

**Adaptation of the genus *piliostigma* to climatic aridity in the sahel-soudanian zone:
Effect of pedoclimatic factors on the root system**

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ABSTRACT

The species of the genus Piliostigma despite the fierce anthropisation they face, still mark the agrarian landscape of Burkina Faso. This study aims to seize the different modes of adaptation in situ, the root system of species of the genus Piliostigma, so as to understand their mechanism of optimal adaptation. For this, the country was divided into transect zones going from the sub-Saharan areas in the north to the sudanian ones in the south. In these areas clusters Piliostigma reticulatum and / or Piliostigma thonningii aged 25 to 30 years were studied. For each Piliostigma population considered, a soil profile was developed to determine the depth of the soil, the different soil horizons, and the morphology of the main root. Then all roots were carefully exposed taking into account the distribution of the soil horizons. Piliostigma's root system does not depend on the phytogeographical area. The species of the genus Piliostigma have a twirling root system that adjusts to different types of soils. In shallow soils (0-40 cm), the main root, strongly tuberous, turns into lateral roots in contact with the armor. In moderately deep soils (0-40/60 cm), this root divides into a pitchfork that anchors itself in the armor. With these Piliostigma species, strong lateral roots develop at the second horizon while 60% of fine roots grow at the upper horizon. In addition, the volume of soil explored by Piliostigma's root system is more important in the North-sudanian zone and significantly different from other climatic zones. These characteristics explain the adaptability of Piliostigma to the arid climate of Burkina Faso.

Key words: *Piliostigma reticulatum, Piliostigma thonningii, main root, lateral root, soil, phytogeographical zone.*

INTRODUCTION

Globally, woody formations experience a strong anthropogenic pressure due to the increasing of the poorer rural population [1, 2]. In Burkina Faso, many research works have shown that woody formations experience a considerable degradation due to the combined effect of climatic factors and of the various usages of wood [3, 4, 5, 6]. This environmental degradation can be explained by the importance of woody species to the survival of rural

dwellers. This fact is due to the nutritive contents of some non-woody products retrieved from trees and shrubs. Trees play an important role in the survival strategies of rural populations who face long years of drought [7]. For many authors, the lack of knowledge on the requirements of woody species partly explains the degradation of the woody cover [8, 4, 9]. Because access to the buried part of woody species is difficult, it remains one of the elements of plant least studied. Yet, the root system determines the settlement and development of wood in an environment subject to multiple assaults and in a context of climatic aridity. *Piliostigma* species, pioneer in the recovery of degraded lands [1], induce the emergence and existence of many species in fallow. Under the canopy of species of the genus *Piliostigma*'s, there are favorable conditions for the emergence of a strong floristic diversity [10]. As a species with a high capacity for carbon sequestration [11], these species are still abundant in semi-arid area despite the decline of other many woody species [1]. They are gregarious species present on any type of soil [12]. Their modes of underground adaptation remain fairly known. Nowadays, with the effects of climate aridity, the competitiveness of the root system is a major asset in promoting plant species. It is in this context that this study was initiated to determine the mechanisms of *Piliostigma* root adaptation, in order to allow its better appropriation by populations in the agro-pasture systems.

