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TITLE :

EFFECTS OF INDIGENOUS SOIL AND WATER CONSERVATION PRACTICES ON SOIL HEALTH AND THE PERFORMANCE OF GROUNDNUT (*ARACHIS HYPOGAEA* L.) AND SORGHUM (*SORGHUM BICOLOR* L.) YIELD AS INFLUENCED BY CLIMATE CHANGE IN THE SUDAN-SAHELIAN ZONE OF BURKINA FASO

A thesis, in the Rural Polytechnic Institute of Training and Applied Research (IPR/IFRA) in partnership with the West African Science Service Centre on Climate Change and Adapted Land Use (WASCAL), submitted in partial fulfilment of the requirements for the Doctor of Philosophy in Climate Change and Agriculture of the University of Sciences, Techniques and Technologies of Bamako (USTTB)

Presented and defended on: 06/05/2023

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EFFECTS OF INDIGENOUS SOIL AND WATER CONSERVATION PRACTICES ON SOIL HEALTH AND THE PERFORMANCE OF GROUNDNUT (*ARACHIS HYPOGAEA* L.) AND SORGHUM (*SORGHUM BICOLOR* L.) YIELD AS INFLUENCED BY CLIMATE CHANGE IN THE SUDAN-SAHELIAN ZONE OF BURKINA FASO

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Dedication

To my father, Mr. Larba and mother, Ms. Aïssata for their blessings and support.

To my wife Maïmouna MOURFOU, and to my children Pengdwendé Abdoul Madjid, Nongobzanga Nouriatou, and Nongrepasgo Mohamed Lamine, for all the sacrifices they have made during this study.

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May his soul rest in peace

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List of acronyms and abbreviations

AFNOR	:	French national organisation for standardization
BUNASOLS	:	National Office of the Soils
CILSS	:	Permanent Inter-State Drought Control Committee for the Sahel
CPCS	:	Commission for Soil Science and Mapping
DAS	:	Day after Sowing
DGESS	:	General Direction of Studies and Sectorial Statistics
DGM	:	General Direction of Meteorology
FAO	:	Food and Agriculture Organization
FAOSTAT	:	Food and Agriculture Organization Corporate Statistical Database
FCOVER	:	fraction of cover
ICRISAT	:	International Crops Research Institute for the Semi-Arid Tropics
IPCC	:	Intergovernmental Panel on Climate Change
IRD	:	Research Institute for Sustainable Development
ITPS	:	Intergovernmental Technical Panel on Soils
M.A	:	Ministry of Agriculture
MAAH	:	Ministry of Agriculture and Water Management
MAAHA	:	Ministry of Agriculture and Hydro-Agricultural Development
MAAHMA	:	Ministry of Agriculture, Hydraulic Development and Machinery.
MAH	:	Ministry of Agriculture and Hydraulics
MECV	:	Ministry of the environment and living conditions
MEEVCC	:	Ministry of the Environment, Green Economy and Climate Change

NGOs	:	non-governmental organizations
RGPH	:	General Survey on Human Habitat and Population
SAT	:	semi-arid tropics
SE-BF/FVC	:	Executive Secretariat of Green Climate Fund
SGC	:	Surface gravel charge
SME	:	Soils Materiaux et Environnement
SP / CNDD	:	Permanent Secretariat of the National Council for Sustainable Development
SPSS	:	Statistical Package for Social Sciences
SWCP	:	Soils and water conservation practices
Tmin.	:	Average minimum temperature
Tmax.	:	Average maximum temperature
UNFCCC	:	United Nations Climate Change Conference
USDA	:	United State Department of Agriculture
WMO	:	World Meteorological Organization's
WOCAT	:	World Overview on Conservation Approaches and Technology

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Résumé

La précarité des pluies et la faible fertilité des sols sont des contraintes pour la production agricole au Burkina Faso. Les techniques de conservation des eaux et des sols se positionnent comme des alternatives climato-intelligentes pour contrer ces obstacles. Cette étude vise à déterminer l'influence des pratiques de zaï, cordons pierreux, labour en billons et l'association zaï avec cordons pierreux sur la santé du sol et la productivité de l'arachide et du sorgho en zone soudano-sahélienne du Burkina Faso. Pour ce faire, une enquête a été menée dans quatre villages sur 135 chefs de ménages. Les données socio-économiques, agro-pédologiques, environnentaux et gestion des sols ont été collectées à l'aide de questionnaires. Deux dispositifs expérimentaux, constitués de cinq blocs de Fisher randomisés comprenant quatre traitements en cinq répétitions, ont été installés. Les données collectées sur le terrain sont l'humidité de surface, le nombre de la macrofaune, les paramètres de croissance et des composantes des rendements des cultures. 208 échantillons de sols ont été prélevés pour des analyses aux laboratoires. Les résultats obtenus montrent que l' âge, le niveau d'éducation, l'appartenance à une organisation locale, la possession de têtes bovines et le petit commerce sont les déterminants clés de l'adoption des techniques de zaï et des cordons pierreux. Le zaï a amélioré l'humidité du sol sous arachide (+21.95%) et sous sorgho (+23.55%), les teneur en carbone organique, azote total, phosphore assimilable des sols et les valeurs de pH. Ces améliorations ont rendu les conditions favorables au développement des cultures qui s'est traduit par une augmentation des rendements des cultures sous les traitements zaï, cordons pierreux et zaï associés aux cordons pierreux. Les cordons pierreux ont amélioré la respiration des sols. Le nombre d'espèces de termites sur sols sous arachide a été multiplié par 4 fois sur sols sous sorgho. Tandis que le nombre de fourmis a été multiplié de 3 fois environs. Aucun vers de terre n'a été enregistré en sol sous arachide. Pour une production durable de l'arachide et du sorgho en zone soudano-sahélienne du Burkina Faso, les pratiques de zaï et leurs association avec les cordons pierreux demeurent des alternatives. Cependant pour rendre leurs effets rapides et plus éfficaces il serait important de changer annuellement les positions des poquets de zaï. Egalement, une investigation s'avère nécessaire pour comprendre l'absence de vers de terre dans sol sous production d'arachide.

Mots clés: *Agroécologie, cordons pierreux, dégagement de CO_2, humidité du sol, labour en billons, macrofaune, performance des cultures, santé du sol, zaï.*

Abstract

The poor rainfall and low soil fertility are constraints to agricultural production in Burkina Faso. Soil and water conservation practices positioned as climate-smart alternatives to overcome these obstacles. This study aimed to determine the influence of *zaï*, stone rows, ridge tillage, and the combination of *zaï* with stone rows on soil health and productivity of groundnut and sorghum in the Sudan-Sahelian zone of Burkina Faso. To do this, a survey was carried out in four villages on 135 heads of households randomly selected. Socio-economic, agro-pedological, environmental and soil management data were collected by using questionnaires. Two experimental designs, consisting of five randomised Fisher blocks with four treatments in five replications, were set up. The data collected in the field are related to soil moisture content, macrofauna number, growth parameters, and crop yield components. 208 soil samples were collected for laboratory analysis. The results revealed that age, level of education, membership in a local organisation, ownership of cattle, and the practice of small trade are the key determinants of the adoption of *zaï* and stone rows practices. *Zaï* improved soil moisture under groundnut (+21.95%) and sorghum (+23.55%), soil organic carbon, total nitrogen, available phosphorus content and pH values. These improvements created a more suitable environment for crop development, which resulted in a significant increase in yields of crops treated with *zaï*, stone rows and *zaï* combined with stone rows. The stone rows improved soil respiration. The number and species of termites on soils under groundnut increased by 4 times on soils under sorghum. While the number of ants increased by approximately 3 times. No earthworms were recorded in soil under groundnut cultivation. To boost sustainable groundnut and sorghum production in the Sudan-Sahelian zone of Burkina Faso, the *zaï* technique and its association with stone rows are and remain agro-ecological alternatives. However, to make their effects faster and more efficient, it would be important to change the positions of the *zaï* pits annually. In addition, an investigation should be carried out to elucidate the non-existence of earthworms in the soil under groundnut cultivation.

Keywords: *Agroecology, crops performance, macrofauna, release of CO_2, ridge tillage, soil health, soil moisture, stone rows, zaï.*

CHAPTER ONE: INTRODUCTION

1.1. Justification of the study

Soil degradation is an environmental concern whose consequences are felt most strongly by poor people in developing countries. The world is losing 12 million hectares of cropland with corollary consequences (UN, 2023). This cropland loss is coupled with population growth over the last two decades (Klein et al., 2017). According to Bationo et al., (1998), areas of soil degradation are extensive in Sub-Saharan Africa in the regions bordering the Sahara and Kalahari deserts. Also, West African soils are much weathered and fragile and mostly of low to moderate inherent fertility. Low nutrient holding capacities, high acidity, low organic matter, poor soil structure and low water-holding capacity are other constraints to soil productivity. These constraints are in some cases exacerbated by over exploitation through continuous cropping and low nutrient application rates (Mafongoya et al., 2007).

Burkina Faso's agriculture is characterized by low productivity. Yields of cereal and oilseed crops are and remain below their potential. For instance, Sorghum yield is 1008 kg ha^{-1} and Groundnut yield is 917 kg ha^{-1} (FAOSTAT, 2020; MAAHMA, 2021). This situation is attributable to various factors including pedoclimatic conditions (low soil fertility, variable rainfall and distribution, extreme temperatures), anthropogenic actions (deforestation, farm expansion, urbanization) and socio-economic (land tenure insecurity, low purchasing capacity, low level of input use, low level of technical equipment, low use of e-agriculture) (Zougmoré et al., 2005a; Ouédraogo et al., 2008; Sawadogo et al., 2008; CILSS and CIS, 2009). These factors lead to sustaining soil degradation. Indeed, analysis of soil degradation maps of Burkina Faso, according to indicators such as land use, land productivity and soil carbon stock reveals degradation of 469,950 ha of land from 2002 to 2013 (SP/CNDD, 2016; MEEVCC, 2017a).

To counteract further soil degradation, some local practices have developed and made it possible to exploit these low productivity soils (Bagre et al., 1987; Roose et al., 1993). These techniques aim to contribute to the sustainable intensification of production and preservation of soil fertility through the restoration of soil quality. The major techniques are *zaï*, stone rows, half-moon, grass strips, different types of ploughing, agroforestry etc.. This study focused on *zaï*, stone rows and ridge tillage techniques. *Zaï*, ridge tillage and stone rows are some soil and water conservation techniques disseminated by the government in order to contribute to the sustainable management of the region's natural resources.

In Burkina Faso, cereals occupy 71.62% of the land area, with cash crops occupying 28.38% of the rest. Sorghum and millet occupy 73.43% of the area used by cereals. In 2021, with 1,617,000 tons, Burkina Faso is ranked to second place after Nigeria in terms of production of sorghum grain in West Africa (FAOSTAT, 2023). Groundnut occupies a major place in the oilseed sector with production doubling over the decade. Thus, it increased from 265, 322 tons in 2011 to 630 526 tons in 2020 (MAAHMA, 2021). While the area under groundnut has increased from 388,704 hectares in 2011 to 670,798 hectares in 2020. Yield has varied from 671 $kg.ha^{-1}$ to 917 $kg.ha^{-1}$ from 2011 to 2020, but remains below its potential. Several studies have shown the impacts of the *zaï*, stone rows and ridge tillage techniques on soil chemical and physical properties, and on crop yields (Ndiaye, 2009; Amede et al., 2011; Zougmoré et al., 2014a; Kouelo et al., 2017; Partey et al., 2018; Dembélé et al., 2019; Oduor et al., 2021). Though, the effects of them on soil biological properties are not most investigated. Such, the impacts of their combination on soil biological, chemical, and physical properties remain few studied. Furthermore, research on the impact of *zaï* on groundnut yield parameters is almost nonexistent. Thenceforth, the depth investigation will be needful

1.2. State of the knowledge

1.2.1. Climate change

There are several definitions of climate change. This is because scientists face a many difficulties in establishing a definition of climate change that is capable of achieving global consensus. Two of them are worth noting. That of the Intergovernmental Panel on Climate Change (IPCC, 2022), which states that this phenomenon is understood as "a change in the state of the climate that can be detected (e.g., by statistical tests) by changes in the mean and/or variability of its properties and that persists for an extended period, typically decades or more. It refers to any change in climate over time, whether due to natural variability or human activity. This definition differs from that of the United Nations Framework Convention on Climate Change (UNFCCC, 1992), which defines climate change as "variations that are attributed directly or indirectly to human activity that alters the composition of the global atmosphere and that are in addition to natural climate variability observed over comparable time periods". This allows us to say that climate change is a long-term (at least 30 years), spatial, and temporal dynamic of climate factors. These dynamics can be natural or the result of human actions, the behaviour of certain households, or wild animals. There are many indicators of climate change. These include physical responses such as changes in global and regional surface temperatures, greenhouse gas concentrations, extreme events, atmospheric water vapour, precipitation, severe events, glaciers, ocean and land ice, and sea level (Cubasch et al., 2013). Africa warmed at an average rate of about +0.3°C per decade between 1991 and 2021, faster than the 1961–1990 rate of +0.2°C per decade. The year 2021 was the third or fourth warmest year on record in Africa. Droughts and floods are among the main concerns. Over the past 50 years, drought-related hazards have claimed the lives of more than half a million people and caused economic losses of more than $70 billion in Africa. More than 1,000 flood-related disasters have reported, resulting in more than 20,000 deaths. In West Africa, the long-term decline in river flows is attributed to rising temperatures, drought, and increased water supply demand (WMO, 2023).

1.2.2. Impacts of climate change on agriculture

In West Africa, agriculture, mainly rainfed, is a major economic sector and the one most vulnerable to climate change. Climate change impacts are negatively affecting agriculture, forestry, fisheries and aquaculture, increasingly hindering efforts to meet human needs. The impact of projected climate change on agriculture is greater in northern West Africa (Sudano-Sahelian countries, 18% median response) than in southern West Africa (Guinean countries, 13%), which is probably due to drier and warmer projections in the northern part of West Africa. In addition, negative impacts on crop productivity increase in the same direction as intensified warming (Roudier et al., 2011). Yields declined by a median of 6% (−8% to +2% depending on the crop) due to climate change in all scenarios. Climate change has already affected West African agriculture through changes in rainfall patterns, characterised by strong inter-annual rainfall fluctuations, increased frequency of rainfall extremes and prolonged droughts (Salack et al., 2016; Sultan et al., 2019). Agriculture in West Africa is predominantly rainfed and thus highly vulnerable to climate change and variability, making crop production uncertain (Sultan and Gaetani, 2016; Zougmoré et al., 2016). In general, changes in crop yields due to climate change are negative for maize, sorghum, millet, rice, yam, and cassava. These negative impacts of climate change on these crops in West Africa are partly explained by the negative role of higher temperatures, which shorten crop cycle length and increase evapotranspiration (Sultan and Gaetani, 2016). In addition, previous studies have confirmed that climate change is negatively influencing crops (Jalloh et al., 2013) and found a median yield loss of -11% for the main staple crops (Roudier et al., 2011) . In a broader regional analysis, Knox et al., (2012) found average yield changes of -17% (wheat), -5% (maize), -15% (sorghum) and -10% (millet) in Africa.

1.2.3. Practices to cope with climate change adverses

Crop production in West Africa is mainly rainfed and remains vulnerable to climate change manifested in unpredictable rainfall patterns and high temperatures. Sustaining the yields of the crops has been challenged (among other factors) by declining soil fertility (Sultan et al., 2017) and expected climate change impacts (Roudier et al., 2011). Indeed, projections on the future climate of West Africa reveal negative impacts that may lead to productivity crises if sustainable solutions are not developped. We should act now by using some climate-smart agriculture practices belong to the place. This idea was support by IPCC, (2022), which highlight that nature remains a solution to the climate problem. It reveals that reducing the destruction of ecosystems, restoring them and improving the management of cultivated land, such as farms, are the most effective options for mitigating carbon emissions. To keep up with this dynamic, agricultural practices for adaptation and mitigation of the adverse effects of climate change are being developed and disseminated in Burkina Faso. These include the incorporation of organic matter, and soil and water conservation techniques. *Zaï*, stone rows, ridge tillage, and their combination with organic manure have emerged as alternatives for climate change adaptation and mitigation. Research has confirmed their positive effects on low soil fertility and drought sequences, leading to increased or optimised crop yields. The purpose of the *zaï* is to foster retention of soil moisture and increase nutrients availability; the stone rows aims to improve water infiltration and to reduce the runoff potential, then protecting the topsoil against erosion action (Maatman et al., 1998; Reij et al., 2005). Many studies have shown that these techniques significantly improve soil structure, crop yields, groundwater recharge, and rainfall infiltration (Zougmoré et al., 2005b; Kabore-Sawadogo et al., 2012). Indeed, results of Lamachere and Serpantie, (1991) indicate that stone rows are able to increase water infiltration into the soil by 15%. The results of Zougmoré et al., (2004a) confirmed a reduction in runoff from 45% to 53% following the installation of stone rows. The stone rows have an impact on millet, sorghum, and maize yields, with a net increase of about 30%. It is true that stone rows have many positive effects, but there are some limitations to their implementation and maintenance by farmers. However, the major challenge remains the lack of labour, small equipment, and purchasing power of farmers (Pretty and Shah, 1997). In addition, some studies have shown that *zaï* combined with organic manure can double or triple sorghum yields and improve chemical properties of the soil, such as pH and organic matter content (Gnoumou et al., 2017; Dabré et al., 2017; Ouédraogo et al., 2021), in Burkina Faso.

1.3. Research hypothesis

The following hypotheses have been formulated:

- Several indigenous SWCPs are used as coping strategies to climate change for improving soil quality and crops yields.
- *Zaï*, stone rows, *zaï* combined with stone rows, and ridge tillage, significantly improve the soil properties under groundnut and sorghum cultivation.
- *Zaï*, stone rows, *zaï* combined with stone rows, and ridge tillage, significantly improve groundnut, and sorghum agronomics parameters.

1.4. Objectives

1.4.1. Overall objective

The main objective of this thesis is to determine the influence of the *zaï*, stone rows, ridge tillage and their association on soil health, groundnut and sorghum yields performance in Sudan-Sahelian zone of Burkina Faso.

1.4.2. Specific objectives

Specifically, the objectives of this study are to:

- analyse perceptions of farmers on the determinants of the used indigenous SWCPs;
- determine the influence of the *zaï*, stone rows, ridge tillage and the association *zaï* with stone rows on soil health.
- determine the effects of *zaï*, stone rows, ridge tillage, and association *zaï* with stone rows on the performance of groundnut and sorghum yields as influenced by climate change.

