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INFLUENCE OF TREES DENSITIES IN WATER INFILTRATION IMPROVEMENT IN AGROFORESTRY PARKLAND IN BURKINA FASO

[1*]Koala Jonas; [2]Kagambega O. Raymond; [1]Yelemou Barthelemy

[1]Institut de l'Environnement et de Recherches Agricoles (INERA), Centre National de Recherche Scientifique et Technologique (CNRST), BP 10, Koudougou, Burkina Faso

[2]Ecole nationale des eaux et forêts(ENEF) 01 BP 1105 Bobodioulasso, Burkina Faso 01

*Corresponding Author

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ABSTRACT

Soil structure is an essential factor in soil organic carbon sequestration. Infiltration capacity (IC) is a key property for semi-arid soils because rains in this area fall with high flows. Objective of this study was to measure soil stability in Prosopis africana agroforestry parkland with contrasted trees density. Specifically, it was to compare water infiltration rate in plots. Study was carried in Saria research station in Burkina Faso, West Africa. Design used is a factorial with three repetitions. Only one treatment was applied. This is trees density which has 4 levels: Density 0 = 0 trees per hectare (Control); Density 1 = 434 trees ha-1; Density 2 = 217 trees ha-1 and Density 3 = 109 trees ha-1. Measurement was made using a single-ring infiltrometer. Change in water depth in cylinder was measured over 2h30 at time intervals. Infiltration rate and cumulative infiltrations for each period were calculated. Results show that presence of tree density impacted significantly water infiltration rate and cumulative infiltration. Density 1 and 2 had better infiltration rate and cumulative infiltration. This result show how the presence of trees in production system could lead to water properties and/or carbon sequestration improvement in these ecosystems.

Keywords: Infiltration rate, Cumulative infiltration, Trees density, Burkina Faso

1. INTRODUCTION

Agroforestry is a system of land use that has ensured survival of African populations for generations [1]. It has been considered as sustainable system because it could contribute to solving land degradation problems. Its impact on improving soil fertility and populations well-being has been demonstrated by several studies [2]. Agroforestry technologies, through presence of woody species, provide many products for human and animal food, crafts, pharmacopoeia etc. [3]; [4]. They also contribute to increasing soil organic matter, recycling nutrients, controlling soil erosion and, consequently, increasing agricultural yields [5]. However, agroforestry technologies have the disadvantage of competing with crops [6]. But, the multiple benefits they provide to environment and population that are widely recognized mean that this production system is attracting attention of several researchers who are increasingly interested in the role it could play in carbon sequestration [7]. In Burkina Faso, some studies have focused on above ground biomass carbon pool [8]; [9], but Few studies have been carried out on Agroforestry belowground carbon storage capacity and conditions[10]. This present study aims to fill this gap and has a purpose to measure agroforestry parkland soils structure stability in contrasting tree densities. And this, because it is recognized that soil structure is an essential factor in soil organic carbon (SOC) sequestration. Indeed, SOC is one of the most important terrestrial carbon pools [11], and the rate of soil water infiltration is positively correlated with soil stability and its ability to resist soil erosion [12]. While erosion is considered to be one of main disturbing factors affecting the level of organic carbon in soils [11]. A more stable soil could sequester carbon more sustainably. Infiltration capacity is a key property for semi-arid soils because rains in this area fall with high flows [13]. In this context, high *infiltration rate* prevents surface runoff and soil erosion that is common phenomena in Burkina Faso. Specific objective of this study was to measure water *infiltration rate* and *cumulative infiltration* as a function of *trees density* in *Prosopis africana* parkland.

2. MATERIAL AND METHODS

2.1. Study site

Study was carried in Saria research station (12°16'00.0"N 2°09'00.0"W, 300 m altitude) in Burkina Faso, West Africa.