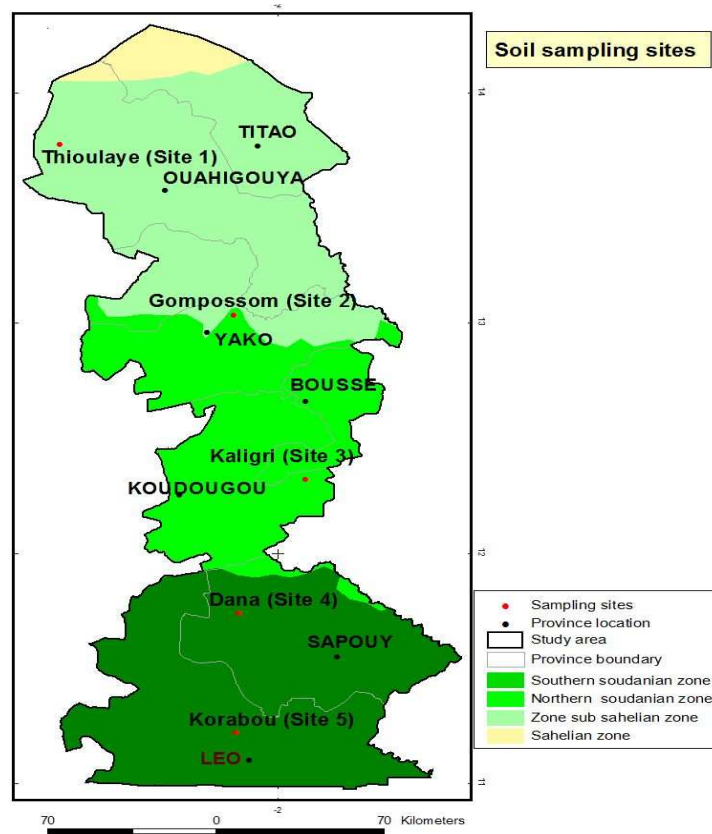


Figure 1: Localization of study's sites

MATERIALS AND METHODS

Study area

The research area stretches across the latitudes $10^{\circ} 80'N$ and $14^{\circ} 30' N$ and the longitudes $1^{\circ} 30'W$ and $2^{\circ} 97'W$ (Figure 1). At all sites, the vegetation is strongly seasonal and virtually all woody species are deciduous; most herbs are either annual or die back to the ground each dry season. The altitude of most sites was moderate and was about 300 m a. s. l. Phyto-geographically; the study area goes through North and South in the following sectors [13]. The North part of our study zone, which comprises the Yatenga and Passoré provinces, is subject to a Soudano-Sahelian Climate. Rainfall is scarce and irregular with an average annual rainfall ranging between 600 – 700 mm. The central part of our study zone, the Bulkiemde province, is subject to a North-Soudanian zone with an average annual rainfall ranging from 600-900 mm. The Southern part, comprising Ziro and Sissili, has a South-Soudanian climate type with an average annual rainfall above 900 mm (Figure 2). The rainy season lasts 6 to 7 months. From North to South, the number of rainy days goes from 89 to 166 days [14].

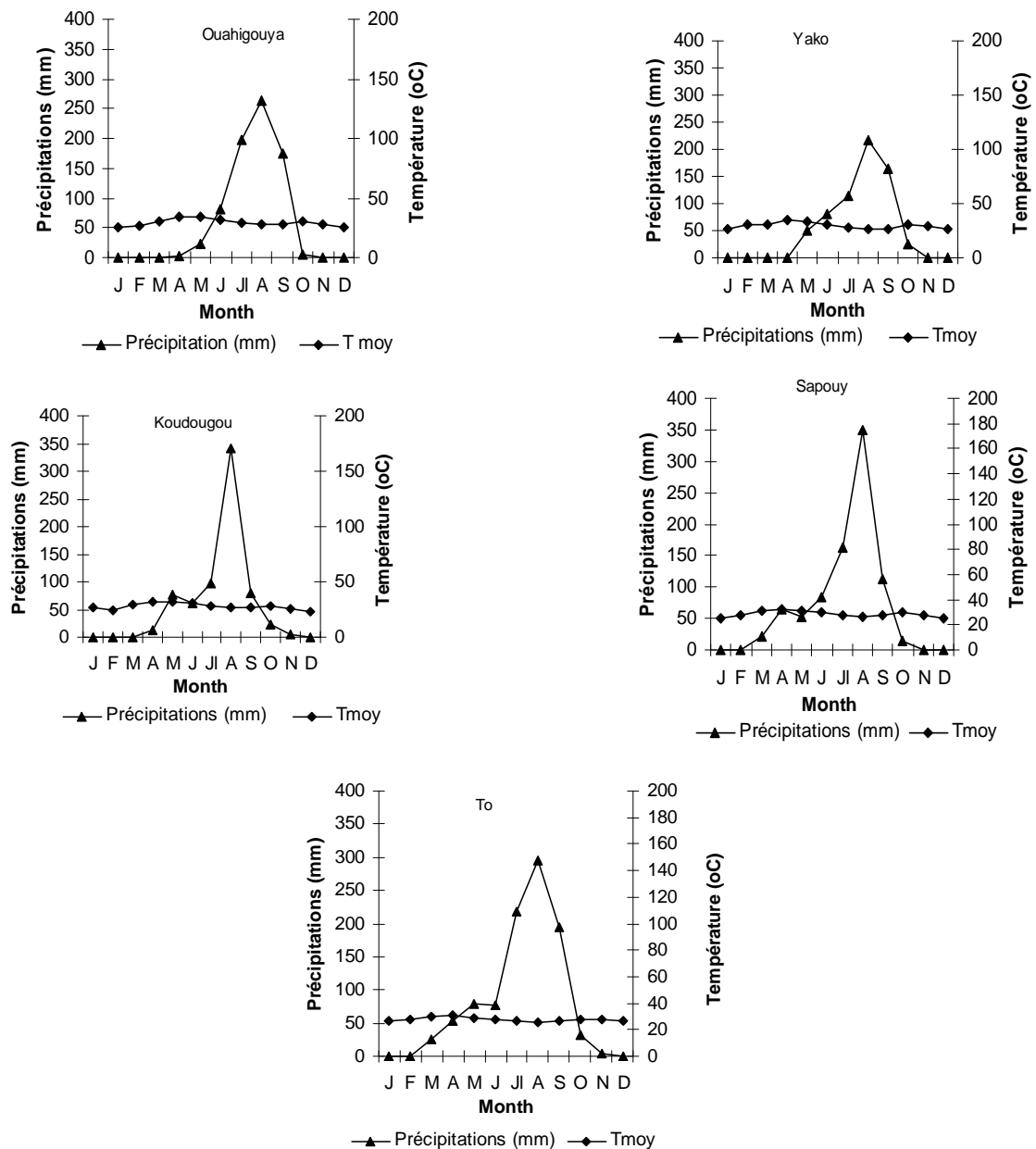


Figure 2: Ombrothermic charts, from 1987 to 2007 in 5 meteorological stations in our study area