CHAPTER TWO: LITTERATURE REVIEW

2.1. Sorghum *(Sorghum bicolor L.)*

2.1.1. Taxonomy, description and services

Sorghum [*Sorghum bicolor* (L.) Moench] is a self-pollinating, diploid (2n = 2x = 20) species belonging to the Poaceae family with a genome size of 730 Mb, about 25 % the size of maize. Basically, there are five and ten hybrid races of cultivated sorghum (Table 1), each with specific characteristics (FiBL, 2012; Kumar, 2016). Sorghum is an annual plant, monoecious, tall, with one to many tillers originating from the base or stem nodes. Botanical parts of a sorghum plant are adventitious root, node, leaf sheath, leaf blade, stem or stalk, peduncle and panicle. Roots are concentrated in the top of the soil but sometimes extending to twice that depth, spreading laterally. The growth and development of sorghum are divided into the vegetative, reproductive, and maturity stages (Figure 1).

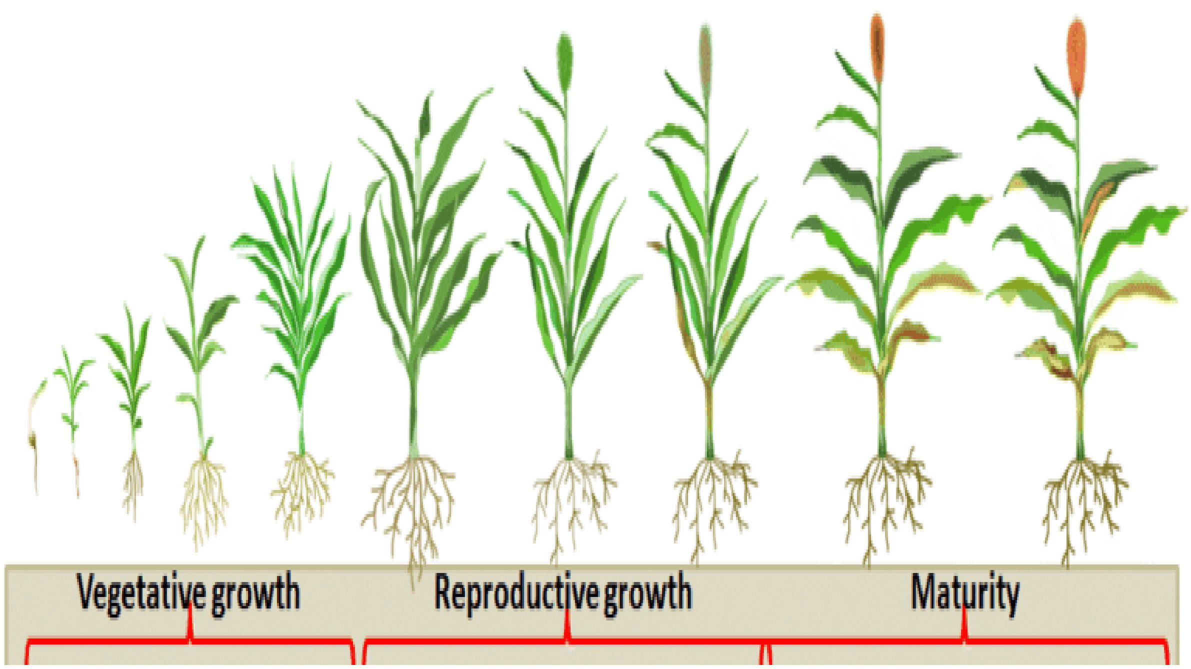


Figure 1. Growth stages of a Sorghum plant

Sorghum (*Sorghum bicolor* (L.) Moench) is an important food crop in Africa and is the fifth most important cereal crop grown in the world (Hakeem et *al.*, 2020), after wheat, rice, maize, and barley (Bhattacharya et al., 2011). In 2019, the top 10 sorghum producers globally are the United States, Nigeria, Ethiopia, Mexico, Sudan, China, India, Brazil, Niger and Burkina Faso

(FAOSTAT, 2023). Sorghum is one of the most important cereal crops grown in the semi-arid tropics of Asia, Africa, and the Americas for its food, feed, fodder, fuel value and even for green manure production (Bhattacharya et al., 2011; Kumar, 2016). Sorghum (*Sorghum bicolor* (L.) Moench) is an indigenous crop to Africa, and though commercial needs and uses may change over time, sorghum will remain a basic staple food for many rural communities. Sorghum is mainly used as flour or paste processed into porridge, and pate. Sorghum is also processed into malt for malted drinks and foods, high quality flours, and as a raw material for the poultry and fish feed industries. Otherwise, Sorghum is processed into cake, biscuits, sweets and other confectionaries (Ajeigbe et al., 2020).

Table 1. Classification of *Sorghum bicolor* (L.) Moench, subspp. *bicolor*

Basic races	Intermediate/hybrid races
1. Race *bicolor (B)*	6. Race *guinea-bicolor* (GB)
2. Race *guinea (G)*	7. Race *caudatum-bicolor* (CB)
3. Race *caudatum (C)*	8. Race *kafir-bicolor* (KB)
4. Race *kafir (K)*	9. Race *durra-bicolor* (DB)
5. Race *durra*(D)	10. Race *guinea-caudatum* (GC)
	11. Race *guinea-kafir* (GK)
	12. Race *guinea-durra* (GD)
	13. Race *kafir-caudatum* (KC)
	14. Race *durra-caudatum* (DC)
	15. Race kafir-durra (KD)

Source : Kumar et al., 2016

2.1.2. Sorghum ecology

Sorghum is a C_4 plant with higher photosynthetic efficiency and higher abiotic stress tolerance (Nagy et al., 1995; Reddy et al., 2009) adapted to a range of environments around the world. Sorghum (*Sorghum bicolor* (L.) Moench) is among the climate-resilient crops that can better adapt to climate changes (Reddy et al., 2011). It is characterized by high climate parameters (temperatures, radiation, evaporative demand), unreliable and irregular rainfall, and soils of low water-holding capacity (Reddy et al., 2009), and tolerant to drought and heat stress (Poehlman and Sleper, 1995). Water scarcity has a huge impact on food production. Without water people do not have a means of watering their crops and, therefore, to provide food for the fast growing population. According to the International Water Management Institute, agriculture, which accounts for about 70% of global water withdrawals, is constantly competing with domestic, industrial and environmental uses for a scarce water supply (IWMI, 2023). Then, it is a potential crop to support the poor and disaster of the world, because, sorghum is mainly grown on low potential, shallow soils with high clay content. Soils with a clay percentage of between 10% and 30% are optimal for sorghum production. The temperature plays an important role in growth and development after germination. Then, the optimum range of air temperature for sorghum is 26–34°C during the vegetative period and 25–28°C during the reproductive period (Hammer et al., 1993; Prasad et al., 2006, 2008). Sorghum is a short-day plant requiring long night hours before the reproductive stage. It grows well in a wide range of soils. It grows best on fertile, well-drained soil with a moderate amount of organic matter and a pH between 6 and 7.5. Under these conditions, the roots take up nutrients well (Lubadde et al., 2019). The optimum photoperiod, which will induce flower formation, is between 10 and 11 hours. Photoperiods longer than 11 to 12 hours stimulate vegetative growth. The tropical varieties are usually more sensitive to photoperiod than the quick, short-season varieties. Sorghum plants are most sensitive to photoperiod during flower initiation (Chantereau et al., 2013).

2.2. Groundnut (*Arachis hypogaea* L.)

2.2.1. Taxonomy, description and services

The groundnut (*Arachis hypogaea* L.) is a leguminous, cultivated in all the tropical zones through the world. It is an herbaceous annual with plants of about a 45–60 cm tall and 30 cm wide with a deep taproot. The roots typically contain the nitrogen fixing bacterial nodules of rhizobium, which coexist in a symbiotic relationship by providing the necessary nitrogen for plant growth while deriving sustenance from it. The plants are self-fertilizing and have a unique mode of reproduction where flowers are produced on the plant and following fertilization, the gynoecium enters the soil through formation of a peg. Then, pods containing the seeds are produced underground. The root system contains nodules of nitrogen-fixing bacteria that convert inert atmospheric nitrogen into ammonia. The groundnut is tetraploid species and has a chromosomal filling of 2n=40. That plant is autogamous and allogamy rate is 0.2% for *Virginia* type opposed to 6.6% for *Spanish* and *Valencia* types. It is a one of oleaginous that is widely products in west Africa. The most popular type is: *Virginia bunch* and *runne*; *Valencia Peruvian*, *Spanish* and *Peruvian hirsuta*, *Eaquatorian* (Alleidi et al., 2016). The kernel is used extensively in the oil industry because of its high oil content (Alleidi et al., 2016). The growth stages of groundnut plants based on visual observations of vegetative and reproductive growth have been described and defined by Boote (1982). This widely adopted system describes a series of vegetative (V) and reproductive stages (R), and all stages are discrete population-based events which are mostly determined by field observations. Different reproductive stages of groundnut are shown in Table 2. The total growth period of the pod from fertilization to maturity is around 60 days depending on cultivar and soil temperature (Robson, 2007). Groundnut seed can be consumed raw (non-heated), boiled, and roasted and used to make confections and its flour to make baked products. The groundnut shells are used for making particle boards or used as fuel or filler in fertilizer and feed industry. Groundnut haulms constitute nutritious fodder for livestock (Janila et al., 2013).

Table 2. Reproductive and vegetative growth of stages of groundnut

Stage	Stage title	Description
VE	Emergence	Cotyledons near the soil surface with the seedling showing some part of the plant visible
R1	Flowering	One ope flower at any node
R2	Pegging	One elongated peg (gynophores)
R3	Podding	One peg in soil with swollen ovary at least twice the weight of the peg
R4	Full pod stage	One pod fully expanded to dimensions characteristic for the cultivar
R5	Beginning seed	One fully expanded pod with which seed cotyledon growth is viable when the fruit is cur in cross-section
R6	Full seed	One pod with cavity apparently filled by the seed when fresh
R7	Beginning maturity	One howing visible natural colouration or blotching of inner pericarp or testa
R8	Harvest maturity	66-75% of all developed pods have testa or pericarp colouration

Source: Var Prasad et al., 2009

2.2.2. Groundnut ecology

The major environmental factors that reduce groundnut pod yield and quality are temperature and soil moisture (Robson, 2007). The groundnut plant produces runners (horizontal stems) which in turn produce flowers at each node. Then, for good production, the soil must have a low clay content (less than 20%) with a loose structure so that the peg may penetrate the soil freely. Soils with a high clay percentage in the topsoil may cause the groundnut pegs to break at harvest. Soil compaction can also be a problem if the fine sand fraction of the topsoil is high. This situation can be aggravated in soils where the organic residues are low. Substantial evidence exists to show that groundnuts respond to additional fertilizer applications, even though in rural situations this is not imperative. Groundnuts are adapted to a soil with a pH (H_20) of 6.5 to 7 (Singh and Oswalt, 1995).

2.3. Sorghum and groundnut production in Burkina Faso

The cereals production varied by 3,666,000 tonnes to 5,179,104 tonnes respectively from 2011 to 2020. The production area varied by 3,684, 447 hectares in 2011 to 4 104 827 hectares in 2020. The sorghum seeding area varied by 1,681,881 hectares in 2011 to 1,734,614 hectares in 2020. In the region of plateau central, sorghum production area varied by 111,503 hectares in 2011 to 121,714 hectares in 2020. Nevertheless, sorghum production changed from 102,524 tonnes in 2011 to 125,724 tonnes in 2020. About yield, it varied by 785 $kg.ha^{-1}$ in 2011 to 1008 $kg.ha^{-1}$ in 2020 for white sorghum and by 1041 $kg.ha^{-1}$ to 1160 $kg.ha^{-1}$ for red sorghum (MAAHMA, 2021). That increase of yield is accounted for multiple development action from government, non-governmental organizations (NGOs), development project/program, farmers' local organizations, research institutes and farmers themselves.

The Groundnut production varied by 265,322 tons to 630,526 tonnes respectively from 2011 to 2020. The production area varied by 388,704 hectares in 2011 to 670 798 hectares in 2020. About yield, it varied by 671 $kg.ha^{-1}$ in 2011 to 917 $kg.ha^{-1}$ in 2020 (MAAHMA, 2021). That increase of yield is accounted for multiple development action from government, non-governmental organizations (NGOs), development project/program, farmers' local organizations, research institutes and farmers themselves.

2.4. Constraints of the Sorghum and Groundnut production in Burkina Faso

Sorghum and groundnut production faces natural, technical, socio-economic and financial difficulties: climate change effects, increasing soil degradation, low soil fertility, poor control of agricultural water, pests and diseases, insects and birds damage, low productivity of production systems (especially extensive) and low intensification of crop production, high cost of inputs and equipment, persistent insecurity of land tenure, poor performance of extension services to farmers, low level of farmer local organization and training, poor use of weather information, not enough financial resources (Kindo et Aparisi, 2015; MAAHA, 2015; Traore and Koura, 2019; Lorenz et al., 2019; Ki et al., 2021; Sinare et al., 2021), and the threats to the aggregate sector and urbanization. Sorghum and groundnut do not bend rules.

2.4.1. Climate change issues in Burkina Faso

Climate change in IPCC usage refers to a change in the state of the climate that can be identified (e.g. using statistical tests) by changes in the mean and/or the variability of its properties, and that persists for an extended period, typically decades or longer. It refers to any change in climate over time, whether due to natural variability or as a result of human activity. Climate change may be due to natural internal processes or external forcings such as modulations of the solar cycles, volcanic eruptions and persistent anthropogenic changes in the composition of the atmosphere or in land use (IPCC, 2014).

The effects of climate change are perceived by producers through the following indicators: increased temperatures, irregularity of rainfall, decrease in the number of rainy days with a very irregular distribution in time and space, fluctuations in the period of establishment of the rainy season and greater frequency of the drought, shifting of sowing dates, phenological disruption of plants, reduction of arable land (Gnoumou et al., 2017; Bougma et al., 2018). The rainfall in Burkina Faso has been decreasing over the last 60 years (Figure 2) with mean temperature isotherms migrating from the north to the south of the country. To address these adverse effects of climate change, Burkina Faso developed its national adaptation plan (NAP) in 2015 and implemented it from 2015 to 2020. The implementation of this NAP is in accordance with the recommendations of the international community regarding adaptation to climate change by 2050. Also, a National Council for the Environment and Sustainable Development (CNDD) and an Executive Secretariat of the Green Climate Fund (SE-BF/FVC) have been created (MEEVCC, 2021). On the legal front, we note the law on the (i) environment code of 2013; (ii) orientation and sustainable development of 2014; (iii) prevention and management of risks, humanitarian crises and disasters of 2014; iv) water management of 2001; v) agrarian and land reorganisation of 2012; vi) Agro-sylvo-pastoral, halieutic and wildlife orientation in Burkina Faso of 2015; and vii) rural land tenure of 2009. Each of these laws contains direct or indirect provisions related to adaptation to the adverse effects of climate change.

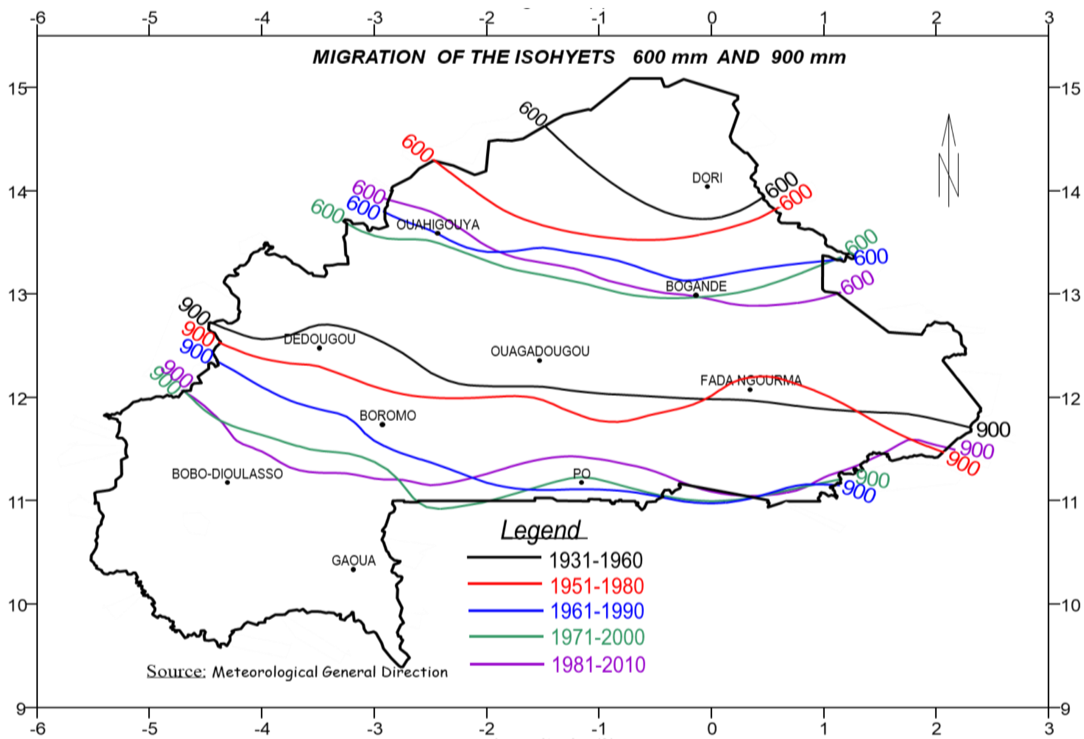


Figure 2. Spatial evolution of decadal rainfall from 1931 to 2010.

