019.