The vegetation is characterized by tiger bushes, a patterned vegetation formation that consists of alternating bands of trees or shrubs, separated by bare ground or low herb cover, which is typical of the sahelian climate. Patchy shrub savannah are encountered on a large part of this sector zone in which species in the Combretaceae and Mimosaceae families dominate the woody vegetation; the herbaceous vegetation is dominated by Poaceae. The common woody species are *Combretum spp*, *Acacia spp* and *Piliostigma reticulatum*. Land use system consists of fallow lands and mainly traditional agro-forestry parklands with annual food crops, where the common woody species are *Vitellaria paradoxa*, *Parkia biglobosa*, *Lannea microcarpa*, *Combretum spp* and *Diospyros mespiliformis*. The North-Sudanian sector has a mean annual rainfall ranging between 600 – 900 mm with the number of rainy days per annum ranging between 50 and 70. The South-Sudanian sector has a mean annual rainfall ranging between 800 – 900 mm and the number of rainy days per annum between 60 and 80. In the North-Sudanian and South-Sudanian sectors more than 90% of the soils encountered are washed or impoverished tropical ferruginous soils. The vegetation is of the Sudanian Savannah type, characterized by the coexistence of trees and grasses. The natural vegetation mostly comprises dry forests and a mixture of shrubs and trees of the savannah types not growing above 7 m. There is also a tree savannah specific to the south-soudanian climate and essentially constituted of trees of 7 to 12 m. Much of the two Sudanian sectors is used as parklands where useful trees are spared from cutting, and sorghum, maize, millet or other crops are cultivated beneath. Dominant tree species often belong to Combretaceae

and Caesalpinioideae, some Acacia species are also important. The most common species are: *Vitellaria paradoxa*, *Detarium microcarpum* Guill. and Perr., *Parkia biglobosa*, *Lannea microcarpa*, *Acacia albida*, *Anogeissus leiocarpa* (DC.) Guill. & Perr., *Pterocarpus erinaceus* Poir., *Burkea africana* Hook.F., *Isoberlinia doka* Craib. and Stapf., *Tamarindus indica*, *Crotopteryx febrifuga* (Afz.ex G. Don) Benth., *Adansonia digitata*, *Combretum micranthum* and *Piliostigma thonningii*. The dominant grass species are usually Andropogoneae, especially the genera *Andropogon* and *Hyparrhenia*, on shallow soils, as well as *Loudetia* and *Aristida*.

Sites selection

The existence of a *Piliostigma* population was a prerequisite to setting a site. A population of *Piliostigma* (Figure 3) was defined by the relative dominance (canopy cover > 5%) of *Piliostigma* species on at least 1 hectare. The sites were chosen to represent the widest possible range of stand conditions, mainly reflected by stand quality and density of the species. By site of *Piliostigma* population, three feet of *P. reticulatum* and / or *P. thonningii* (if one or two species are present), were studied. The age of *Piliostigma* population ranges between 20 and 25 years.

Choice of individuals

Individuals selected must not have been pruned. They should be as close as possible to each other (if the two species exist on the same site) and their crown should have the same size as possible. Adult, but not too old, subjects were chosen because of the importance of the root system. In the subsahelian zone, 3 feet of *P. reticulatum* have been studied, in north soudanian area, 4 feet of *P. thonningii* and 6 feet of *P. reticulatum* and in south soudanian area 3 feet of *P. reticulatum* and 5 feet of *P. thonningii*. Individuals choiced present a variability of dendrometric parameters (Table 1).

Table 1: Dendrometric Characteristics of plants choosed

Phytogeographic zones	Species	Basal circumference (cm)	Total heigh (cm)	Canopy (cm)
South soudanian	<i>P. reticulatum</i>	12.24±1.55	147.40±33.57	83.85±16.87
	<i>P. thonningii</i>	10.87±1.64	154.08±19.07	93.40±25.75
North soudanian	<i>P. reticulatum</i>	10.4±1.05	83.85±16.87	160.20±51.20
	<i>P. thonningii</i>	11.7± 4.56	93.40±25.75	123.50±27.73
Sub sahelian	<i>P. reticulatum</i>	11.83±2.30	126.00±8.88	92.83±25.90

Soil and root profile

In a site, after choosing a *P. reticulatum* or a *P. thonningii* individual, a soil pit is made under the trunk along the main root, sparing all other roots encountered (Figure 1). Quite often, in order to reach the extremity of the taproot, a crowbar is necessary because of the toughness of the rock encountered.

The different layers of soil are identified and their thickness recorded (Figure 4). For the root profile, the excavation method described by Bohm [15] and used by Ganaba [16] was adapted. Lateral roots are exposed to the tip with great care, using a pick, and often hands. This method measures the rooting depth and the intensity of colonization of the soil by the root system of the woody [16].



Figure 3: Population of *P. reticulatum* in subsahelian zone



Figure 4: Soil profile under *P. reticulatum* in sub sahelian zone

The root system hereby exposed is described following soil horizons, drawn, and the lateral roots counted and measured by horizon. The main root and the depth of the collar are also described and measured. In order to estimate *Piliostigma* fine roots, 6 classes of depth were determined as follows: [0-20 cm], [20-40 cm], [40-60 cm], [60-80 cm], [80 - 100 cm], [100-120 cm]. A 20 cl capacity cylinder was used to take some piece of soil following the different classes and the depth of the soil. By class considered, each sample was washed through a sieve (2mm in diameter). The fine roots obtained were counted, and then oven-dried and weighed.