Regarding temperature, De Longueville et al., (2016) had characterized the overall temperature of the country over the period 1981-2010 and results indicated that the frequencies of warm temperatures, above a certain threshold, increase throughout the country. By contrast, the indices for the coolest conditions show a decrease in frequency, especially during the nights. But, in a specific way, Bambara et al., (2018) revealed a change in mean annual temperatures for the periods 1956-1985 and 1986-2015 in the central (+2.1%) and northern (+2.9%) regions. Indeed, in the central region, the values varied from 28.2°C to 28.8°C for the average annual temperatures. In the northern region, these values varied from 28.6°C to 29.4°C for annual average temperatures. The decrease in rainfall is justified by the increase in the area covered by the average annual rainfall of 301-500 mm and the reduction in that of 1101-1300 mm (Figure 3, 4). The variability of rainfall frequency explains these changes in annual rainfall in Burkina Faso. The dynamics of rainy season characteristics for period 2021-2050 compared to period 1971-2000 is that there will be a decrease in the frequency of very light rains, a lengthening of the average duration of dry sequences, a late end to the rainy seasons and an increase in the average intensity of heavy rains (Ibrahim, 2012). Bambara et al. (2019) reported that climate dynamics were accompanied by a shortening of the wet season duration by -25% in the centre of the country and -3% in the north, with the duration of active vegetation period decreasing from 102 days before disruption to 48 days after disruption in the centre and from 67 days before disruption to 21 days after disruption in the north. Over the period 1961-2009, the rainfall pattern evolution was significantly subdivided into three small periods: a significant decrease in annual rainfall of 20% in the period 1971-1990 compared to 1961-1969, and an increase of 15% in annual rainfall in the period 1991-2009 compared to the period 1971-1990 (Ibrahim et al., 2014).

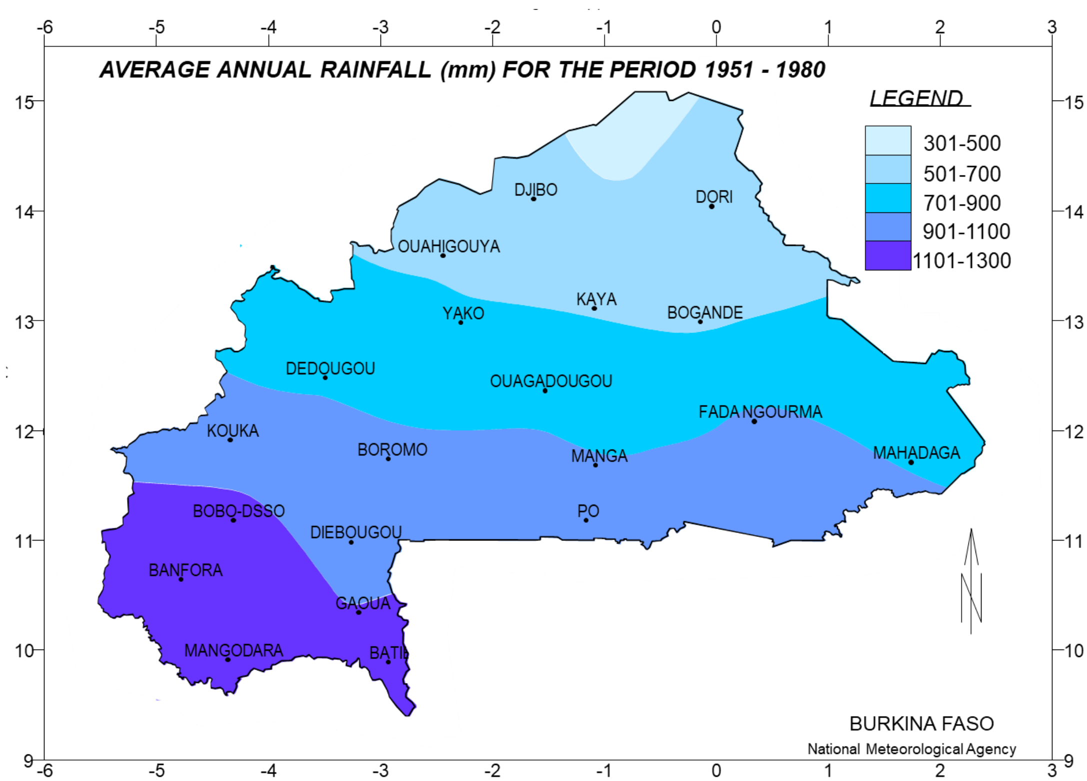


Figure 3. Variability of rainfall for the period 1951-1980 of Burkina Faso.

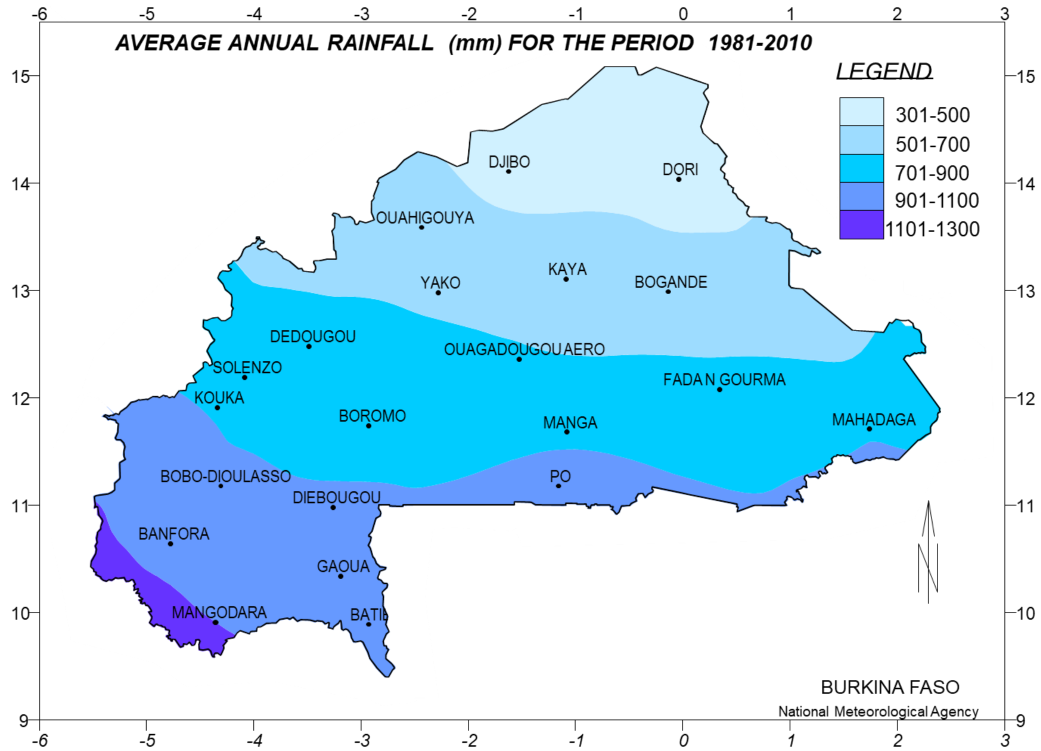


Figure 4. Variability of rainfall for the period 1981-2010 of Burkina Faso

2.4.2. Soil fertility issues in Burkina Faso

The country is characterized by a great heterogeneity of soils linked to a long geomorphological evolution and to the nature of the different geological substrates (crystalline granitic rocks, schistous metamorphic rocks and sandstone sedimentary rocks). Indeed, from a pedogenetic point of view, most of Burkina's soils have sandy-silty to sandy-clay textures with a clear predominance of kaolinite (a clay that does not swell very much and is chemically not very active in soils) in their clay fraction. They are developed on a parent material poor in major nutrients (nitrogen, phosphorus and potassium) and exchangeable bases. This has influenced the characteristics of the soils formed: poor in nutrients and organic matter (Ouattara, 2007). On these rather fragile soils, the organic matter content is less than 1% for 55% of the soils. The low availability of phosphorus (Koulibaly, 2011) in these soils limits the effectiveness of nitrogen and potassium mineral fertilizers. According to Stoorvogel and Smaling (1990), annual nutrient deficits were 12 kg.ha^{-1} for potassium (K_2O), 14 kg.ha^{-1} for nitrogen (N) and 4 kg.ha^{-1} for phosphorus (P_2O_5) in 1983. The nutrient deficit was estimated at 14 kg N, 2 kg P_2O_5 and 10 kg K_2O per hectare according to Bationo et al. (1998). Mazzucato and Niemeijer (2001) shown a decrease in nitrogen content in uncultivated and undeveloped soils between 1969 and 1996. Also, a decrease in organic matter was observed. Moreover, they are characterized by a low water retention capacity (10-15% of water for plants), shallow depth and structural instability and are therefore sensitive to water erosion (Guillobez et al., 2000). Indeed, 28t, 8-15t, 3-9t.ha^{-1} are lost annually in the north, centre and south-west respectively. These soils are generally compacted (low porosity) and are very sensitive to surface crusting. A major runoff phenomenon then develops, causing the little water that falls to escape the crops (FIAB, 2001). Thus, these soils are unable to meet the water needs of crops under the current climatic conditions, and tend to become more acidic with pH values between 4.5 and 5.8 in some localities (Segda et al., 2014; Epolyste et al., 2014). Under natural conditions, these soils are highly susceptible to poor structuring as soon as they are under cultivation. As in most sub-Saharan African countries, this low soil fertility remains a constraint to agricultural production in Burkina Faso. This low soil fertility remains and is increasing because of climate change, overexploitation, mining, demographic pressure and poor agricultural practices. These phenomena expose soils to degradation and consequently increase their impoverishment. Furthermore, socio-economic and technical aspects such as inadequate training and extension services, inconsistent and inadequate policies, support soil fertility declining.

2.5. Soil degradation causes and state in Burkina Faso

Soil degradation refers to the processes, primarily human induced, by which soil declines in quality and thus made less fit for a specific purpose, such as crop production. Soil is complex and has multi-faceted nature, and then his degradation cannot be measured or expressed by a single quantitative indicator. Its assessments are therefore either qualitative or quantitative referring to specific aspects such as the degree of alteration of certain properties or amount of soil loss; or to loss/reduced of specific ecosystem services (Bindraban et al., 2012). In Burkina Faso, gold mining, extensive land use for agriculture, wood cutting, population growth, expansion of urban/industrial areas, fire, overgrazing reduce aboveground, climate change (Da et al., 2008; Ouedraogo et al., 2010; Dimobe et al., 2015) and insecurity remains the major drivers of soil degradation. The land state was analysed in terms of physical occupation (LULC) and characterization of level of land degradation in 2018. It emerges that 31% of land is degraded, all degraded classes taken together, or in the process of degradation, including 6,498,610 hectares that are highly degraded. The physical, chemical, and biological degradation are encountered. Physical degradation manifests itself through surface crusting of soils, structural dislocation, skeletonisation and compaction (Hien, 1995). This degradation affects the morpho-pedological characteristics of soils by reducing their productivity and agronomic profitability. Chemical degradation is the result of the depletion of soil nutrients due to farming without the use of fertilizers or organic amendments, the sources of the mineral elements. Indeed, according to Thiombiano (2000), this degradation is the cause of the pH increasing or decreasing (leading respectively to alkalization or acidification), low cation exchange capacity, depletion of nutrients in the environment, and quantitative and qualitative changes in the pedofauna and pedoflora. The massive use of fertilizers in their current formulations can also lead to a depletion of soil bases (acidification) and organic matter, which particularly results in potassium deficiency and aluminium toxicity (Sedogo, 1993). For example, desaturation of the absorbent complex, phosphorus deficiency (<30 mg. kg^{-1} for 93% of soils), nitrogen deficiency (<0.6 mg. g^{-1} for 71% of soils), potassium deficiency increasing with the age of the plots and poverty in exchangeable bases (Bationo et al., 2014; MEEVCC, 2017b). Biological degradation manifests by a decrease in soil organic matter content, the burning of biomass, the depletion of the vegetation cover and soil fauna. Indeed, the current situation is as follows: decrease in the rate of organic matter (< 1% for 60% of soils), reduction of vegetation cover, loss of plant diversity, declining of wildlife species and the disappearance of certain species, eutrophication and pollution of water bodies, disappearance of certain aquatic resources, disappearance of forest formations (loss of 2,114,762 ha from 1980-2002) (SP/CONEDD, 2006; MEEVCC, 2017b). In addition, a study of the evolution of plant cover in Burkina Faso between 2007 and 2012 carried out using the "fraction of cover (FCOVER)" indicator, shows rather a regression of the plant cover at the national level (Ganaba et al., 2014). In particular, between 2007 and 2012, the low vegetation cover class (0-20) went from 27,748 km² to 66,614, that of 20-40 from 39,165 to 56,793 and finally that of 60-80 from 62,470 to 88,129. The Plateau Central region is known as a region where the imbalance between the carrying capacity of natural ecosystems and their intensity of use has led to an advanced degradation of the vegetation cover. The appearance of bare and crusted areas, called

"*Zipelles*" in the national language of Mooré, and especially their extension, illustrates this situation (Hien et al., 1996).

2.6. Function and Ecosystem services of soils

Soil is one of the more species-rich habitats of terrestrial ecosystems and its functions include biomass production, maintaining nutrient balance, chemical recycling and water storage to name a few (Blum, 2005). Soil is a very slow forming resource, and similarly to other habitats and ecosystems, it is coming under increasing pressures due to anthropocentric activities. According to the European Union, seven soil functions that are vulnerable to soil threats: biomass production, including agriculture and forestry, storing, filtering and transforming nutrients, substances and water, biodiversity pool, such as habitats, species and genes, physical and cultural environment for human activities, source of raw materials, acting as a carbon pool, archive of geological and archeological heritage. The categories of ecosystem services can be divided into four broad classes: production/provisioning, regulating, habitat/supporting services and information, and cultural services. There is the link between soil functions and ecosystem services (Table 3) and soil sustainable management involves smart combining of supporting, provisioning, regulating and cultural services provided by soil that are maintained or enhanced without significantly impairing either the soil functions that enable those services or biodiversity (FAO and ITPS, 2015).

Table 3. Ecosystem services provided by soil and the soil functions that support these services.

Ecosystem service	Soil function
Supporting services: *Services that are necessary for production of all other ecosystem services; their impacts on people are often indirect or occur over a very long time*	
Soil formation	• Weathering of primary minerals and release of nutrients • Transformation and accumulation of organic matter • Creation of structures (aggregates, horizons) for gas and water flow and root growth • Creation of charged surfaces for ion retention and exchange
Primary production	• Medium for seed germination and root growth • Supply of nutrients and water for plants

Nutrient cycling	• Transformation of organic materials by soil organisms • Retention and release of nutrients on charged surfaces
Regulating services: *benefits obtained from the regulation of ecosystem processes*	
Water quality regulation	• Filtering and buffering of substances in soil water • Transformation of contaminants
Water supply regulation	• Regulation of water infiltration into soil and water flow within the soil • Drainage of excess water out of soil and into groundwater and surface water
Climate regulation	• Regulation of CO_2, N_2O, and CH_4 emissions
Erosion regulation	• Retention of soil on the land surface
Provisioning services: *products obtained from ecosystems of direct benefit to people*	
Food supply	• Providing water, nutrients, and physical support for growth of plants for human and animal consumption
Water supply	• Retention and purification of water
Fibre and fuel supply	• Providing water, nutrients, and physical support for growth of plant growth for bioenergy and fibre
Raw earth material supply	Provision of topsoil, aggregates, peat etc.
Surface stability	Supporting human habitations and related infrastructure
Refugia	Providing habitat for soil animals, birds etc.
Genetic resources	Source of unique biological materials
Cultural services: *nonmaterial benefits which people obtain from ecosystems through spiritual enrichment, aesthetic experiences, heritage preservation and recreation*	
Aesthetic and spiritual	• Preservation of natural and cultural landscape diversity • Source of pigments and dyes
Heritage	Preservation of archeological records

Source: FAO and ITPS, 2015

At the global scale, the major threats to soil function remain erosion, loss of soil organic carbon, and nutrient imbalance. However, global assessment should not mask large regional differences in soil threats. Indeed, soil erosion is a major threat in sub-saharan African countries (Montanarella et al., 2016). But, biodiversity is responsible for the provision of many ecosystem services; human well-being is based on these services, and consequently on biodiversity (Blouin et al., 2013). Soil living organisms play an important role in soil formation. They are the most important component of soil organic matter decomposition and behave efficiently in the soil formation and development of structure and aggregate. Earthworms, ants and termites are commonly termed ecosystem engineers (Usman et al., 2016).

2.7. Contribution of ecosystem engineers to soil ecosystem functions and services

Ecosystem is a network of interaction and soil organisms play an important role in its functioning. In soil management, knowledge of invertebrates in situ is important. They are very sensitive indicators of soil quality and fertility (Bachelier, 1978; Black and Okwakol, 1997; Lavelle et al., 2006) and the current unsustainability of agricultural systems worldwide is partly due to the disappearance of these invertebrates (Lavelle et al., 2006). Soil engineers play a role through their bioturbation actions and their effects on soil parameters (Bachelier, 1978). Thus, they can control the availability of essential resources (water, nutrients) for other organisms, due to physical modifications of the environment (Konate et al., 2005).

The impact of termites on soil pedogenesis, soil properties, and soil functions is significant in most tropical and subtropical regions. This impact is correlated with temperature, rainfall, altitude, seasonality, latitude, longitude, and geology. Indeed, the act of tunneling in the soil and using the excavated mineral material to build mounds above and below ground and runways above ground by termites influences the mineral material physically and chemically (Bignell, 2006; Bera et al., 2020). This physical-chemical and biological interaction remains important for the soil. Thus, soils that are well populated by termites are better drained, more stable, and likely to have a higher retained organic matter content than equivalent soils that are depauperized. The majority of termite species have beneficial activities: facilitating drainage by maintaining macropores, mixing organic and mineral matter, mineralizing carbon (decomposition), translocating soil and microbial propagules, stimulating microbial metabolism, and promoting hydraulic conductivity (Bignell, 2006; Jouquet et al., 2016).

Ants are one of the main sources of soil disturbance worldwide due to their high diversity and abundance, wide geographical distribution and social behaviour (Folgarait, 1998; Frouz and Jilkova, 2008; Farji-Brener and Werenkraut, 2017). Ants often clear the soil surface of vegetation and mobilise large amounts of subterranean soil to the surface layers to build and maintain their nests. Their nests are key soil modifiers, because they nests improve soil fertility by accumulating organic waste on the soil surface and increasing plant diversity at larger spatial scales along environmental gradients. The effects of ant nests as islands of fertility are greatest in drylands because of the inherently lower fertility (Farji-Brener and Werenkraut, 2017).