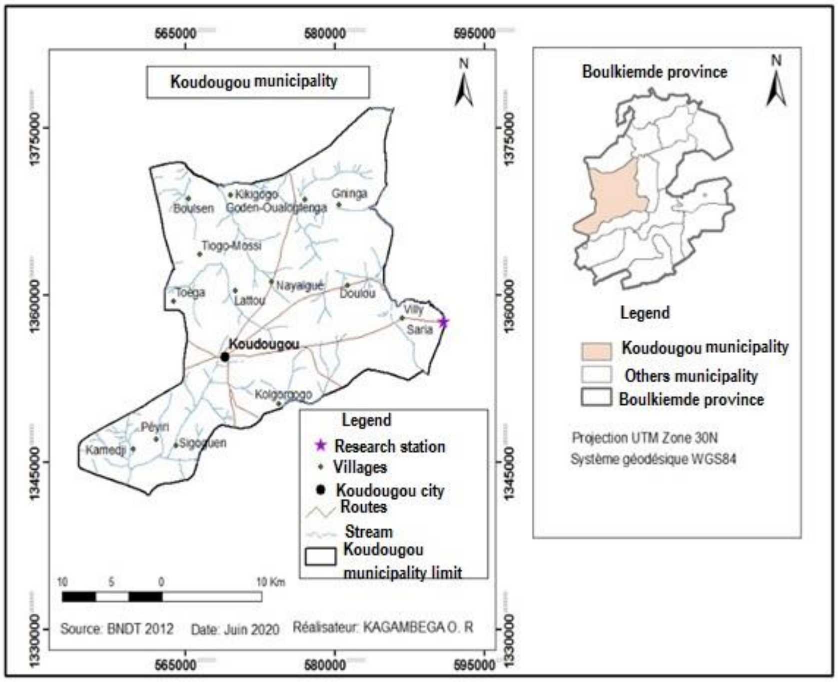

Figure 1: Study site location

Climate is north sudanian [14] and mean annual rainfall during the last 30 years is about 822, 36±95, 14 mm year^{-1}. The rainfall is mono-imodal and last mainly for 5 months from June to October. Mean daily temperatures vary between 30°C during the rainy season and may reach 35°C in April and May

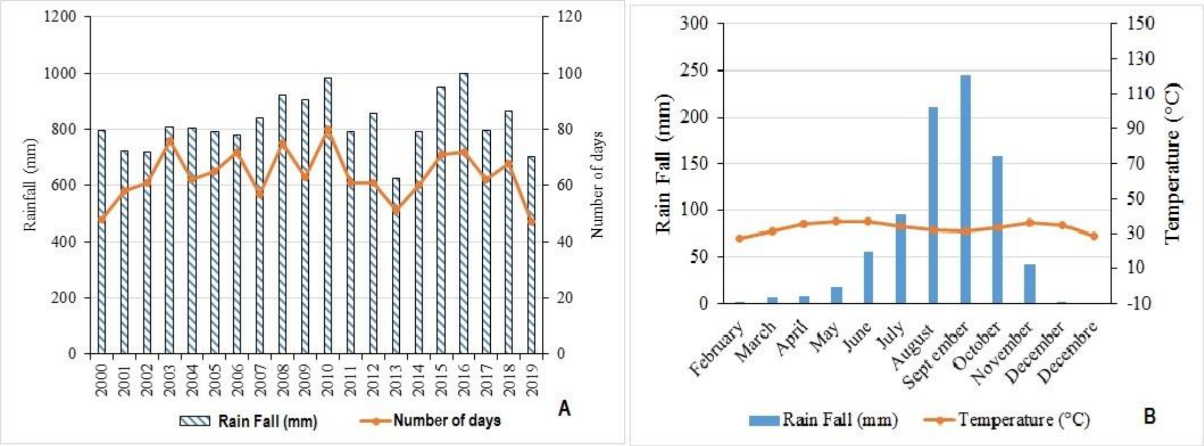

Figure 2: Rainfall and number of rainy days for the last 20 years (A) and monthly rainfall means (B)

Soil type is Ferric Lixisol with an average slope of 1.5%. Woody vegetation is composed by tree and shrubs species. Trees species are dominated by *Parkia biglobosa*, *Vittelaria paradoxa*, *Lannea microcarpa*, *Tamarindus indica*, *Khaya senegalensis* and *Azadirachta indica*. For shrubs, the common species are *Guiera senegalensis*, *Ximenia americana*, *Combretum micranthum*, *Piliostigma reticulatum*, *Acacia macrostachya* and *Acacia pennata*. The most widely cultivated agricultural speculations in the research station and surroundings areas are different varieties from genuses *Sorghum*, *Pennisetum and Vigna*.