Dendrometric characteristics like the diameter of the great canopy, the diameter of the small canopy, the height of the foot, the diameter at the base of the stem or stems, the health and anthropisation state of the foot, were measured before the excavation phase.

Data analysis

Data were recorded using Excel 2013. Drawings allowed us to determine the various architectural types of the root system of *Piliostigma*. The computation of the volumes of soil explored by the roots allowed us to determine the intensity of the root colonization. Different averages of root parameters were set according to the different phytogeographical areas. Variance calculations allowed us to establish correlations between tree-ring parameters and phytogeographical areas. The LSD tests were used to determine the significance of variables in the different areas. Significance levels were set at $P < 0.05$. SPSS version 10.0 and STATISTICA version 6.0 were used for the statistical analysis.

RESULTS AND DISCUSSION

Root morphology and soil texture

P. reticulatum and *P. thonningii*, have an underground fixture comprising a main taproot and lateral secondary roots. The root system has various adaptations depending on the soil's texture.

In shallow soils, where the armor is encountered at 30-40 cm depth, the main root of *Piliostigma* turns into a horizontal one. The main root remains in this horizon over the armor. It ramifies into smaller roots ascending to the surface horizons (Figure 5 and 6).

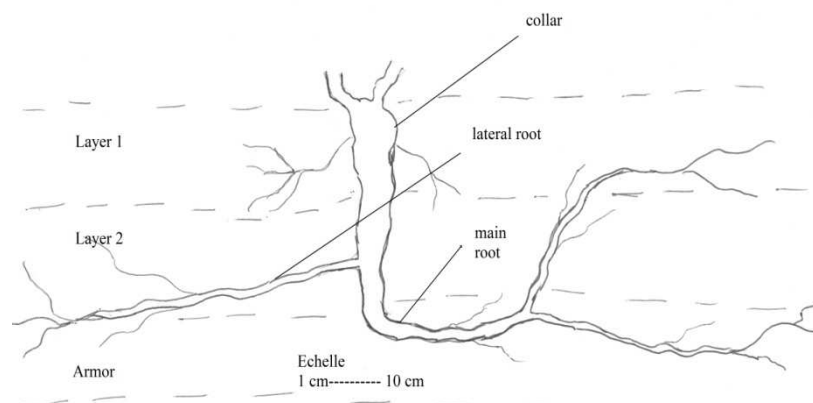


Figure 5: Transformation of the main root in a lateral one at *P. thonningii*

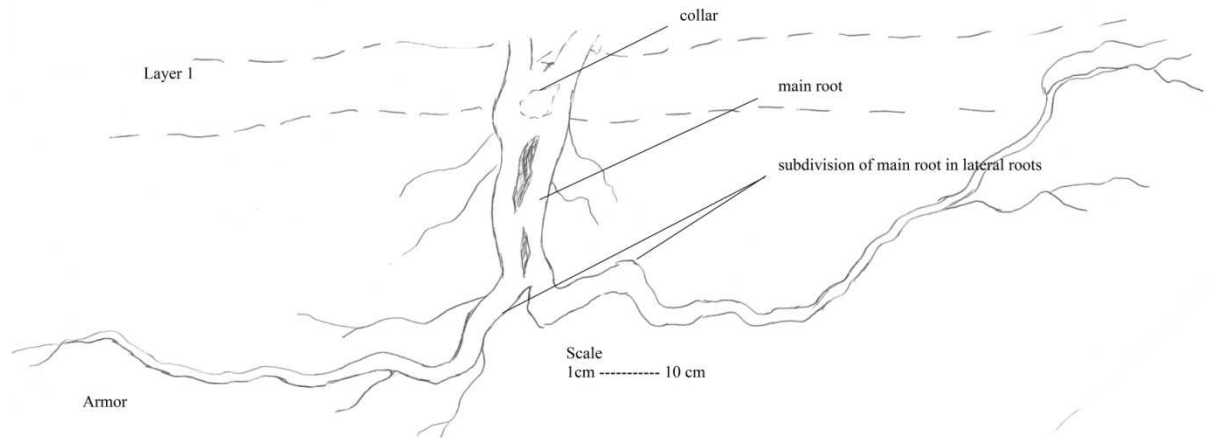


Figure 6: Subdivision of the main root in two lateral one

The main root can also divide into two lateral roots on each side of the tree. These lateral roots originating from the taproot's transformation, are generally strong roots that firmly establish the species into the soil. In these shallow soils, short taproots have a high tuber from the collar.

In moderately deep soils (40-60 cm), the main root penetrates the ground in a more or less straight line, as a single root until it reaches the armor. It then subdivides into a two-tooth pitchfork sinking roughly in the armor. This root morphology is found both in *P. reticulatum* and *P. thonningii* and in all phytogeographical zones (Figure 7).