Considered to be the most important ecosystem engineers in soils, earthworms are important bioindicators of soil health (Van Capelle et al., 2012). As they burrow into the soil, earthworms produce large pores that are important for water flow and retention, aeration, and root development. They mix organic matter in the soil, participate in the formation of aggregates and play an essential role in nutrient cycling and the decomposition of organic matter (Kladivko, 2001). There are different species of earthworms playing different roles in soil functioning. For example, anaerobic earthworms increase crop yields, above-ground biomass (Van Groenigen et al., 2014), water infiltration rates (Andriuzzi et al., 2015), nitrogen mineralization of crop residues (Van Groenigen et *al.*, 2014) and soil organic carbon stocks that are closely associated with nutrient availability and plant quality. However, they are greatly reduced in agricultural fields (Van Capelle et al., 2012) and climatic factors also moderate their populations (Briones and Schmidt, 2017). To the benefit of plants, worms act by releasing available nutrients (N and P), modifying microorganism communities and stimulating their activity, controlling disease agents, releasing phytohormones, or stimulating symbioses between plants and microorganisms (rhizobium, mycorrhizae) (Barot et al., 2007; Chapuis-Lardy et al., 2010; Bernard et al., 2012).

2.8. Farmers' coping strategies to climate change in Burkina Faso

In response to the negative effects of rainfall variability and soil fertility decrease, some farmers in the Sahelian and Sudano-Sahelian zones have drawn on their indigenous knowledge to develop strategies for adapting and mitigating climate change such as soil and water conservation practices. These are techniques initiated by local communities in drylands with the aim of improving soil fertility through the conservation of runoff water. The most used are: *zaï*, stone rows, ridge tillage, half-moon, mulching, flat ploughing, grass strips, pit composting, micro-dose fertilization, soil scarifying, ridging, subsoiling, filter dykes, gully treatment, dune fixation, improved fallow etc….

2.8.1. *Zaï* pits

Zaï is an ancient peasant technique rediscovered after the great drought of 1973/74 and then developed by the various stakeholders working with farmers. These are sowing holes about 20 to 40 cm in diameter and 10 to 15 cm of deepness. The distance between the holes is 70 to 80 cm. These holes are dug perpendicular to the slope and staggered rows (Figure 5). It influences by trapping organic matter displaced by wind and water in the soil, thus improving soil fertility. During the rainfall event, it captures, infiltrates and stores water at depth, thus reducing evaporation losses (WOCAT, 2011). *Zaï* technology is mostly practised in Burkina Faso, Mali and Niger (Adimassu and Mekonnen, 2012; Partey et al., 2018). It is also called "*Tassa*" in Niger and is an intervention that improves precipitation capture, reduces runoff and evaporation, and increases agricultural productivity (Wouterse, 2007; Partey et al., 2018). Most of the west cultivated lands are characterized by hardpan formation, compaction, inadequate aeration, reduced permeability and limited plant root development crusted (Zougmoré et al., 2014a), and *zaï* can enhance water retention capacity and decrease water runoff (Kaboré and Reij, 2004; Amede et al., 2011). According to Oduor et al., (2021), z*aï* can improve soil chemistry, and increase crop yields.

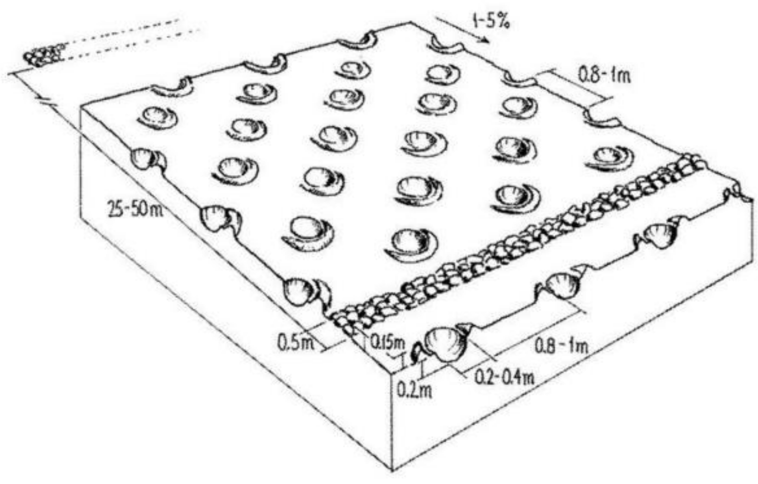


Figure 5. Technical drawing of the zaï technology (Source: WOCAT, 2011)

The *Zaï* system fulfils three functions: soil and water conservation and erosion control for encrusted soils. In particular, the advantages are that it (Suzanne et al., 2005): (i) captures rain and surface/run-off water; (ii) protects seeds and organic matter against being washed away; (iii) concentrates nutrient and water availability at the beginning of the rainy season; (iv) increases yields; (v) reactivates biological activities in the soil and eventually leads to an improvement in soil structure, (vi) and the manure applied to the pits contains seeds of trees or bushes. This helps the regeneration of the vegetation on fields treated with pits.

The use of *zaï* pit system is appreciated by producers and has enormous advantages demonstrated by many researchers. However, there are some constraints to its application, including hardness of the work and the high cost of labour, availability of organic manure and lack of means of transport. Indeed, it takes about 300 to 450 hours/ha to dig the *zaï* holes and another 250 hours/ha to fertilize them (Roose et al., 1993; Kaboré and Reij, 2004; Barro et al., 2007).

2.8.2. Stone rows

The technique reduces water erosion. It is partially permeable, dissipates runoff upstream of the stones and improves the water infiltration into the soil and the sedimentation of floating materials transported (straw, faeces, various grains, and various organic matter). Stone rows are anti-erosive devices built of blocks of rubble assembled by series of two to three. They are built in lines along a contour line after stripping 10 to 15 cm of ground along the line. The tops of the stones reach a height of 20-30 cm from the ground. The distance between the stone rows is 20-50 m depending on the slope of the ground (Figure 6). Stone rows help to combat water erosion by slowing down runoff. This benefits water infiltration and prevents the loss of rainwater. They also promote the sedimentation of fine soil particles carried along by water and manure.

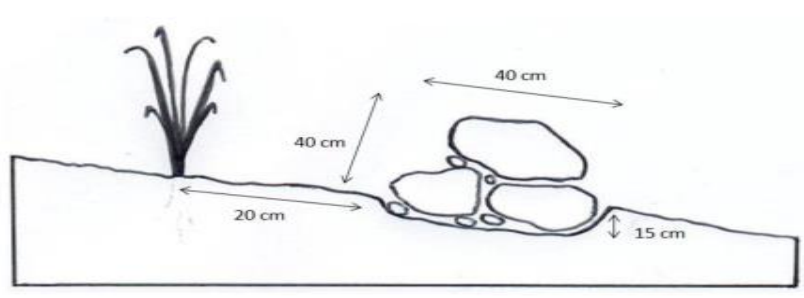


Figure 6. Technical drawing of the stone rows technology (Source: WOCAT, 2011)

Diverse positive effects of stone rows are reported and verified: soil retention and restoration, facilitation of grassing, better vegetative development of crops, better retention of rainwater. The productivity of Sahelian rain-fed agriculture can be improved by using stone rows technique. In fact, synergistic effect of water-harvesting practices and the supply of organic or mineral resources increased water use efficiency even during an erratic rainy season. Also, application of compost with stone rows reduced runoff and increased soil water storage and sorghum biomass production (Zougmoré et al., 2004b). In spite of this, there are some constraints to its application: difficulties in mechanization tasks with hitched implements, in crossing fences, in finding stones and the lack of material and financial means.

2.8.3. Ridge tillage

Ridging is a ploughing technique that results in the formation of a series of ridges called "ados". It is done with a hoe, a plough or with ridgers. The ridging is done perpendicular to the slope. These ridges are made with a gentle slope (0.1 to 0.2%) to avoid overflow during heavy rainfall. The height of the ridges depends on the nature of the soil, the rainfall and the plant and varies between 0.15 and 0.40 m (CILSS, 2012). The distance between two ridges will be 0.80 to 1.5 m for cereals and 0.60 m for groundnut. The prowess of ridging on crop yields and soil has been widely mentioned by some authors. Indeed, the ridging technique had a positive effect on the production of fresh tuberised roots by an increase of 62.79% (Dembele et al., 2020). Ridging improves maize productivity compared to direct seeding. Indeed, the best indices (foliar, harvest), the best growth rate and the best yields (grains, stalks, spathes, straw) were obtained with ridging (Kouelo et al., 2017).

2.8.4. Organic and mineral supplements

Organic inputs are simple techniques for improving soil fertility and have two main objectives: (i) to intensify the cropping system and to make the most of the investment in land development fairly quickly; (ii) to improve the soil structure (contribution of organic matter) and to fight effectively against the degradation of the surface condition and the detachment of soil particles (Guébré, 2021). The use of organic manure contributes to the improvement of crop productivity. This is due to its improving effect on the physico-chemical and biological parameters of the soil. In fact, organic matter improves soil properties with a greater importance and durability for sheep manure (Koull and Halilat, 2016). The same authors noted that with 113.4 $t.ha^{-1}$ of organic matter, there is a decrease in pH from 8.72 to 7.73; an increase in electrical conductivity from 4.30 to 7.83 dS/m; an increase in water retention capacity from 29.96 to 39.45% and an increase in cation exchange capacity from 7.85 to 18.12 meq/100 g of soil. Also, Koulibaly et al. (2015) showed that compost improved available P, available K, mineral nutrition, and nitrogen in the soil under cotton, but deficient in nitrogen and phosphorus for the soil under maize. Thus, the impacts of organic inputs on soils depend on the crops grown.

The African continent is still not able to feed itself, hence the need to improve agricultural productivity. Although fertilizers are one of the key inputs to the agricultural sector, their use remains below the target set in the 2006 Abuja Declaration of using at least 50 kg of nutrients per hectare of arable land. The fertilizer consumption in West Africa is less than 40 kg. ha^{-1} (Camara and Heinemann, 2006). In Burkina Faso the use of NPK fertilizer in the rainy season is 32.24 $kg.ha^{-1}$ (MAAHA/DEGESS, 2021). To encourage farmers to use minerals, the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) and its partners have developed a micro-dosing technology for fertilizers. This technology has proven to be a suitable precision farming tool for smallholder farmers in the Sahelian region of Africa (Blessing et al., 2017). Thus, the microdosing technique presents itself as an alternative solution to overcome this constraint of low application of mineral fertilizers. Fertilizer micro-dosing technology consists of the application of a small quantity of mineral fertilizer together with seeds of the target crop in the planting hole at sowing or two weeks after planting (Blessing et al., 2017; Hayashi et al., 2008; Saba et al., 2018). The advantages of this technology include: (i) locating the fertilizer close to the root, which results in a high concentration zone that facilitates nutrient uptake; (ii) reducing phosphorus fixation by the soil; (iii) reducing nutrient losses due to leaching; (iv) obtaining an early start to plant growth; (v) increasing the efficiency of fertilizers used; (vi) minimizing production costs; (vii) improving the income of small-scale producers; (viii) increasing the number of users of mineral fertilizers.

2.8.5. Half-moon

The objectives of the half-moon are to increase infiltration and soil water stock, and to recover and restore the fertility of crusted soils for agronomic and agroforestry use. The half-moon differs from the *zaï* in that it is wider, offers more surface area for sowing and water collection. In a drought year, it is more advantageous. It slows down and collects run-off water, thus favoring its infiltration on soils that are not suitable for agriculture (Zouré, 2019). The half-moon is a semicircular trough opened by digging with picks and shovels. The excavated soil is deposited downstream of the semi-circle in a semi-circular bead with a flattened top. The dimensions commonly used are diameter: 4 m; depth: 15-40 cm; interlines: 8 m; interhalf-moons: 4 m, with a density of 312-417 half-moons per hectare (Figure 7). The staggered arrangement of the half-moons on the slopes allows runoff to be retained and soil moisture to be maintained (Mando et al., 2001; R. Zougmoré et al., 2004a); this allows the plants in the half-moon to receive much more water than they receive directly from the rain (Guébré, 2021). Thus, the retention of runoff water would allow the storage of fine soil particles, which would improve it quality. They are well adapted to semi-arid and arid areas. In Burkina Faso, this technique is mostly used in the Sahel, North-Central and Plateau Central regions due to severe land degradation. The half-moons allow an improvement of soil water reserves as well as an increase in the depth of wetting from 20 to 40 cm (Guébré, 2021). It influence on agricultural production is reinforced with a combination of stone rows, and addition of mineral or organic supplement.

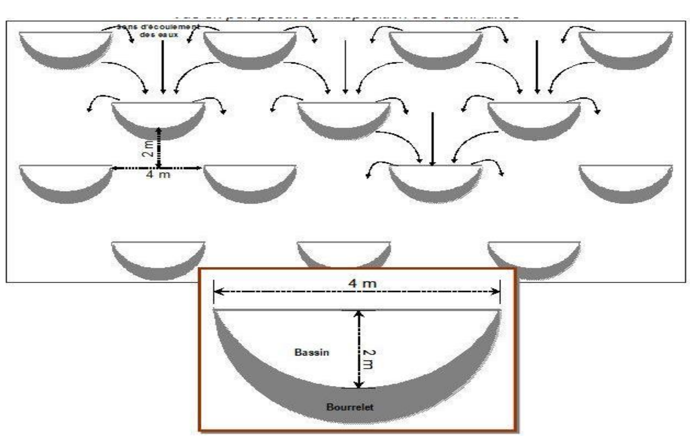


Figure 7. Technical drawing of half-moon (Wocat, 2014)

2.8.6. Grass strips

These are strips of perennial grasses (*Andropogon gayanus, Andropogon ascinodis, Cymbopogon ascinodis, Vetiveria zizanioïdes*), established perpendicular to the direction of diffuse flows and following the contour lines. They favor three types of processes: (i) the slowing down of the diffuse surface runoff that crosses them, due to the significant surface roughness of the vegetation in the grass strip; (ii) the possible reduction of this diffuse runoff flow, by increased infiltration due to the presence of dense vegetation; (iii) the deposition of sediments as a result of the two previous processes (Guébré, 2021). Based on their impacts on the three processes, they would play the role of stone barriers on certain soils. The creation of grassed strips is a complement or alternative in areas where stone quarries are not available for the creation of stone barriers (Zouré, 2019). They also increase the availability of herbaceous biomass for livestock feeding and soil fertility.

2.8.7. Varietal adaptation

In climate change context and the poverty of cereals farmers, adapted crops seeds is and stand necessary. Its can increase the resilience level of farmers. Improved varieties are the product of formal breeding programs that undergone testing and are released through a formal process. Court cycle and reasonable yield varieties are the more looked for the farmers and short-cycle varieties adapt to the shorter rainy season (Kissou, 2014).

2.8.8. Agroforestry

Agroforestry is a collective name for land use systems and practices in which woody perennials are deliberately integrated with crops and/or animals on the same land management unit (Leakey, 1996) to obtain profitable ecological and economic interactions. This makes agroforestry systems varied, complex, and a multidisciplinary science. But agroforesty is not just a simple addition nor a juxtaposition of agriculture and forestry (Depommier, 1998). It embraces an agro-ecological approach, putting emphasis on multi-functionality and the management of complex systems and polycultures rather than focusing exclusively on monoculture. It is promoted as a landuse strategy to support climate change mitigation and climate change adaptation, biodiversity conservation, sustainable agriculture and other goals (Gassner and Dobie, 2022). The meta-analysis from Bayala et al. (2018) revealed that agroforestry practices including alley cropping, improved fallow, mulching and parkland significantly increase soil organic carbon, nitrogen. In Niger, agroforestry is a promising option for improving crop production. Indeed, Bado et al., (2021) shown that cropping systems (Ziziphus-Millet, Ziziphus-Cowpea, Ziziphus-millet/cowpea inter cropping, with low fertilizer input) improved soil nitrogen and pH.Therefore, the presence of Ziziphus trees increased millet yields by 41 %. Otherwise, in Burkina Faso, Coulibaly et al., (2021) shown that total soil carbon content increased when rainfall increased or decreased under Parkia biglobosa and Vitellaria paradoxa and respectively.

CHAPTER THREE: RESEARCH METHODOLOGY

3.1. Study area

3.1.1. Selection of sites

The study was carried out in the Plateau Central region of Burkina Faso. The study covers two provinces with an area of 5,392 km2, and includes four municipalities: *Boussé, Dapélogo, Laye* and *Zitenga* (Figure 10). In each municipality, one village was selected after consulting with agricultural extension officers and according to the accessibility to the village, the receptiveness of innovations, and the use of soil and water conservation practices. The village of *Sandogo* hosted the experimental fieldwork. Two sites, in farming environments, were chosen to install the experimental devices. The choice of the two sites, located in the same village and on different soils, aims to understand the effect of the selected techniques on existing agricultural practices. On the first site, located at the upper slope, the techniques applied on groundnut. On the second site, located at the lower slope, the techniques applied on sorghum.

3.1.2. Geographical and administrative location

The Plateau Central region is located in the Sudan-Sahelian zone of Burkina Faso with an area of 8,605.11 km². It is bounded to the northeast by the Centre-North region, to the northwest by the North region, to the south by the Centre and the South Centre regions, to the west by the Central-West region, and to the east by the Eastern Centre region. In terms of administrative organisation, the Plateau Central region is subdivided into 3 provinces (*Ganzourgou*, *Kourwéogo*, *Oubritenga*), 20 departments, 3 urban communes, and 17 rural communes. The survey was carried out in four villages: *Dayagretenga, Gantin, Poedogo, and Sandogo*. The experiments were carried out on field site during two rainy season (2021 & 2022) in *Sandogo*, commune of Boussé, province of Kourwéogo. Its geographical coordinates are: 648290 WGS84 and 1395772 WGS84 (Figure 8).

3.1.3. Geology and geomorphology

The metamorphic formations and the crystalline rocks, resulting from the mid-Precambrian, are the two geological formations that constitute the substratum. The rocks include parametamorphic (clay and tuffaceous schists, sericitoschists, chloritoschists, amphibolites), orthometamorphic (andesites, schists, amphibolo-pyroxenolites, amphibole), syntectonic acid (calc-alkaline granites) and post-tectonic acid (alkaline and calc-alkaline granite). Geomorphologically, the residual relief is marked by ironclad mound and outcrop, rock mound and outcrop, and ironclad plateau. The functional surface is characterised by the eroded mountainside and a glacis system subdivided into three levels: high-slope glacis, medium-slope glacis, and low-slope glacis. Alluvial lowlands and terraces and colluvial valleys characterise the fluvial-alluvial complexes (BUNASOLS, 1998).