2.2. Design

Design used is a factorial with three repetitions. Only one treatment was applied. This is Tree density which has 4 levels: Density 0 (D0) = 0 tree ha^{-1} (Control); Density 1 (D1) = 434 trees ha^{-1}; Density 2 (D2) = 217 trees ha^{-1} and Density 3 (D3) = 109 trees ha^{-1}

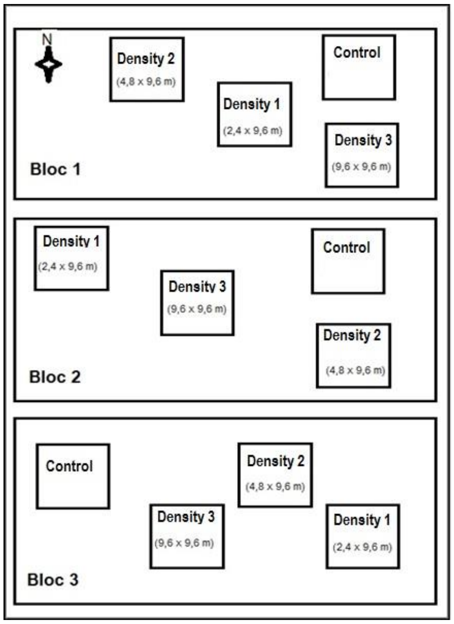

Figure 3: Experimental design

2.3. Infiltration measurement

Measurement in the field was made using a single-ring infiltrometer with 10 cm diameter and 20 cm cylinder height [15] measurements were repeated 3 times per plot in each block. For infiltration process, site was prepared by removing all residues and any large clods in tilled soils that would interfere with achieving a level surface. Infiltrometer cylinder was pushed at least 3 cm into the ground. To prevent lateral flow, firstly we wet the soil by putting water in the cylinder and left for 15min. After this time, water was filled to its initial level before starting the reading process. Change in water depth in cylinder was measured over a period of 2h30 at time intervals of 5, 10, 15, 20, 30, 40, 60, 75, 90, 105, 120 and 150 min.

2.4. Data analysis

Data collected in samples plots for each type of *trees density* was used to calculate 2 variables: *infiltration rate* and *cumulative infiltration*.

Water depth in mm (fi) at each recording period that represent *cumulative infiltration* in this period was calculated as

$$fi(t) = Qn - Q0 \qquad (1)$$

With *fi(t) cumulative infiltration* (in mm) in each measurement period, *Qn*=water level at the end the period and *Q0*= water level at the beginning.

Further, measurements of steady *infiltration rate* were made after each measurement period in dividing the *cumulative infiltration* water depth for the period by the required times (Wuest, 2005).

$$ri(t) = \frac{fi(t)}{t} \qquad (2)$$

With ri(t)=*infiltration rate* (in mm/min) at each recording period, t= time of this period and fi(t), the *cumulative infiltration* in this period (in mm)

And total *infiltration rate* was calculate as the mean of all ri(t) using the following equation

$$r(t) = \frac{\sum_{t0}^{t} ri(t)}{n} \qquad (3)$$

By integrating equation 1, we calculated total *cumulative infiltration* (C(t)) for each measurement point.

$$C(t) = \int_{i=0}^{150} fi(t) \qquad (4)$$

Data was examined with an emphasis on comparing *infiltration rate* and *cumulative infiltration* due to *trees density* difference. Different plots and blocs were not of particular interest here since they were considered as random affect. Data was not normally distributed, but we avoided data transformation as a solution to meet assumption of parametric analysis considered mostly as more robust, because some interesting ecological information could be thrown away [16]. Therefore non parametric analysis was used for data analysis. Marginal means and different standard deviations of each variable (*infiltration rate* and *cumulative infiltration*) for each treatment (*trees density*) were estimated and Kruskal-Wallis test was used to compare variation of the two infiltration parameters. All statistical analyses were done with IBM SPSS Statistics 22.

3. RESULTS AND DISCUSSION

3.1. Impact of trees density on Infiltration rate and cumulative infiltration

Tree density impacted significantly *infiltration rate* and *cumulative infiltration*. These two variable in plots with *tree density* 1 and 2 were statistically different with plots with density 3 and Control plots showed lowest values for *infiltration rate* and *cumulative infiltration* (Figure 4).