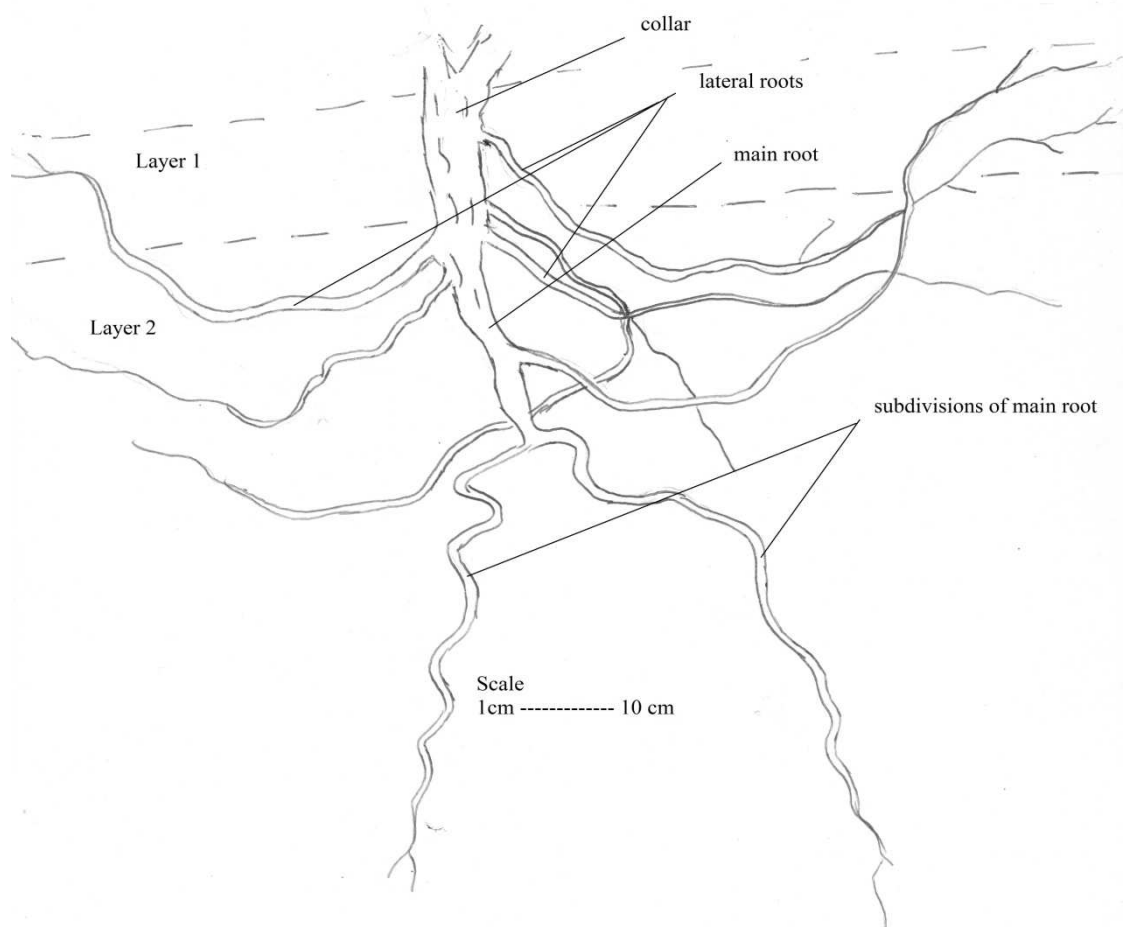


Figure 7: Architecture of *P. reticulatum*'s root in moderate deep soil in subsahelian zone

In these soils, the root morphology of *Piliostigma* is characterised by a remarkable presence of secondary roots at the horizon 2 (16/20 to 40 cm). These are long and thick lateral roots.

In deep soil, whatever the phytogeographical area, the main root sinks steadily into the ground, ending in a point. In these types of soils, secondary roots, strong and many, are located in the horizon 2 (Figure 8).