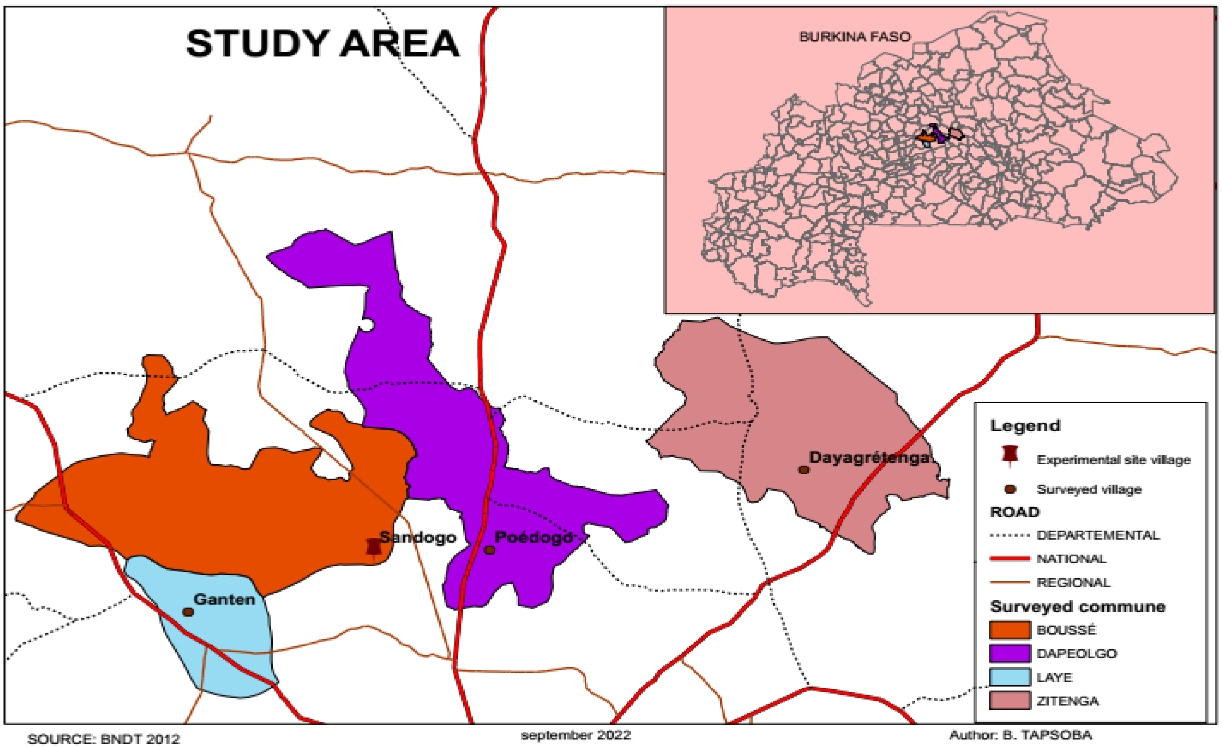


Figure 8. Localisation of the study area.

3.1.4. Climate

The climate of *Sandogo* is of the Sudan-Sahelian type with a rainfall of over 600 mm and less than 900 mm. The rainy season does not exceed four months (June to September) with average annual thermal amplitudes and a dry season of 8 months (October to May). In the past 30 years (1991-2020), the rainy season marked by fort inter-annual variability in time and space with an average annual rainfall of 780.91 mm. The year 1997 had the lowest rainfall (587.80 mm) and 2012 was the wettest year (1003 mm). The maximal temperature had ranged from 34.49 to 36.04 (Figure 9a) and the minimal from 21.54 to 23.46 °C (Figure 9b). From 1991-2020, the wind speed varied from 1.486 to 3.151 m.s^{-1}. The year 1993 recorded the lowest speed and 2020 the highest. From 1991-2020, the average humidity varied from 47.61 to 52.71%. The year 1996 recorded the low humidity and 2010 the high humidity. From 1991-2018, evapotranspiration has fluctuated between 5.32 mm and 6.17 mm. 1993 had the lowest ETP and 1995 the highest (Anam, 2020).

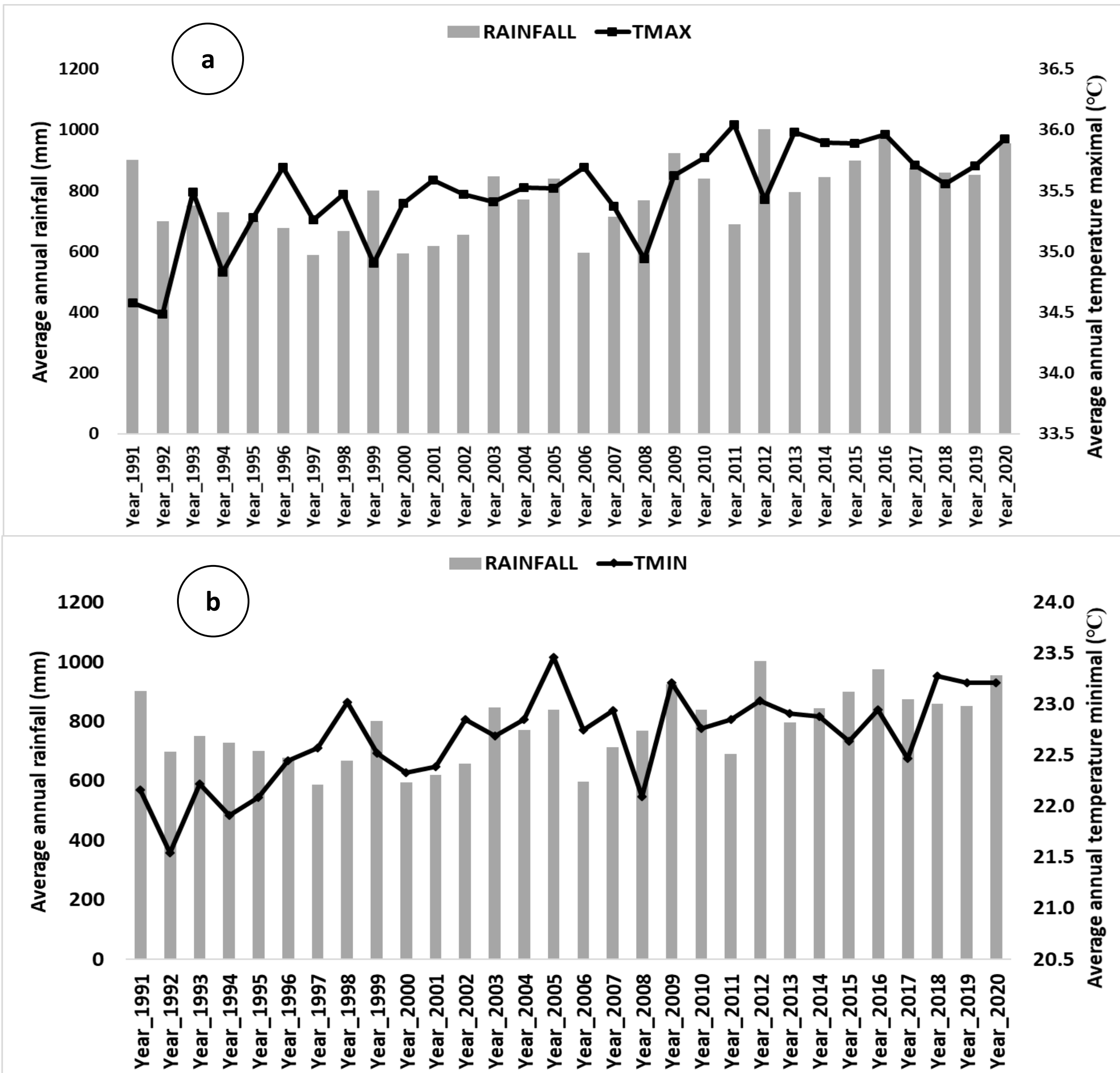


Figure 9. Average variation in annual rainfall and average temperature maximum (**a**), and minimum (**b**) over the last 30 years at the rainfall station near to the study area

3.1.5. Soils and vegetation

The majority of the soils are lithosols, leached tropical ferruginous soils, ferruginised tropical eutrophic brown soils and hydromorphic tropical eutrophic brown soils. A study of BUNASOLS (1998) shows that its soils have a low to medium overall fertility. Organic matter, total nitrogen and phosphorus (total and available) levels are low. The province of *Kourwéogo* is characterised by vegetation formations consisting of wooded savannahs or wooded savannahs resulting from the degradation of the initial vegetation due to anthropic practices (BUNASOLS, 1998). In the village of *Sandogo*, the woody vegetation is essentially composed of *Guiera senegalensis, Combretum micranthum, Combretum glutinosum, Diospyros mespiliformis, Vitellaria paradoxa, Lannea microcarpa, Tamarindis indica, Lannea acida, Sclerocarya birrea, Anogeissus leiocarpus, Ficus gnafalocarpa, Parkia biglobosa, Cassia sieberiana, Piliostigma reticulatum, Piliostigma thoningui.* On mounds and outcrops of armourstone Combretum species (*C. Micranthum, C. glutinosum*) in the form of thickets. In the lowland areas species such as *Mitragyna inermis, Pterocarpus santalinoides, Acacia polyacantha*. The herbaceous carpet is essentially made up of *Hyptis spycegera, Loudetia togoensis, Eragrostis tremula*.

3.1.6. Population and economics activities

The estimated populated of Plateau Central region is 978,614 with 884,898 rural residents. The population of Kourwéogo is 138,217 with 122,349 rural residents. Their main activities are agriculture and livestock breeding. Rainfed crops represented by cereals (sorghum, pearl millet, maize and rice), legumes (groundnut, bambara groundnut, sesame, cowpeas, and mung beans) and tubers dominate crop production. In terms of spatial distribution, sorghum, rice and sweet potato occupy the lower parts of the functional units, the lowlands and the plains. Legumes are grown on the middle and upper glacis. Irrigated agriculture is marginal and mainly concerns vegetable crops (tomato, eggplants, onion) and practiced around water bodies in the dry season. The areas under cultivation in hectares are 24,895 for sorghum, 3,041 for maize, 10,095 for pearl millet, 1,272 for rice, 5,107 for groundnut, 1,340 for sesame, 3,918 for cowpea and 1,891 for Bambara groundnut. Concerning livestock, it includes goats (149,000 heads), sheep (98,000 heads), cattle (48,000 heads), donkeys (25,000 heads) and poultry (576,000 heads) (MAAHMA, 2021). The department of *Boussé* has 58,643 with 33,621 residents and 6,682 households whose 45.29% men and 54.71% women. The village of *Sandogo* has 1408 men and 1461 women, making a population of 2869 (INSD, 2008, 2021).

3.2. Data

- **Agronomic survey data** included socio-economics characteristics (gender, major activity, age, level of education, affiliation to organisation, type of land tenure, size of the household, active members of household, number total of equipment, number of small ruminants, number of big ruminants and types of big ruminants), agro-pedological characteristics (Sorghum and Pearl millet yields dynamics, causes of Sorghum and Pearl millet yields dynamic, soil and water conservation technique used on farm, Straw uses), environment and soil management situation (natural ressources status, level of soil fertility, soil and water conservation practices used to cope with natural ressource status, disaster risk).
- **Soil data concerned** soil moisture content, soil macrofauna, Sand, Silt and Clay content, pH, total organic carbon, total nitrogen, available phosphorus, exchangeable Ca, K, Mg and Na, CEC, Base saturation, respiration
- **Sorghum plant data** concerned height, collar diameters, grains and straw yields, 1000-grains weight.
- **Groundnut plant data** concerned number of nodules, number of branches, number of flowers, number of the leaves, pod and haulm yields, 100-seeds weight.
- **Climate data** obtained from meteorological agency were daily rainfall, temperatures, solar radiation, wind speed.

3.3. Equipment

- **Survey equipment :** questionnaire, pencils, pen, motorbike and laptop
- **Equipment for site identification and characterisation :** GPS, markers pens, laptop, vehicle, tape measure, shovel, pickes, water sprayer, code munshell, and camera
- **Equipment for the delimitation and installation of the experimental plot : t**ape measure, iron stakes, scotch tape, markers pens, notepad, pickes, shovel

- **Equipment for collection and transport of soil samples to the laboratory : t**ape measure, marker pen, plastic bucket, plastic bag, scotch tape, and auger

- **Equipment for packaging, transport and characterisation of macrofauna :** metallic square, 75 % alcohol, plastic bottles, tarpaulin for sorting, ocular magnifying glass, macrofauna determination keys, markers pens, scotch paper, precision scale, and vehicle

- **Equipment for measuring plant growth : t**ape measure, scoring sheet, digital caliper, and pencil

- **Equipment for measuring the release of CO_2 :** tubes, measuring device (Figure 10), micropipette of 1000 µL, scoring sheet, demineralised water, soil samples, precision scale (Figure 11), pencil, aluminum foil

- **Equipment for the determination of the gravel content of sites : s**cotch tape, notebook, precision scale, metallic box, shovel, and plastic skewer

- **Equipement for soil moisture content measurement :** notebook, pencils, and measuring device (Figure 12).

Figure 10. Equipment for measuring CO_2 emissions

Figure 11. Precision scale for measuring the weight of 100 pods.

Figure 12. Probe to measure surface moisture

3.4. Methodology

3.4.1. General methodology

The general methodology (Figure 13) was based not only on literature review, agricultural surveys, implementation of an agricultural experiment but also on advice received from resource persons. In this way, classic methods adapted to the realities of the locality where the agricultural experiments carried out were used both in the field and in the laboratory:

- **Choice of study area:** The study area is the Plateau Central region. The region is located in the Sudan-Sahelian climatic zone and has a highly degraded environment. As a result, farmers in the area are vulnerable to environmental changes. The sites selected for the experimentation were located in a typical village with degraded soils in the Sudan-Sahelian zone. In addition, the techniques of *zaï* and stone rows are strongly supported by many development projects and program. Sorghum (main cereal crop) and groundnut (second cash crop after cowpea) growth were among the selection criteria.
- **Analysis on the determinants of indigenous SWCPs used:** to evaluate and analyse the determinants of adoption of these practices as well as their logical combining, an agronomic survey was conducted among farmers in the Plateau Central region.
- **Experimentation of the practices of *zaï*, ridge tillage, stone rows and their combination:** these experiments were carried out in a one village (*Sandogo*). The objectives are to determine the influences of these practices on soil health and on the performance of groundnut and sorghum yields as influenced by climate change. The whole experiment were set up according to randomized fisher block design with four treatments in five replications taking into account the technical factors of SWCPs (*zaï*, stone rows, ridge tillage).

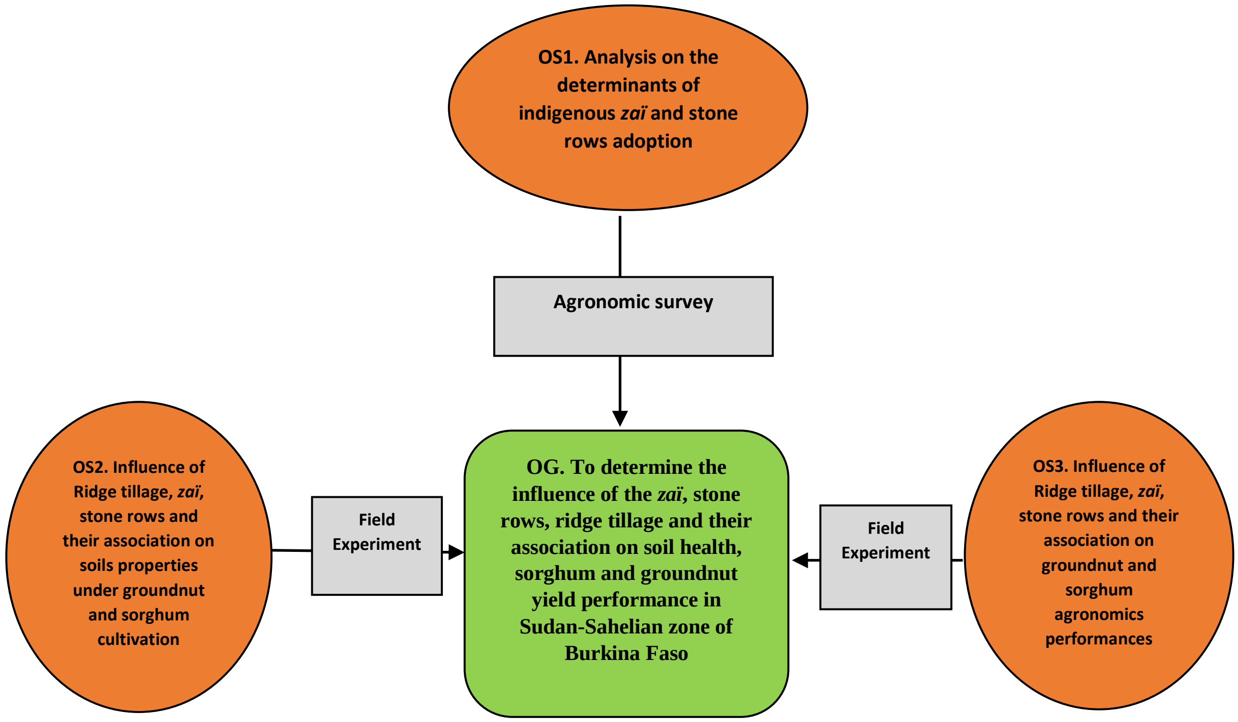


Figure 13. General methodology of the thesis work

3.4.2. Analysis on the indigenous determinants of the *zaï* and stone rows techniques use to cope with climate change

To analyse the determinants of adoption of these practices as well as their logical combining, a survey had been conducted in four villages. The objective of this socio-economic approach is to analyze the factors that motivate households to adopt *Zaï* pits and Stone rows practices in the Plateau Central region. It aims to identify the agronomic, sociological, economic and environmental drivers that condition *zaï* pits and stone rows practices using in that region.

3.4.2.1. Sample size

In each province, two municipalities selected. Based on accessibility, soil and water conservation practices adoption level and acceptability to news technologies, one village selected in each municipality. Thirty farmers are randomly choose in three villages and fourty-five in one village (Table 4) according to their use of soil and water conservation techniques for survey conducting. The local leaders and the agricultural extension officers assisted us in the selection of villages and farmers.

Table 4. Distribution of respondents in the different municipalities of the study area

Municipality	Village	Number of farmers surveyed
Dapélogo	*Poédogo*	30
Zitenga	*Dayagretenga*	30
Boussé	*Sandogo*	45
Laye	*Gantin*	30
Total		135

3.4.2.2. Data collection and factors considered

Data were collected from May to June 2021 using participatory rural approaches like focus group, individual survey and direct observations. For focus group, open questions were discussed with village leaders (traditional and religious leaders, village development committees, population), women's agricultural production organisation, and local representation of regional farming council.