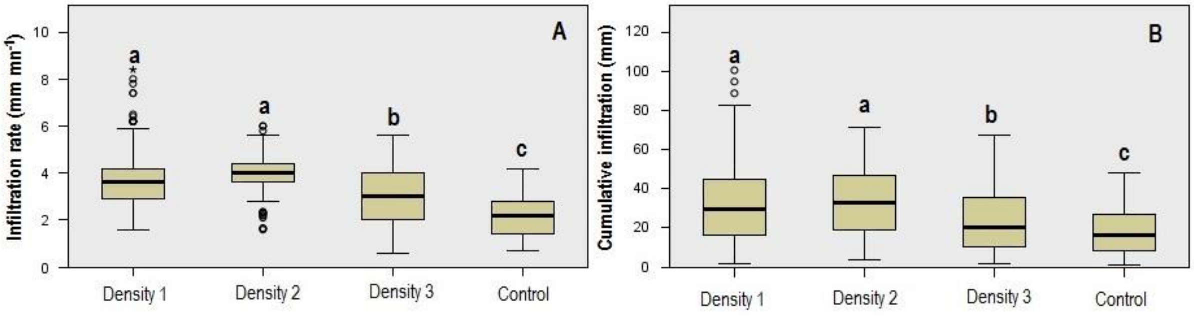

Figure 4: Difference of infiltration rate (A) and cumulative infiltration (B) between contrasting trees density plots

Infiltration rate in plots with densities 1 and 2 was higher than the rate in density 3 (Figure 4). *Infiltration rates* were 3.8 ± 1.4 mm mn^{-1}, 3.9 ± 0.8 mm mn^{-1} and 3.0 ± 1.3 mm mn^{-1}, respectively (tableau 1) in plots with densities 1, 2 and 3. Control plots recorded lowest *infiltration rate* of 2.2 ± 0.8 mm min^{-1} (Table 1).*Cumulative infiltration* during the 150 min (2 h 30 min) in *density 1* (31.9 ± 20.0 mm) and *density* 2 (33.2 ± 17.2 mm) were greater (P<0.001) than the one in *density* 3 (24.6 ± 17.3 mm) (Figure 4). Each of the three densities (D1, D2, D3) recorded a *cumulative infiltration* greater (P<0.001) than that obtained in the control plots (D0) (18.4 ± 11.7 mm) (Figure 6).

Table 1: Mean of infiltration rate and cumulative infiltration in 150 minutes in plots with contrasting densities

Density	***Infiltration rate*** **(Mean±SD mm mn^{-1})**	***Cumulative Infiltration*** **(Mean±SD mm)**
Density 1	3.8±1.4	31.9±20.0
Density 2	3.9±0.8	33.2±17.2
Density 3	3.0±1.3	24.6±17.3
Control	2.2±0.8	18.4±11.7

3.2. Trend of infiltration rate and cumulative infiltration during measurement period

Analysis of infiltration evolution during measurement period shows that the greatest *infiltration rate* was obtained during 0-5 min (3.7 mm min^{-1}). It is followed by 5-10 min (3.3 mm min^{-1}) and 10-20 min (3.1 mm min^{-1}) (Figure 5A). During entire measurement period (150 min), *infiltration rates* in densities 1, 2 and 3 were higher than those in control plots (Figure 4). The highest *infiltration rates* were obtained during the first 5 minutes. They gradually decreased to reach a constant pace from 130 minutes (Figure 5A).