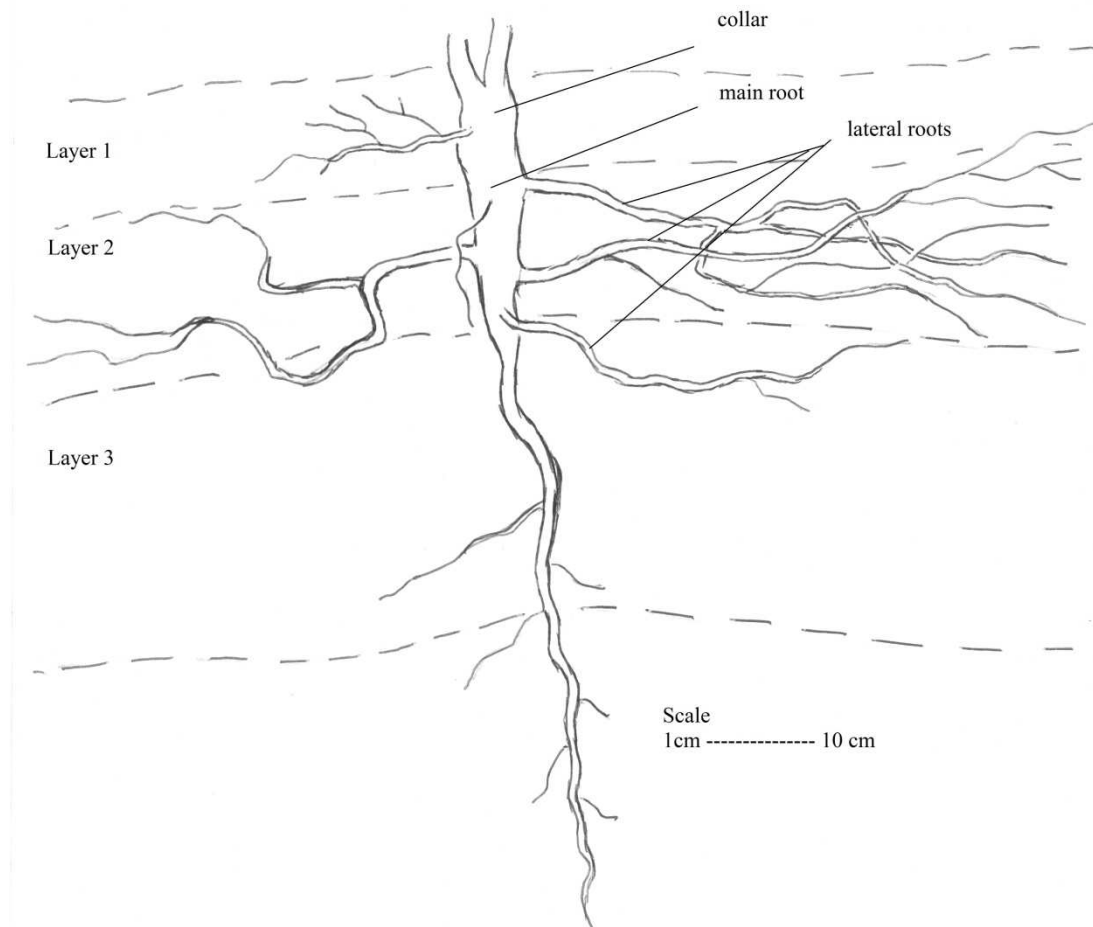


Figure 8: Evolution of *P. thonningii* root system in deep soil

Species of the Piliostigma type have a taproot system with lateral roots [12, 17]. This type of root system, while fixing the plant to the ground allows it to explore the side layers. Piliostigma root systems have many adaptations' modes depending on the depth and texture of soil, allowing to firmly anchor the plant in its environment. This function of securing establishment into the soil is confirmed by the existence of strong roots (by their diameter), especially in the second horizon. This morphological adaptation of Piliostigma root system seems to be related not to climate variability but rather to the soil. Indeed, Piliostigma adapts to many types of soil [12, 17]. In addition, the various shapes in the endings of the main root (pitchfork, spin), reflect the adaptation of the species to the texture of impermeable soil layers. Even though the root system of Piliostigma does not stretch very deep (fixed to the soil in which it is located), the shape taken by the terminal part of the pivot contributes to anchoring it firmly into the ground. Piliostigma adapts to water erosion and strong winds.

Piliostigma's main root presents an important tuber due to an accumulation of reserves [18, 19, 20]. *Piliostigma reticulatum* presents an early development of the root system with a strong predominance of the main root [17]. The pivot's thick and rough bark compared to the lateral roots shows the main root precocity. With *Piliostigma reticulatum* and *Piliostigma thonningii*, the collar is buried in the soil. This morphological characteristic is an adaptation of the species to multiple anthropogenic pressures.

Indeed, despite frequent bush fires in the Sahel and wood cuttings for the purpose of firewood [21] or for pharmacopoeia [1, 22, 23, 24], *P. reticulatum* and *P. thonningii* remain present in the agricultural landscape [10].

Evolution of root density

The fine roots considered are those with a less than 2 millimeters diameter. For all species of Piliostigma, the surface horizon contains the highest proportion of fine roots (60%). This proportion of Piliostigma fine roots decreases sharply in the horizon 0-20 cm, and more in the horizon 20- 40 cm (29%), and eventually reverses at the depth 60-80

cm (3%) and 80-100 cm (0%) (Figure 9). *Piliostigma* fine roots are mainly located in the horizons 0-20 cm and 20-40 cm. Statistical analysis shows a particularly significant different ($P < 0.001$) proportion of roots at the horizon 0-20 cm and 20-40 cm (Table 2). *Piliostigma*'s fine roots distribution according to the phytogeographical areas shows a higher proportion of roots in the northern Sudan zone than in the sub-Saharan zone. The southern Sudan zone has the lowest proportion of roots (Figure 10).

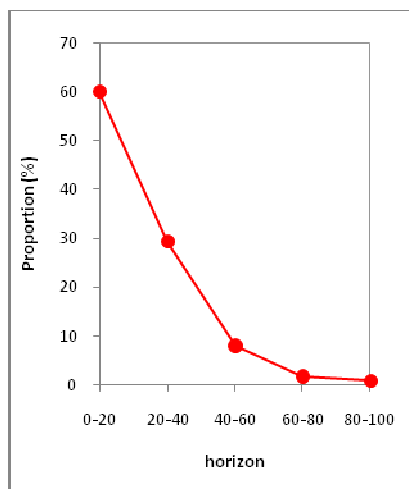


Figure 9: Fine roots evolution by soil horizon

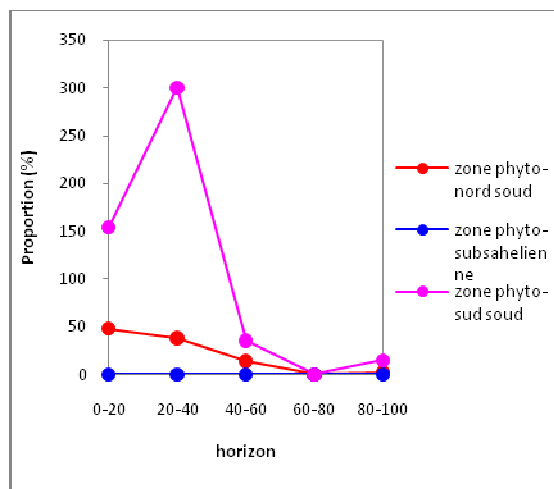


Figure 10: Fine roots and phytogeographic zones

Table 2: Data analysis (ANOVA) of fine roots proportion according to zones and soil level