A questionnaire was prepared and has been tested on 10 farmers. Then, focus group and the test survey allowed us reviewing the formulation and order some questions. The information collected through individual interviews with the respondents in the dominant dialect (Mooré) included local people perception of climate change impacts, age, gender, education level, household activity, causes of natural resources degradation.

3.4.2.3. Conceptual framework and model specification

To guide the scientific analysis, the conceptual framework and model specification presented.

- **Conceptual framework**

Agricultural technology adoption theory is multi-disciplinary field that combines elements of decision theory and diffusion of innovations theory in an attempt to explain why some farmers adopt new technologies and others do not. The lessons from the literature related to the adoption of agricultural technology three paradigms exist: the innovation-diffusion; the economic constraints and the adopter-perception (Adesina and Zinnah, 1993; Sidibé, 2005; Prager and Posthumus, 2010; Ruzzante et al., 2021), and three types of models often are used: linear probability, Logit and Probit models. Linear probability models have disadvantages as the probability can often exceed 1. Logit and Probit models are the most commonly used in most adoptions studies (Gujarati, 1995; Wooldridge, 2009). According to Rogers (1983), agricultural technology adoption can be describing as a mental process, commonly known as the innovation-decision process, farmers go through a stage of being aware or knowledgeable of a new technology, to forming positive or negative attitude towards agricultural technology, and ultimately to deciding whether to adopt the technology or not. This framework has been widely applied to investigate the adoption pattern of various agricultural technologies. Agricultural technique adoption has a several definitions, but like Featherstone et al. (1997), we define adoption as the extent to which a new technology is utilized, balanced with other activities and the farmer has lot of information on the technology and its potential. According to Coulibaly (2018), the adoption of soil and water conservation techniques can be considered as a multivariate function. Then, Adoption = f (age, active, education, training, equipment, number of cattle, number of small ruminants, perception, area, etc….).

- **Model specification**

In most of the studies on soil and water conservation techniques adoption, the Logit model is generally used (Coulibaly, 2018; Koutou et al., 2007; Sidibé, 2005). In this study we used it because of it compatibility and evidence shown by many authors (Adesina et al., 2000; Mafongoya P, 2015; Nana and Thiombiano, 2018; Sigué et al., 2018; Yabi et al., 2016a), as well as it fluency in results usage (Hurlin, 2003). The adoption is defined like the farmer who uses one of the SWCPs freely of the quantity of practices adopted. The resoluteness to adopt is considered like dependent variables in the regression of whom is 0 or 1. Denoting P as the probability of reaching an option among the predictors X1 to X12, the mathematical formulation of the binary logit model used in this study is expressed in equation:

$$Y = Logit(P) = Ln\left(\frac{P}{1-P}\right) = \alpha + \beta 1X1 + \beta 2X2 + \beta 3X3 + \cdots \beta zXz$$

Where: P: Probability that respondent use stone rows or *zaï* techniques; 1-P: Probability that respondent use any technique; Y: respondent group (with 1= technique user, 0=no technique user); X1: Age of respondent (in years); X2: Gender of respondent (with 0=female, 1=male); X3=Marital status (with 1=unmarried, 2=married, 3=widowed); X4= Education level (with 1=non educated, 2=non formal educated, 3=primary school, 4=secondary school, 5=high school); X5: Membership into a local organization (with 0=No, 1=Yes); X6: household size (Number of persons in the household); X7=Active household size (number of active persons in the household); X8: Type of landownership (with 1=landowner, 2=loaning, 3= purchase, 4= donation); X9: Equipment size (with 1=0, 2= [1-5], 3= >5); X10: Number of cattle; X11=secondary activity.

In the model, the notations β1, β2, ………, β10 (generally termed as βk) denote the slope coefficients of the explanatory variables X1, X2,……………., X12 (generally termed as Xk) and α is the intercept term (constant). The exponential Exp(B) of the slope coefficient βk associated to the explanatory variable Xk is interpreted as the Odds Ratio (OR) of the occurrence of the events2 (using SR or Z) for each adoption in the predictor.

In this model a positif coefficient means that the probability increases with rise of the independent variable correspondent (Neupane et al., 2002). The factors being able to influence *zaï* or stone rows practices adoption are kept a record in Table 5.

The empirical definition of the farm-specific variables that are expected to determine the probability of adopting *zaï* and stone rows is: where adoption is a dummy variable and the dependent variable indicates the decision to adopt the technology or not. The bs are the coefficients of the independent variables Xi (Table 6 gives the definition and expected influence of the variables) indicating the influence of these variables on the probability of adoption. Therefore, if the estimated coefficients for these variables are positive and significant, we can infer that farmers with higher values for these variables are more likely to adopt soil and water conservation practices.

Table 5. Factors identified as likely to influence the decision to adopt *zaï* or stone rows practices

Variable	Type	Description
Gender	Qualitative	Respondent’s gender, male or female
Age	Quantitative	Respondent’s age (years)
Marital status	Qualitative	The condition of being married or unmarried
Education level	Qualitative	Respondent’s years of formal education (years)
Household size	Quantitative	Number of persons living in household
Active household size	Quantitative	Number of active persons in the household
Landownership type	Qualitative	Farmer’s rights on the land

Agricultural equipment	Quantitative	Agricultural equipment owned by household head
Number of cattle	Quantitative	Number of cattle in the household
Organization membership	Qualitative	Farmer is member of a local organization
Secondary activity	Qualitative	The secondary activity of the head of household

Table 6. Expected relationship between variables used and the adoption of *zaï* or stone rows practice

Variables	Use of *Zaï* pits technique	Use of stone rows technique
Gender	Negative	Negative
Age	Negative	Negative
Marital status	Negative	Negative
Education level	Positive	Positive
Membership in farmer's organization	Positive	Positive
Perception of soil degradation	Positive	Positive
Perception of vegetation degradation	Positive	Positive
Perception of fauna degradation	Positive	Positive
Perception of soil fertility level	Positive	Positive
Number of active workers	Positive	Positive
Number of agricultural equipment	Positive	Positive
Number of small ruminants	Positive	Positive
Number of big ruminants	Positive	Positive
Component of big ruminants	Positive	Positive
Type of land tenure	Negative	Negative
Risk disaster	Positive	Positive

3.4.3. Assessment of the influence of *zaï*, stone rows, and ridge tillage practices on soil health, and performance of groundnut and sorghum yields

3.4.3.1. Soil characterization of study sites

- **Description of pedological pits**

Prior to the experimental design implementation, in each experimental site, we conducted a field investigation based on both pedological trench description and sampling. For pedological trenches, soil descriptions and classification were conducted following the guidelines for soil description by the FAO and adapted by BUNASOLS to the agro-climatic conditions of Burkina Faso. Five soil samples were collected in each pedological trench according to the horizon (one composite sample per layer) for laboratory analysis in order to obtain additional data on the initial soil characterisation. The following parameters were analysed for: pF (2.5 & 4.2), texture, pH, soil organic carbon, total nitrogen, available phosphorus, available potassium, exchangeable bases.

- **Determination of surface gravelly charge (SGC)**

The surface gravelly charge (gravel, ferruginous pebbles, quartz, pottery debris, slag, coal and other metallic debris) was first assessed by visual observation. Then, the quantitative estimation was done using a square metal grid of 80 cm x 80 cm placed on each elementary plot in its median part. The surface rough minerals (in the square) were collected with a local broom and a metal shovel and then passed through a 2 mm sieve. All rough minerals greater than 2 mm were weighed and then extrapolated to the total area in m^2 of each elementary plot to estimate the surface gravel charge (SGC).

- **Determination of Soil refusal rate (SRR)**

After harvesting, soil samples were collected from each elementary plot along the diagonal using an auger. Three samples were collected per plot and mixed to form composite samples. These samples were sieved to 2 mm. The refusal (mineral + organic) was weighed and the refusal rate was determined by the formula:

$$\text{Refusal rate (\%)} = \left(\frac{Weight\ of\ soil\ refusal\ (g)}{Weight\ of\ soil\ sample}\right)*100$$

- **Determination of the initial soil fertility class**

The soil chemical fertility level classification is based on the (BUNASOLS, 1990) guideline. The full range of parameters were used to determine this class: Organic matter, total nitrogen, available phosphorus, total phosphorus, available potassium, total potassium, CEC, Base saturation, Sum of exchangeable bases, and pH. Each parameter is assigned a rating according to its content in the soil. The rating goes from 1 (unfavorable) to 5 (favorable). The sum of the ratings defines the fertility class (Table 7), and the corresponding interpretation for each soil type.

Table 7. Soil fertility class

Class	**Very low**	**Low**	**Medium**	**High**	**Very high**
Summation cotation	<20.9	21-26.9	27-32.9	33-38.9	>39

Source: BUNASOLS, 1990

- **Land quality assessment**

The determination of the cropping ability of the land at the sites used for the agricultural experiment was done using the FAO's (1983) guidelines for land evaluation. These only concern the soil aspects. The qualities of the land assessed are as follows: Oxygen availability, nutrient availability, rooting conditions, and flood risk.

Oxygen availability in the root zone (w): this is assessed on the basis of the natural drainage of the soil, the depth of hydromorphic patches, the depth or fluctuation of the water table, and the permeability of the soil. The diagnostic factor used is the FAO drainage class.

Rooting conditions (r): The FAO textural class was used to assess this soil quality. It takes into account the effective depth of the soil (cm), the gravel load (%), the structure, and the consistency.

Flood risk (i): The diagnostic factors used are vegetation cover (%), textural class of the first horizon, presence of gullies/gravels and slope.

3.4.3.2. Experimental material

3.4.3.2.1. Plant Material

Sorghum (*Sorghum bicolor* L.) variety "Kapèlga" with a sowing-maturity cycle between 90 and 110 days was used. This variety has an average grain yield of 0.8 to 2.8 t ha^{-1} respectively in the field and in the control environment. The cultivation areas of this variety are between 500-850 mm isohyets. In addition, this variety is commonly used and it is resistant to striga, resists post-flowering drought and is resistant to lodging.

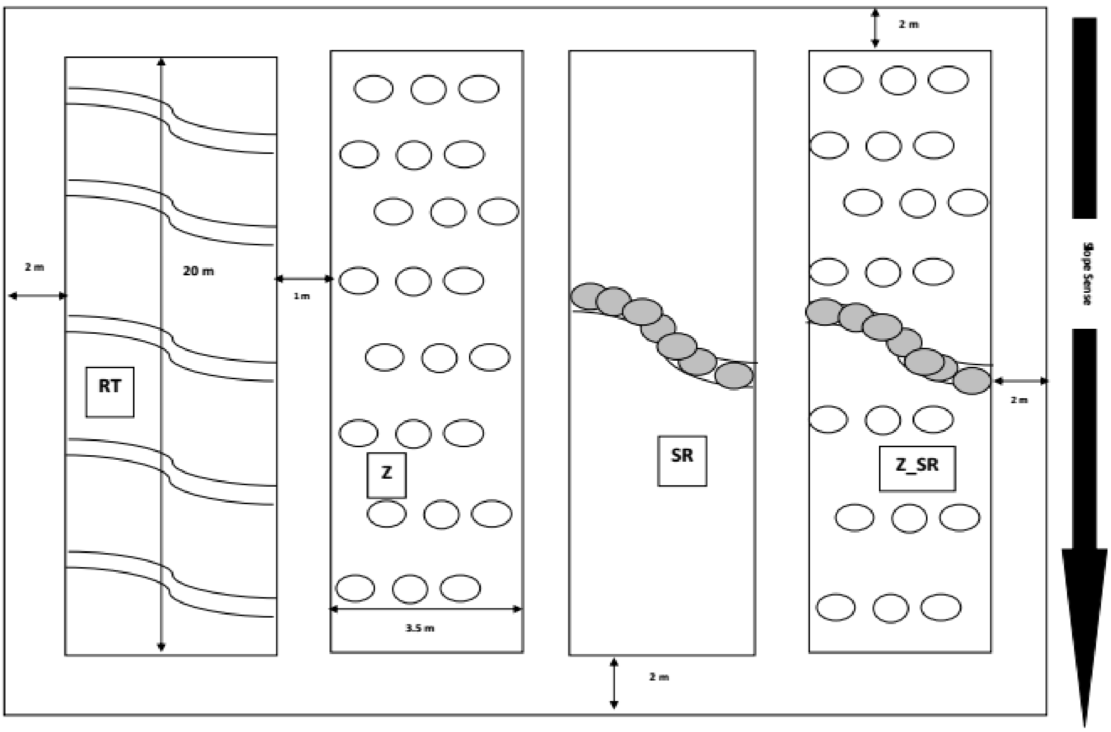
Groundnut (*Arachis hypogaea* L.) of the variety SH 470P was used. It has a semi-trailing plant, sequential flowering, medium to large, black-dark elliptical leaves. It has an average height of 30 cm and a spread of 20 cm. Depending on the growing area and the length of the rainy season, SH 470P can have a ripening cycle between 90 and 110 days.

3.4.3.2.2. Fertilisers used

- The mineral fertilizer used is NPK compound fertilizer of the formulation 14-23-14+6S+1B and Urea with 46%.
- The organic manure used was cattle manure.

3.4.3.3. Experimental design and crops management

Two experimental fields in a randomized Fisher bloc design (Figure 14) with four treatments (Table 8) and five replications were carried out during two consecutive years (2021, 2022). The blocks, made up of groups of experimental units homogeneous, were carried out perpendicular to the slope. The treatments were composed of Ridge tillage as a control (RT), *Zaï* (Z), Stone Rows (SR), *Zaï* + Stone Rows (Z_SR). Stone rows are anti-erosion works consisting of a judicious arrangement of stones on contour lines. One line was built in each treatment. Each stone row was consisted of two rows of stones placed in a furrow. The upslope row of large stones were stabilized by the downslope row of small stones. Each stone row is about 0.2 to 0.3 m high. The *zaï* is 15 cm deep and has a diameter of about 20 cm. The treatments applied on sorghum and groundnut. The *zaï* pits and the stone rows have been implemented on June 2021. The organic manure was applied in the first year of the experiment at a dose of 5,000 kg. ha^{-1}. The same *zaï* pits were used in 2022. Sorghum was sown on 15 July 2021 and 24 June 2022 (Table 9) at 0.8 m x 0.4 m spacing and thinned at two plants per hill, i.e. 62,500 plants per hectare at a rate of 8 kg. ha^{-1}. Groundnut was sown on 30 July 2021 and 20 July 2022 at 0.6 m x 0.15 m spacing, i.e. 110,000 plants per hectare at a rate of 60 kg. ha^{-1}. The treatments were applied on plots of 20 m x 3.5 m size separated at intervals of 1 m x 10 m. The fertiliser NPKSB was applied 21 days after sowing (DAS) in microdose, i.e. 2 g/hole on sorghum and 0.57g/hole on groundnut. The supplementary urea (1 g/hole) was applied on day 45 after planting on sorghum only. Weeding were done manually. Sorghum harvesting was done 105 DAS in 2021 and 105 DAS in 2022. Groundnut harvesting was done 96 DAS in 2021 and 105 DAS in 2022.



RT: Ridge tillage; **Z**: *Zaï*; **SR**: Stone rows; **Z_SR** : *Zaï* associated with stone rows

Figure 14. Experimental design

Table 8. Treatments

N°	Codification	Composition
T0	**RT**	Control (ridge tillage)
T1	**Z**	**Z**aï
T2	**SR**	**S**tone **R**ows
T3	**Z + SR**	**Z**aï + **S**tone **R**ows

Table 9. Timetable of field activities and collection of soil samples

Activities	Sorghum		Groundnut	
	2021	2022	2021	2022
Delimitation of trial plots	22-30 May		22-30 May	
Soil sampling before sowing	15-June		15-June	
Digging of the *zaï* pits and building of the stone rows	22-29 June		22-29 June	
Arrangement of *zaï* pits and stone rows		01-20 June		01-20 June
Supply of organic matter	30-June		30-June	
Sowing	15-July	24-June	30-July	08-July
Re-sowing	22-July	08-July		20-July
1st weeding	03-August	07-July	18-August	20-July
Supply of fertilizer NPK	05-August	15-July	18-August	01-August
2nd weeding	24-August	22-July		15-August
Supply of fertilizer Urea	01-September	11-August		
Collect of groundnut nodules				10-September
3rd weeding	05-September	12-september		8-September
Ridging	01-September	12-August		
Harvest	01-November	20-October	6-November	22-October
Soil sampling after harvest	10-December	03-November	10-December	03-November

3.4.3.4. Field plants data collection

3.4.3.4.1. Sorghum

The heights (cm) and collar diameters (mm) of sorghum plants were measured on twenty plants from each elementary plot. Measurements were made using a graduated metal tape measure and a digital caliper. The measurement was carried out every fortnight on four replications, starting on day 35 after sowing. The overall growth (in height and diameter) was determined by the difference between the final mean values (of height or diameter) at 95 days after sowing and the initial mean values at 35 days after sowing.

3.4.3.4.2. Groundnut

Number of nodules, leaves, flowers, and branchs of groundnut plants were collected on the 60th day after sowing. To do this, in the row next to the two border rows, five plants were selected. Then, the number of leaves, the number of flowers and the number of branches of each plant were carefully counted and recorded. Subsequently, the plants were carefully uprooted with a pickaxe and the roots were washed on a sieve under a jet of water. The plants were placed on a paper towel in the shade to air dry. The nodules were then carefully detached from the roots by hand and dried for a fortnight in ambient air. The total number of nodules from the five plants was divided by 5 to obtain the number of nodules per plant and the corresponding weight was divided by 5 to obtain the dry weight of nodules per plant.

3.4.3.5. Assessment of yields

The sorghum (grain and straw) and groundnut (pod and straw) yields of a plot are the yields of all the plants in the useful plot (35.2 m² for sorghum and 44.1 m² for groundnut). The useful plot is obtained by eliminating two crop lines on each side of the elementary plot to avoid border effects. Grain, pod, haulm and straw yields are computed taking into account all sorghum and groundnut plants in the useful plot at harvest. Groundnut haulms and sorghum straws were weighed in the field. Aliquots of fresh biomass were taken and transported to the laboratory; they were weighed, air-dried for a fortnight and then reweighed to obtain the quantity of dry matter with a constant weight. This value was used as the basis for calculations to obtain the average yields in $t.ha^{-1}$ of groundnut and sorghum per treatment. The average yields per hectare of groundnut and sorghum were also determined. To determine the pod load, twenty plants were randomly selected from the harvested lot and their pods were detached, counted and the number recorded. This value was averaged over the twenty plants to obtain the pod load, which is defined as the average number of pods that have been produced by one plant. A precision scale determined the weights of one thousand sorghum grains and one hundred groundnut pods.