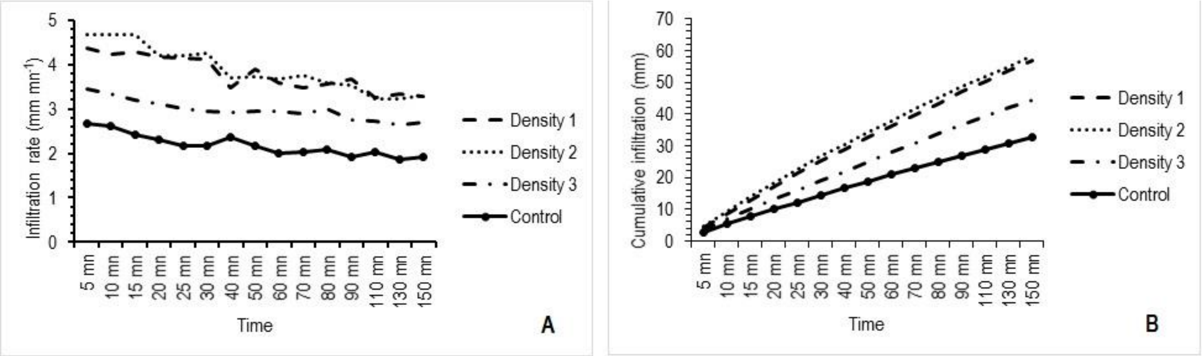

Figure 5: Evolution of infiltration rate (A) and cumulative infiltration (B) in different trees density plots

4. DISCUSSION

Soil stability which represent one of important pool of carbon had to be studied especially since erosion is considered as one of the major disturbance factor which affects SOC level [11]. *Infiltration rate* is positively correlating with the soil stability and it ability to resist scouring (erosion) [12]. Results provided in this study provide evidences that vegetation exerts control on infiltration/runoff dynamics through direct interactions with soil quality and surface characteristics [17].

4.1. Impact of trees density on Infiltration rate and cumulative infiltration

This result is in agreement with studies by Chartier et al., (2011) that reported decrease in *infiltration rate* in conditions with vegetation cover reduction. Vegetation cover reduction expose soil surface to impact of raindrops which in turn often leads to crusting. The mechanical energy input from raindrops increases the dispersion of soils and results in the blockage of surface pores and reduced infiltration in most soil types [18]; [19]). In addition to the mechanical disturbance, difference in vegetation lead to difference of organic matter between plots. Trees increase soils organic matter content by shedding leaves and continuous renewal of fine roots [20]; [21]. When organic matter are incorporated into the soil, it firstly gets better moisture holding capacity and better aggregate structure and secondly decrease runoff speed. These two phenomena lead to improve *infiltration rate*. Also, fine roots death leaves channels where water can flow more easily. Other explanations could be that grazing cattle prefer shade under trees in agroforestry parklands and this leads to a greater amount of faeces with a compost effect under trees. Also, birds, landing on tree crowns may also contribute to same effect through their droppings [13]. However, other authors report negative effects of the presence of animals on soil structure. Cattle grazing results in mechanical pressure on the ground as animal trampling contributes to altered soil structure through soil compaction and reduction of soil porosity [22]; [23]; [24].

4.2. Trend of infiltration rate and cumulative infiltration during measurement period

Infiltration gradually decreased to reach a constant pace from 130 minutes. This could be explained by the fact that during the first 5 min interval, infiltration concerned superficial layers. As time passed, infiltration speed was strongly reduced at depth.

This trend is due essentially to the decrease in pressure gradient that could be reinforced by partial clogging of pores and formation of surface crust following degradation of soil structure causing particles migration [25]. Indeed, Infiltration refers to the transfer of water through the surface layers of the soil, when it receives a downpour or if it is exposed to submersion. Infiltration water first fills the interstices of the soil on the surface and then penetrates into the soil under the action of gravity and suction forces [26]. The difference in the *infiltration rate* in the first minutes could be explained by difference in soil porosity caused by several phenomena like soil micro flora, interstices caused by coarse roots and fine roots mortality, etc[27]. As for *cumulative infiltration*, difference between *trees density* is observed from the tenth minute. These differences are maintained until the end of the measurement (150 min) (Figure 5B). This is the consequence of infiltration rates difference between treatments which was also maintained in the same way during measurement period.

5. CONCLUSION

Main objective of this study was to determine water infiltration capacity in different *trees density* in agroforestry parkland of *Prosopis africana* (Guill., And Rich.) Taub. *Infiltration rate* and *cumulative infiltration* for each period were calculated. Results show that presence of tree impacted significantly water *infiltration rate* and *cumulative infiltration*. *Trees density* variation impacted *infiltration rate* and *cumulative infiltration*. These results gave an overview of the effects of trees densities on water infiltration and show how the presence of trees in production system could lead to water properties improvement and/or carbon sequestration in these ecosystems.

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