Source	ddl	Sum of squares	Mean square	Fisher's F	Pr > F
Phyto zone	2	41741.416	20870.708	1.126	0.328
Level	4	578029.828	144507.457	7.795	< 0.0001
Phyto zone *Level	8	267247.966	33405.996	1.802	0.085

The evolution of soil depth and the proportion of roots present a statistical difference ($P < 0.0001$). Regarding *Piliostigma thonningii*, there are three statistically distinct groups according to the levels of soil depth, (Table 3). The horizon 0-20 cm differs from horizons 20-40 and 40-60 cm and the latter differs from horizons 60-80 cm and 80-100 cm. The same trend is observed about the distribution of *P. reticulatum* with the absence of roots in the horizon 80-100 cm. Fine roots are mainly concentrated in the horizon 0-20 cm.

Table 3: Roots distribution according to soil depth levels

Layer	<i>Piliostigma Thonningii</i> (%)	<i>Piliostigma reticulatum</i> (%)
0-20	60.22 ± 29.38 a	59.70 ± 24.73 a
20-40	26.40 ± 21.05 bc	31.80 ± 21.92 b
40-60	9.27 ± 15.27 cd	6.96 ± 12.80 cd
60-80	2.10 ± 6.96 d	1.54 ± 5.55 d
80-100	2.02 ± 6.70 d	0e

For each species (column), layers that have the same letter are not significantly different according to the Newman-Keuls test at the 5% level

With *P. reticulatum* and *P. thonningii*, fine roots are mainly located at the upper horizon. Indeed, fine roots play the role of absorbing water and in the case of tropical ferruginous soils, stream and infiltration water are encountered in the upper horizon. Thus for *Piliostigma*, fine roots play their role to the maximum.

The way fine roots fix themselves in the horizon makes species of the *Piliostigma* kind competitive ones under conditions of climate and soil aridity. Beyond 20 cm of soil depth, fine roots of *Piliostigma* become rare. This could be explained by the type of soils these species usually develop on.

Root biomass

Piliostigma develop an important biomass in the soil (Table 4). Upper soil horizons contain an important biomass of fine roots, which isn't dependent on the species of *Piliostigma*.

Table 4: Biomass distribution based on the depth of soil and *Piliostigma* species

Layer	<i>Piliostigma thonningii</i> (g/m ²)	<i>Piliostigma reticulatum</i> (g/m ²)
0-20	168.62 ± 188.15 abc	200.68 ± 208.16 ab
20-40	235.32 ± 298.49 a	139.54 ± 167.63 abc
40-60	27.79 ± 55.65 bc	23.52 ± 53.18 bc
60-80	1.85 ± 6.14 c	3.13 ± 11.30 c
80-100	14.82 ± 49.16 bc	0e

For each species (column), layers that have the same letter are not significantly different according to the Newman-Keuls test at the 5% level.

The analysis of variance shows a highly significant difference in the distribution of biomass according to depth ($P < 0.0001$) (Table 5).

Table 5: Analysis of variance of biomass depending on the species and the soil depth

Source	Ddl	Sum of squares	Mean square	Fisher's F	Pr > F
Species	1	7920.916	7920.916	0.397	0.530
Level	4	870241.443	217560.361	10.912	< 0.0001
Species*Level	4	54297.874	13574.468	0.681	0.607

Piliostigma root biomass is mainly distributed in the first two horizons considered (0-20 and 20-40 cm). The upper horizon with *P. reticulatum*, has a significantly different root biomass from that encountered at deeper horizons. With *P. thonningii*, the depth level 20-40 cm contains an important quantity of root biomass.

The 2 graphs of biomass evolution, all phytogeographical zones considered, sensibly depict the same “L” shape, with important variations from one site to another. At the horizon 0-20 cm the two species present a high and roughly equivalent root biomass. This biomass decreases rapidly when we move deeper (20-40 cm). From 40 cm and above, the weight of the root biomass is relatively low and fixed. The distribution of root biomass according to soil depth and phytogeographic zones doesn't reveal statistical differences between zones (Figure 11).