3.4.3.6. Field soil data collection

- **Soil moisture content**

From the fortieth day after sowing of sorghum and groundnut, surface moisture was measured using a portable moisture meter (IMKO Model HD2 probe moisture meter, Germany). Three moisture measurements were done in each elementary plot in the 0-20 cm soil layer. The measurements were made in five successive times, which are fourty DAS, fifty DAS, sixty DAS, seventy DAS, and eighty DAS.

- **Soil macrofauna**

It was realized 68 DAS in 2021 and 60 DAS in 2022 using Tropical Soil Biology and Fertility method (Ingram and Anderson, 1993) and modified. A metal frame measuring 25 cm x 25 cm x 30 cm is driven into the soil. A monolith is removed, broken up, crumbled and excavated by hand on a tarpaulin in order to collect the macrofauna, which is stored in flasks containing 75% alcohol. Five monoliths were sampled in each treatment. Forty monoliths were collected; twenty from the sorghum experimental plot and twenty from the groundnut experimental plot. The identification of the macrofauna was carried out at the Laboratoire d'Histoire Naturelle du Centre National de la Recherche Scientifique et Technologique (LHN/CNRST) in Burkina Faso. Macroinvertebrates were identified and counted under a binocular magnifying glass using reference books and dichotomous keys (Bouillon and Mathot, 1965; Chinery, 1981). After identification, the number of individuals in each group was recorded and their weights were done using precision electronic scale in the Laboratoire Sols, Materiaux et Environnement (SME) at Joseph KI-ZERBO University.

3.4.3.7. Soil sampling

Both during and at the end of the conducting of the experiments, composite soil samples were collected for laboratory analyses and to assess the influence of the treatments on soil. Soil sampling was carried out at each site in the study area during two periods, 2021 and 2022, during which topsoil samples from different plots were taken to a depth of 0-10 cm and 10-20 cm using the soil auger. The samples were taken with three repetitions on each plot. The 3 equiponderate elementary samples per plot were taken to constitute one composite sample. Forty soil samples were collected annually on the 60^{th} DAS for the measurement of CO_2 release. Sixty soil samples were collected in the second year of the experiment after harvests for the analysis of chemical properties. In total, 140 composite soil samples were taken into account for the database in 2021 and 2022 across the study area. The scheme for sampling pre-sowing and post-harvest soils per unit plot is shown in Figure 15.

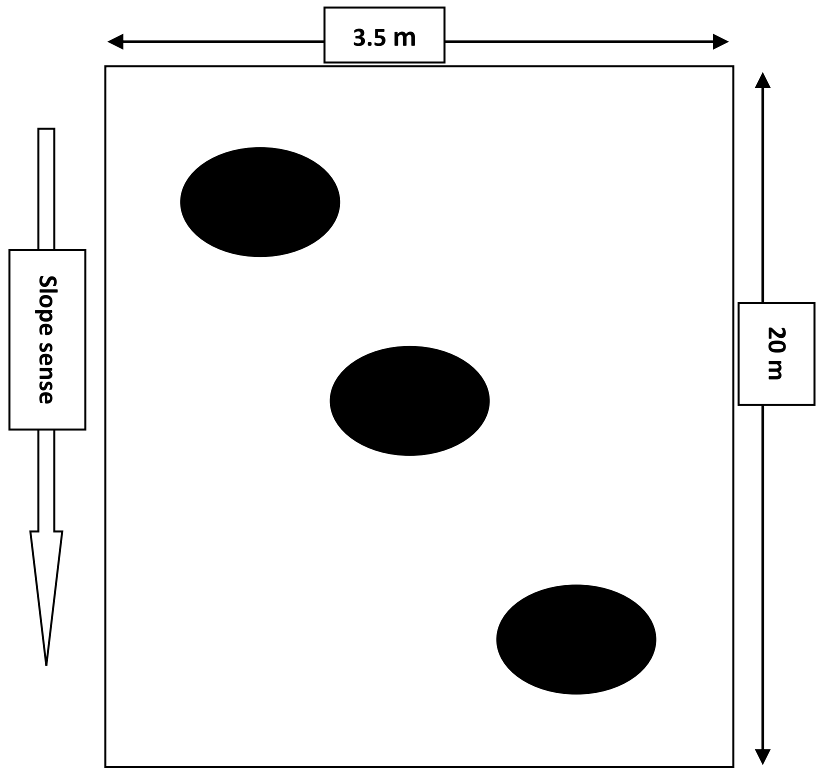


Figure 15. Method of sampling soil for laboratory analysis

3.4.3.8. Soil sample preparation and laboratory analysis

The samples were dried in ambient air. Then, they were sieved to 2 mm. Following this, the fine fractions and rejects (mineral and organic) were weighed separately to determine the gravelly load in the soil layers collected. Finally, a 150 g aliquot of the fine soil from each soil sample was taken, packed in suitable bags, and labeled for analysis in the laboratories of the BUNASOLS (Bureau National des Sols) and IRD (Institut de Recherche pour le Developpement). Analysis concerned the physico-chemical and biological parameters (Sand, Silt and Clay content, pH, total organic carbon, total nitrogen, available phosphorus, exchangeable Ca, K, Mg and Na, CEC, Base saturation, respiration).

- ***Soil Texture*** was determined through the study of the granulometric fractions (3 fractions) which was determined by the international Robinson pipette method after destruction of soil organic matter with hydrogen peroxide (H_2O_2). These fractions are: clay ($ø < 2$ µ), silts (2 µ $< ø <$ 50 µ), sands (50 µ $< ø <$ 2000 µ).

- ***Soil pH*** was measured with a glass electrode using a 1:2.5 soil to water ratio by (AFNOR, 1981) method.

- ***Soil organic carbon*** (SOC) was determined by (WALKLEY and BLACK, 1934) method. The organic carbon is oxidized in concentrated sulphuric solution by excess potassium dichromate. The excess of unreduced dichromate is determined by Mohr's salt $Fe(S0_4)_2(NH)_2$ in the use of colour indicator.

- ***Soil total nitrogen*** (N) was determined by Kjeldahl method taken back by (Novozamsky et al., 1983). This is an attack on organic matter by concentrated sulphuric acid in the presence of selenium as a catalyst. The organic nitrogen is mineralized and converted to the ammoniacal state as ammonium sulphate $(NH_4)_2SO_4$. Nitrate and nitric are not converted. The ammoniacal nitrogen thus obtained is determined by automatic colorimetry with SKALAR, the principle of which is based on the modified Berthelot reaction: ammonium is chlorinated to ammonium chloride which reacts with salicylate to form 5-amminosalycilate. After coupling oxidation, a green complex is formed, the absorbance of which is measured at 660 nm.

- ***Soil available phosphorus*** was measured by Bray I method (Bray and Kurtz, 1945). The phosphorus is extracted with a mixed solution of ammonium fluoride (0.03M) and hydrochloric acid (0.025M). This solution allowed the extraction of acid-soluble phosphorus, a large fraction of the phosphorus bound to calcium, a portion bound to aluminum and iron.

- ***Soil cation exchange capacity (CEC) and exchangeable cations.*** The principle is based on the extraction of exchangeable bases from the soil sample with silver thiourea acid (AgTu) at a concentration of 0.1 M silver thiourea acid (AgTu) with a concentration of 0.1 M $(Ag\ H_2\ NCS\ NH_2)_2^+$. AgTu saturates the complex, also displacing in solution the exchangeable cations (Ca_2^+; Mg_2^+; Na^+; K^+) which are determined in atomic absorption at 422.7; 285.2; 589.0 and 759.9 nm respectively. The total cation exchange capacity (CEC) is calculated as the difference between the Ag+ content in a blank sample and its residual content in the extract of the analyzed sample. The measurement is carried out using atomic absorption at 328.1 nm. The determination of Ca_2^+ and Mg_2^+ in the filtrate is done with a Atomic

Absorption Spectrophotometer (AAS), while the determination of potassium and sodium in the filtrate is done with a The determination of potassium and sodium in the filtrate is done with a flame photometer. As for the CEC is the amount of silver measured in the filtrate.

- ***Soil respiration*** was made by using an IRGA respirometer. It was measured to assess the potential of the biological activity of the soil. The measurement was carried out according to the following protocol: three soil samples are collected in each plot at 0-10 cm depth. For each plot, individual samples are mix to make composite sample. The soil samples were air dried and sieved to 2 mm. 2g of soil were placed in glass anticoagulant tubes (3 replicates), brought to optimum humidity, and then the tubes were sealed. They are then incubated in the in the dark at room temperature. After 2 hours of incubation, the first measurement of CO_2 release is carried out, then the tubes are returned to darkness. The second measurement was after 24 hours of incubation. The other measurements are carried out every 72 hours of incubation (twice) to 96 hours of incubation (twice) for 2 weeks.

3.4.4. Data analysis

The survey data were analyzed using quantitative methods involving rankings with the Statistical Package for Social Sciences software (SPSS) (version 26.0). We used a logistic regression to assess the factors that significantly influenced the decision of people to adopt soil and water conservation practices in our study area. The plants and soil data obtained were subjected to analysis of variance (ANOVA) using R software (version 4.2.1), and the means were separated with the least significant difference (LSD) approach at $p<0.05$. Correlation tests were used to assess the relationships (dependencies) between the two variables. Pearson's correlation coefficients were calculated for variables that follow a normal distribution. For variables that do not follow the normality rules, the correlation coefficients were calculated using the Spearman method. For the verification of normality, the Shapiro-normality test was used.

CHAPTER FOUR: RESULTS AND DISCUSSION

4.1. Results

4.1.1. Socio-economic drivers of indigenous soil and water conservation practices use to cope with climate change in the Plateau Central region

4.1.1.1. Socio-economic characteristics of respondents

The results of the analysis of the socio-economic characteristics are shown in Table 10 and Table 11. The parameters studied were gender, major activity, age, level of education, affiliation to organization, type of land tenure, size of the household, active members of the household, number total of equipment, number of small ruminants, number of big ruminants and types of big ruminants. The results showed that the main activity remained agriculture and the secondary activities included breeding, trade, market gardening as well as arts and crafts. The ages of farmers varied between 23 and 86 years, with an average of 50 years. The majority of farmers were between 41–60 years (54.81%). However, the ages of the farmers using the stone rows technique ranged from 40 to 59 years, representing 55.9% of all farmers. Most of the respondents are literate (57.78%) and are not members of a local organisation (53.33%). The average household size is 11 people with an average number of members of 6. The respondents have small and large ruminants at their disposal. They own cattle + donkeys (53.33%), cattle alone (11.11%) or donkeys (35.55%). Average number of small equipment per household is 3.

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Table 10. Gender, activity, age, education level, membership to organization, and land tenure of respondents.

Characteristic	Modalities	Value
Gender	Male	89.63% (121)
	Female	10.37% (14)
Major Activity	Agriculture	99.26% (134)
	Breeding	0.74% (1)
Secondary activity	Breeding	99.26% (134)
(more than one activity can be carry out by respondent)	Arts & crafts	2.22% (3)
	Trade	11.85% (16)
	Gold mining	0.74% (1)
	Market gardening	14.07(19)
	others	7.41% (10)
Age (Years)	20-40	25.92% (35)
	41-50	27.41% (37)
	51-60	27.41% (37)
	>60	19.26% (26)
Level of education	Illiterate	42.22% (57)
	Primary school	6.67% (9)
	Secondary school	2.96% (4)
	No formal education	48.15% (65)
Affiliation to organization	Yes	46.67% (63)
	No	53.33% (72)
Type of land tenure	Landowner	87.41% (118)
(more than one answer is possible)	Loaning	17.04% (23)
	Acquisition	1.48% (2)
	Donation	5.92% (8)

Table 11. Economic characteristics of respondents.

Characteristic	Modalities	Value
Size of the household	Average	11
	Minimum	3
	Maximum	25
Active members of the household	Average	6
	Minimum	2
	Maximum	18
Number total of equipment	Average	3
	Minimum	1
	Maximum	8
Number of small ruminants	Average	11
	Minimum	0
	Maximum	55
Number of big ruminants	Average	3
	Minimum	1
	Maximum	14
Composition big ruminants	Donkey & bovine	53.33% (72)
	Donkey	35.55% (48)
	Bovine	11.11% (15)

4.1.1.2. Agro-pedological characteristics

Table 12 shows that crops' yields are decreasing (59.3%). Drought and low fertility of soil are the most important causes of crops' yields dynamics. Sorghum (98.5%) and cowpea (97.8%) were mostly cultivated, followed by pearl millet and groundnut. Local seeds are largely used. Farmers growing cereals mostly used stone rows and ridge tillage practices. In legumes cultivation, ridge tillage was mostly used (88.37% in Cowpea). Straws, panicle and seed shells are used in breeding like fodder, in composting, selling and household energy.

Table 12. Agro-pedological characteristics given by respondents.

Characteristic	Sorghum	Pearl millet	Cowpea	Groundnut
Sorghum and pearl millet yields dynamics	Yields increase (11.9%), yields decline (59.3%), mixed evolution (28.9%)			
Causes of lower yields of sorghum and millet	Drought (77.8%), low fertility of soil (58.5%), less technical (13.3%), pest damage (11.9%), flooding (11.1%), winds (8.9%)			
Crop grown	Yes= 133 (98.5%) No= 2 (1.5%)	Yes= 96 (71.1%) No= 39 (28.9%)	Yes= 133 (97.8%) No= 2 (2.2%)	Yes= 83 (61.5%) No= 52 (38.5%)
Crop area	Mean=1.86, median=2, min=0.5, max=6.	Mean=0.89, median=0.50, min=0.2, max=4.	Mean=0.60, median=0.50, min=0.12, max=2.	Mean=0.48, median=0.50, min=0.1, max=3.
Crop seed nature	Local (89.5%), improved (38.35%)	Local (90.63%), improved (11.46%)	Local (71.97%), improved (56.06%)	Local (95.12%), improved (7.32%)
SWCP in crop farm	*Zaï* (39.85%), SR (78.95%), RT (86.47%), *Zaï* _SR (16.54%), Half-moon (6.01%), Mulching (4.51%), SR_RT (55.64%)	*Zaï* (9.38%), SR (61.46%), RT (91.67%), *Zaï* _SR (1.04%), Mulching (3.13%)	*Zaï* (3.03%), SR (43.94%), RT (88.37%), SR_RT (32.58%),	SR (20%), SR_FP (3.75%), SR_RT (18.75%)
Straw use	Mulching (3.76%), Composting (55.64%), Household energy (51.13%), Fodder (94.74%), Selling (9.92%), Potash fabrication	Mulching (3.16%), Composting (55.79%), Household energy (47.37%), Fodder	Composting (5.38%), Fodder (98.46%), Selling (37.69%), Others (1.50%)	Fodder (92.50%), Selling (58.23%)

	(39.77%), Others (2.04%)	(93.68%), Selling (5.32%), Potash fabrication (14.91%), Others (3.51%)		
Panicle/rachis/ seed shell/ use	Composting (42.10%), Fodder (88.72%), Others (2.27%)	Composting (93.68%), Others (36.36%)	Composting (9.23%), Fodder (95.38%), Selling (39.23%)	Composting (30%), Fodder (13.75%), Others (31.07%)

NB: Totals exceeding 100% are explained by the fact that some questions are multiple choice and respondents can choose more than one answer.

4.1.1.3. Environment and soil management situation

The results presented in Table 13 show that soil and vegetation were degraded, and the number of wilds animals was diminished. Soil fertility was low. To cope with the situation, respondents suggested to use *zaï* (67.91%), stone rows (84.33%), assisted natural regeneration (63.43%), and mulching (35.82%). According to the respondents, the best technique to cope with water erosion was stone rows (84.44%) followed by assisted natural regeneration (11.11%). The most difficult techniques for respondents to practice were the stone rows (79.51%) followed by the *zaï* (18.03%). Drought (91.85%), flooding (39.26%), locust attacks (29.63%) and strong winds (26.67%) were disaster risks. These disasters led to a decrease in crops productivity, and to solve it, the respondents suggested techniques such as stone rows (77.04%), *zaï* pits (65.93%), traditional and religious ritual (61.19%), assisted natural regeneration (57.04%), forecast monitoring (34.81%), and *zaï* pits associate to stone rows (20.74%) (Table 14). Furthermore, according to the respondents, the soils in our study area are low in fertility (77.04%). The major causes are climate change, non-use of organic fertiliser, non-compliance with technical services advice, deforestation and aggregate collection (Figure 16).

Table 13. Environment status and soil management propositions by farmers.

Characteristic	Modalities	Value
Land status	Degraded	77.78% (105)
	Improved	22.22% (30)
Vegetation status	Degraded	79.26 (107)
	Improved	20.74 (28)
Wild animals status	Diminished	80% (108)
	Increased	20% (27)
Level of soil fertility	No fertile	77.04% (104)
	Fertile	22.96% (31)
SWCPs to use and cope with that situation **(Several answers are possible)**	*Zaï* (Z)	67.41% (91)
	Stone rows (SR)	83.70% (113)
	Natural assisted regeneration (NAR)	62.96% (85)
	Mulching	35.56% (48)
	Half-moon	8.89% (12)
	Others	30.37% (41)
Best technique to protect the soil from water erosion	SR	76.30% (103)
	Z	11.11% (15)
	NAR	10.37% (14)
	SR_NAR	4.44% (6)
	Grass Strips	5.18% (7)
	Others	9.63% (13)
Technique difficult to implement	SR	71.85% (97)
	Zaï	16.30% (22)
	Others	11.85% (8)

Table 14. Risks disaster and their management by farmers.