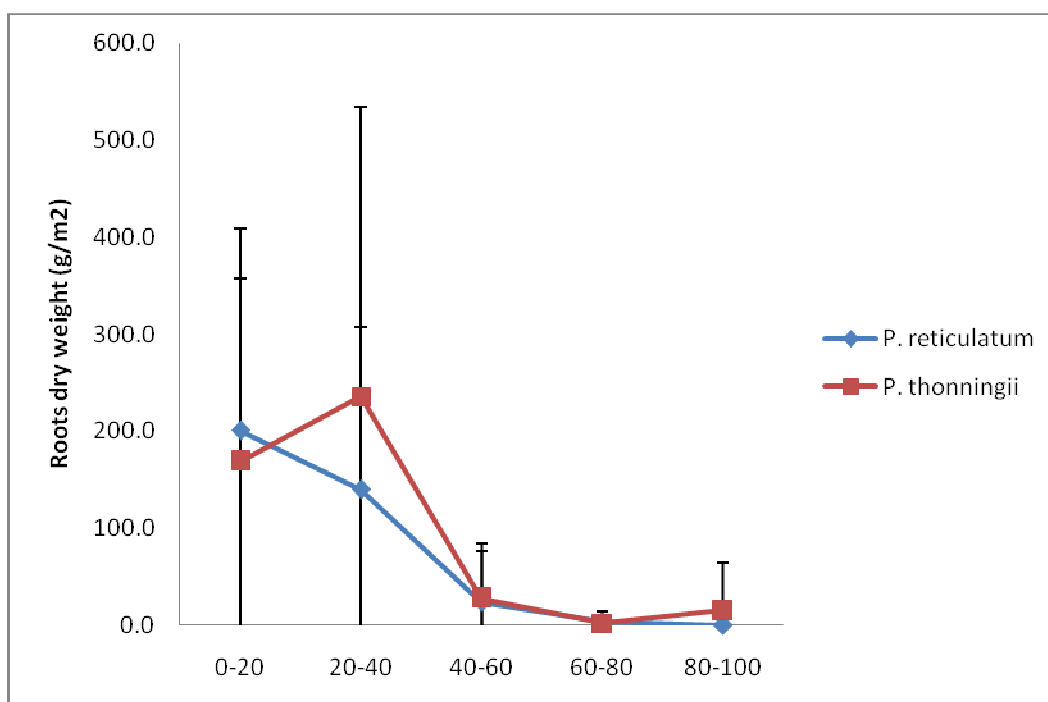


Figure 11: Root biomass evolution according to the levels of soil depth

It is in the surface horizon that root biomass is remarkable. This partly explains the high content in carbon found by some researchers [11, 25, 26], in the soil under the canopy of *P. reticulatum*, and in horizons 0-20 cm. Root development depends more on soil than on phytogeographic zone, which is reflected in the roughly equivalent curves.

Volume of soil explored by the roots according to phytogeographical zones

The volume of soil explored by *Piliostigma*'s root system is more important in the North Soudanian zone (28 to 42 m³) (Table 6). In this zone, we observe important standard deviations between the volumes of soils explored by the roots. In the sub sahelian and in the south soudanian zones, the volumes of soil explored by the two species root systems are roughly equivalent and far less important than that of the North Soudanian zone (2.22 to 2.70 m³).

Table 6: Volume of soil explored by *Piliostigma* root system according to phytogeographical zones

Phytogeographic zone	Species	Collet depth (cm)	Volume of soil explored (m ³)
Sub sahelian	<i>P. reticulatum</i>	5.67 ± 0.58 a	2.30 ± 2.09 a
North soudanian	<i>P. reticulatum</i>	8.29 ± 3.64 b	28.17 ± 22.65 b
	<i>P. thonningii</i>	8.00 ± 2.91 b	42.11 ± 35.27 c
South soudanian	<i>P. reticulatum</i>	8.60 ± 1.14 b	2.70 ± 1.34 a
	<i>P. thonningii</i>	9.6 ± 0.54 b	2.22 ± 2.31 a

For each species, variables that have the same letter are not significantly different according to the Newman-Keuls test at the 5% level.

The depth of the collar varies from 5 to 9 cm. And it is in the sub sahelian zone that *P. reticulatum* presents a collar slightly buried in the soil. The north soudanian and south soudanian zones don't present a statistical difference for the collar depth parameter.

In the north Soudanian zone, the root system of *P. reticulatum* and *P. thonningii* present the most important volume. For *Piliostigma*, the North Soudanian zone is the most suitable. For *P. reticulatum* this phytogeographic zone is the most naturally suited. In the North Soudanian zone, *Piliostigma* has longer lateral roots and a very deep pivot. The deep soils where are located formations of *Piliostigma* explains this situation. However, in the sub sahelian and south Soudanian zones *Piliostigma* formations are generally located on shallow and/or ungrateful soils. *Piliostigma* formations serve as grazing areas or as sources of firewood collection. The volume of soil explored by the *Piliostigma* root system is especially related to the nature of the soil on which *Piliostigma* formations develop. Despite the low volume of soil explored, *Piliostigma*, through his root system architecture, adapts well to its environment.

CONCLUSION

Piliostigma species adapt to their environment through a root system which development reflects the physical condition of the soil. *Piliostigma* are firmly fixed into the ground thanks to strong lateral roots which are generally located in the second horizon and also thanks to a good adaptability of the morphology of the pivot. The low volume of soil explored by the root system is compensated by a great extension of fine roots at the upper horizon thus ensuring that the plant receives the necessary nutrients. *Piliostigma* species also adapt to high anthropic pressure (bush fire, cuttings, overgrazing) by burying the collar into the soil. Considering the biological characteristics of *Piliostigma*, and with increasing aridity of the environment and anthropic pressure, species of the *Piliostigma* type could be used in afforestation programs provided they are well-known by people.

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