Characteristic	Modalities	Value
Disaster risk (DR) **(several answers are possible)**	Drought	91.85% (124)
	Flooding	39.26% (53)
	Locust attacks	29.63% (40)
	Strong winds	26.67% (36)
DR effect on crops production	Decrease	99.26% (134)
	Increase	0.74% (1)
SWCPs to use and cope with DR **(several answers are possible)**	SR	77.04% (104)
	Zaï	65.93% (89)
	Half-moon	11.85% (16)
	NAR	57.04% (77)
	SR_*Zaï*	20.74% (28)
	Forcast monitoring	34.81% (47)
	Traditional & religious	60.74% (82)
	Others	14.07% (19)

Low soil fertility is due to (a) climate change (climate variability), (b) soil erosion, (c) wood cutting, (d) use of pesticides, (e) poor fertilization, (f) long-term monoculture, (g) non-use of organic fertilizer, (h) failure to follow the advice of the extension services, (i) lack of rituals before the start of the season, (j) collection of aggregates for urbanization, (k) population growth, (l) failure to protect the bush and (m) failure to return crop residuesAccording to the respondents, the degradation of the soil, which translates into a drop in fertility, was attributable to factors such as (a) climate change (climate variability), (b) soil erosion, (c) wood cutting, (d) use of pesticides, (e) poor fertilization, (f) long-term monoculture, (g) non-use of organic fertilizer, (h) failure to follow the advice of the extension services, (i) lack of rituals before the start of the season, (j) collection of aggregates for urbanization, (k) population growth, (l) failure to protect the bush and (m) failure to return crop residues (Figure 15).

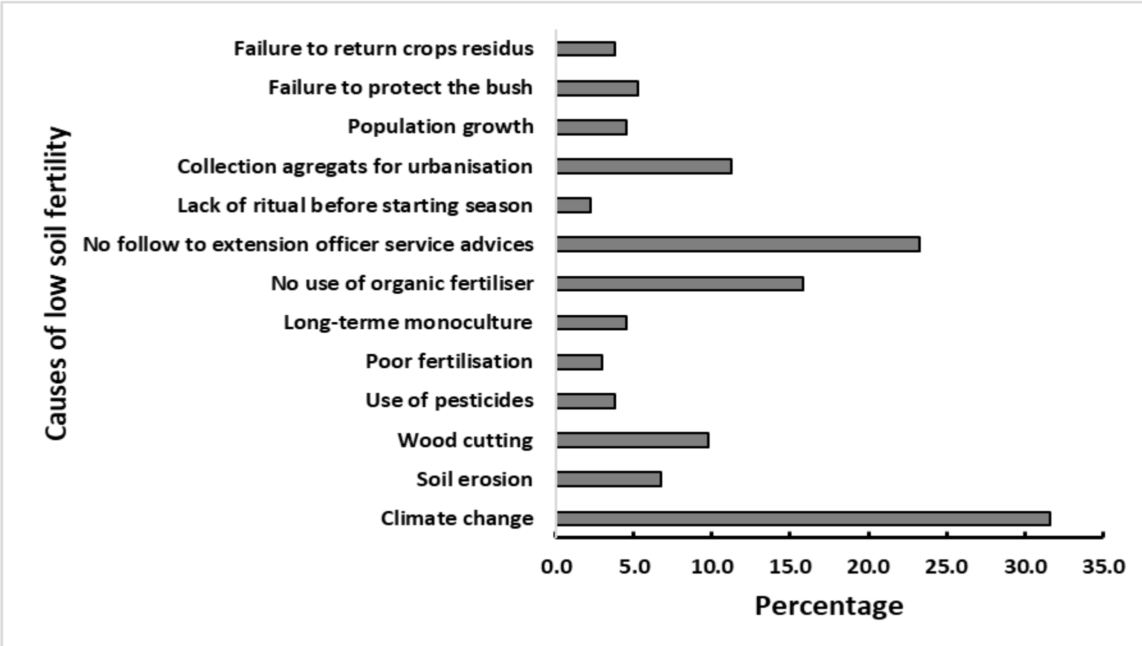

Figure 16. Major causes of low soil fertility

4.1.1.4. Determinants of the adoption of the zaï pits and stone rows practices

The estimated models were globally significant for zaï (Khi^2= 28.31; p= 0.002) and stone rows (Khi^2=20.85; p= 0.02). It could be concluded that the estimation results were efficient, as the overall prediction percentages are 66.70% for *zaï* and 81.50% for stone rows. On its part, the binary logistic regression analysis revealed that some variables significantly affect the decision to adopt soil and water conservation techniques in the study area. Thus, the variable affecting the adoption of stone rows was membership of a local organization (p=0.016). Indeed, belonging to a local organisation increases the probability that the farmer adopts the stone row technique by more than four times. As for the *zaï* technique, its adoption was significantly affected by the level of education (p=0.009), membership to a local organization (p=0.005), possession of cattle (p=0.038) and small trading (p=0.084). This means that the level of education, membership of a local organisation and ownership of cattle positively impact the rate of adoption of the *zaï* technique by 4%, 13% and 21% respectively. On the other hand, the practice of small trading negatively impacts the decision to practice *zaï*. Indeed, factors such as level of education, membership to a local organization and number of cattle significantly and positively influenced the decision to adopt *zaï* and stone rows techniques (Tables 15, 16). On the other hand, the practice of small trading in its forms reduced the probability of adoption of *zaï* technique.

Table 15. Binary logistic regression on the determinants of respondents of the adoption of stone rows practice.

Variable	B	S.E.	Wald	df	Sig.	Exp.(B)	95% C.I for Exp.(B)	
							Lower	Upper
Sex	-117	0.869	0.018	1	0.893	0.889	0.162	4.884
Age			4.018	3	0.259			
[20-40]	0.320	0.620	0.267	1	0.606	1.377	0.409	4.641
[41-50]	1.612	0.860	3.518	1	0.061*	5.015	0.930	27.044
[51-60]	-0.034	0.686	0.002	1	0.960	0.966	0.252	3.705
Education level	0.552	0.509	1.174	1	0.279	1.736	0.640	4.709
Membership in to local organisation	1.415	0.586	5.831	1	0.016**	4.117	1.305	12.986
Cattle	-0.087	0.124	0.497	1	0.481	0.917	0.719	1.168
Trading	1.642	1.168	1.977	1	0.160	5.166	0.524	50.962
Landownership			1.750	2	0.417			
Borrowing	0.579	1.133	0.261	1	0.610	1.783	0.194	16.427
Landowner & Borrowing	1.524	1.229	1.537	1	0.215	4.589	0.412	51.062
Constant	0.326	0.941	0.120	1	0.729	1.386		

*significant at 10%, **significant at 5% ***significant at 1%; Omnibus tests of model Coefficients: Chi-square = 20.851; df = 10; P = 0,022; -2log likelihood = 105.511; Cox et Snell R^2 = 0.143; Nagelkerke R^2 = 0.235; prediction overall percentage = 81.50 %.

Table 16. Binary logistic regression on the determinants of respondents of the adoption of *zaï* pits practice.

Variable	**B**	**S.E.**	**Wald**	**df**	**Sig.**	**Exp.(B)**	**95% C.I for Exp.(B)**	
							Lower	Upper
Sex	-0.868	0.687	1.596	1	0.206	0.420	0.109	1.614
Age			1.817	3	0.611			
[20-40]	-0.408	0.531	0.591	1	0.442	0.665	0.235	1.883
[41-50]	0.312	0.549	0.324	1	0.569	1.367	0.466	4.006
[51-60]	0.046	0.624	0.005	1	0.942	1.047	0.308	3.556
Education level	1.040	0.400	6.769	1	0.009***	2.829	1.292	6.194
Membership in to local organisation	1.139	0.409	7.769	1	0.005***	3.124	1.402	6.961
Cattle	0.214	0.103	4.288	1	0.038**	1.239	1.012	1.516
Trading (Yes)	-1.139	0.659	2.989	1	0.084*	0.320	0.088	1.164
Landownership			1.678	2	0.432			
Borrowing	-0.343	0.751	0.209	1	0.648	0.710	0.163	3.090
Landowner & Borrowing	-0.827	0.656	1.589	1	0.208	0.437	0.121	1.583
Constant	-0.088	0.776	0.013	1	0.910	0.916		

*significant at 10%, **significant at 5% ***significant at 1%; Omnibus Tests of Model Coefficients: Chi-square = 28.318; df = 10; P = 0,002; -2log likelihood = 156.685; Cox et Snell R^2 = 0.189; Nagelkerke R^2 = 0.254; prediction overall percentage = 66.70 %.

4.1.2. Results of the land assessment

Table 17 shows the quality of the soils and their diagnostic factors. The results of the matching of land qualities/characteristics with the requirements of the land use types (BUNASOLS, 1990) have made it possible to establish the cropping suitability for sorghum, pearl millet, maize, cowpea, sesame, and groundnut (Table 18). It is made in relation to the current state of the soil, with the hope that the removal of constraints will improve the suitability of the crops mentioned.

Table 17. Qualities and diagnostics factors per soil type

Qualities/Diagnostics factors / Soil Type	**Oxygen availability O_2 (w)**	**Rooting Conditions (r)**					**Flood Risk (i)**
	Drainage (FAO)	Useful deepth utile (cm)	Loading Gravelly (%)	Structure	Texture (FAO)	Consistency (FAO Class)	Length/frequency
indurated leached tropical ferruginous soil (Plinthosol epipetric)	Normal (4)	35	50-70	Weakly developped	SS	Soft	Null/absence
leached tropical ferruginous soil with stains and concretions (Lixisol Gleyic)	Moderate (3)	120	2-15	Weakly developped	SS-SSC	Crumbly to very firm	Short/occasional

Table 18. Soils suitability for Sorghum, Pear millet, Maize, Rice, Cowpea, Sesame

Crop / **Soil**	**Sorghum**	**Pear millet**	**Maize**	**Rice**	**Cowpea**	**Groundnut**	**Sesame**
indurated leached tropical ferruginous soil (Plinthosol epipetric)	Marginally suitable (S_{3nr})	Moderately suitable (S_2nr)	Marginally suitable (S_{3nr})	Permanently unsuitable (N_{2r})	Moderately suitable (S_2nr)	Moderately suitable (S_2nr)	Moderately suitable (S_2nr)
leached tropical ferruginous soil with stains and concretions (Lixisol Gleyic)	Marginally suitable (S_{3iw})	Marginally suitable (S_{3iw})	Marginally suitable (S_{3iw})	Moderately suitable (S_{2n})	Marginally suitable (S_{3iw})	Marginally suitable (S_{3iw})	Marginally suitable (S_{3iw})

4.1.3. Distribution of rainfall during experimentation

The rainy season mainly covers the months of June to September with an average rainfall of 729.98 mm for the last ten years (2011-2020) and is characterized by interannual variability. During the implementation of the experiment, total rainfall was 602.8 mm with 43 days in 2021 and 708 mm with 37 days in 2022 (Figure17a and 17b). The highest rainfall was recorded in August 2021 (231.8 mm) and September 2022 (291.5 mm). The rainfall recorded in both years is below the average of the previous decade. In 2022, the total rainfall was higher than 2021.

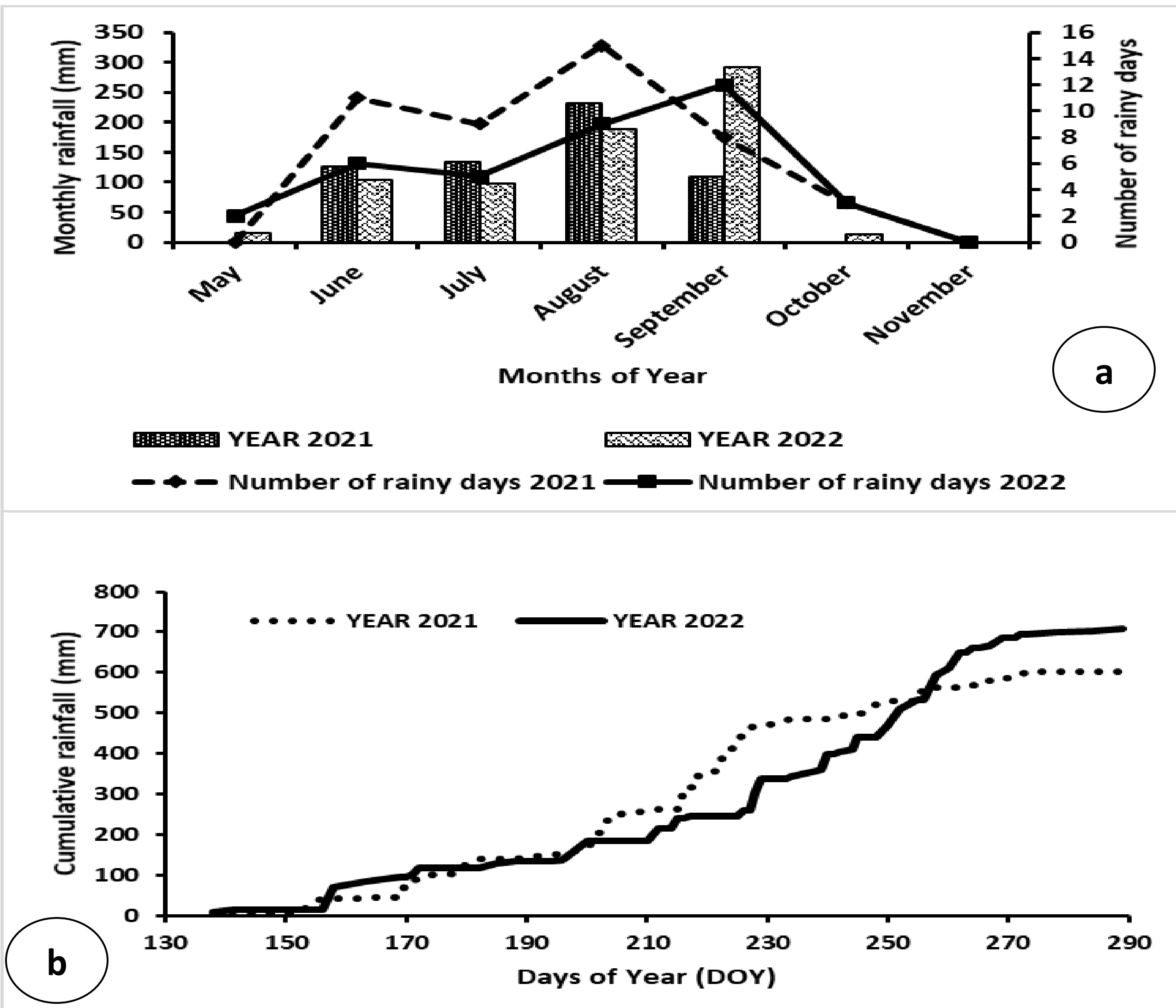

Figure 17. Rainfall distribution in 2021 and 2022: (**a**) montly rainfall and number of rainfall days; (**b**) total annual rainfall.

4.1.4. Characteristics of the soil experimental sites

Based on the descriptions of all the open soil profiles, two types of soil have been identified on the upper and lower slopes: indurated leached tropical ferruginous soils and leached tropical ferruginous soils with stains and concretions (Figure 18a and 18b). These soils belong to the class of soils with iron and/or manganese sesquioxides (CPCS, 1967). The indurated leached tropical ferruginous soil has a depth limited to 35 cm by a ferruginous shell. The colour is brown (10YR 5/3) when dry and dark yellowish brown (10YR 3/4) when wet down to 15 cm. The texture is silty-sandy from 0 to 15 cm and silty-clay-sandy from 15 to 35 cm. There is 50% ferruginous gravel on the useful 15 cm. The drainage is moderate. The structure is weakly developed with polyhedral and subangular aggregates. The consistency is soft on the surface and hard at depth. Roots are numerous. The soil has good porosity and biological activity is well developed. The variations around the profile concern the type of induration (plinthite or pétroplinthite), the level of appearance of the induration to a depth of less than 40 cm, the coarse element content varying between 50 and more than 70%. There are numerous spreades of gravel and ferruginous pebbles. The analysis reveals that this upper slope soil has a high organic matter (OM) content (2.674%), but is highly mineralized (C/N= 12). The cation exchange capacity (6.45 cmol+.kg^{-1}) and the sum of exchangeable bases (3.77 cmol+.kg^{-1}) are low with an average saturation rate of 58%. The soil has a high level of nitrogen (0.125%), and an average level of available potassium (80.90mg.Kg^{-1}), but low levels of available phosphorus (3.99 ppm). The soil is highly acidic (pH-H_2O=5.22) with a cumulative carbon dioxide release of 5670 ppm in 2021.

The soil at the sorghum site is 120 cm deep. The colour is yellowish brown (10 YR 5/6) when wet in the first 17 cm, and brownish yellow (10 YR 6/8) when wet over 17-43 cm. These soils are also reddish yellow (7.5 YR 6/8) when wet over 43-84 cm and dark brown (7.5 YR 5/6) in the last 84-120 cm. Dark brown oxidation stains (10 YR 5/8) are visible at depth (43-120 cm). Their rate varies between 10 and 15%. The texture is silty-sandy (Table 20) on the surface (17 cm), silty-sandy-clay (17-43 cm), and silty-clay (43-84 cm) at depth and clayey beyond (84-120 cm). We observed some iron gravel on the first 84 cm as well as iron and manganese concretions (15%) in the last 36 cm. Drainage is imperfect. The structure is weakly developed with subangular polyhedral aggregates throughout the profile. The consistency is friable to very firm from surface to depth. Roots are numerous in the surface horizons and few at depth. There are numerous pores at the surface and few at depth. Biological activity is well developed at the surface and poorly developed at depth. The organic matter (OM) content is low (0.32-0.77%) throughout the profile. The OM is highly mineralized (C/N= 9-11). The cation exchange capacity is low (4.86-6.45 $cmol^{+}.kg^{-1}$) (Table 19). The sum of exchangeable bases is low (2.87-3.77 $cmol^{+}.kg^{-1}$). The base saturation is relatively average (51-59%). The soil has a low level of nitrogen (0.02-0.04%), and low levels of available phosphorus (1.10-1.79 ppm). The soil is strongly to moderately acidic (4.87-5.8) with an average cumulative carbon dioxide release of 2676.67 ppm in 2021.

(a) Indurated leached tropical ferruginous soil under Groundnut

(b) Leached tropical ferruginous soil with stains and concretions under Sorghum

Figure 18. Soils profiles of the experimental sites

Table 19. Soil chemical properties of the experiments fields at Sandogo, in 2021

Location	**Upper slope**	**Lower slope**	**Lower slope**	**Lower slope**	**Lower slope**
Crop sowed	Groundnut		Sorghum		
Depth (cm)	0-15	0-17	17-43	43-84	84-120
pH (H_2O)	5.22	4.87	5.17	5.52	5.8
pH (KCl)	4.24	4.12	4.34	4.48	4.6
Total carbon (%)	1.551	0.449	0.303	0.296	0.184
Total nitrogen (%)	0.125	0.042	0.031	0.026	0.021
Total P (mg.kg^{-1})	1081,01	613.60	509.18	410.51	353.61
Available P (mg.kg^{-1})	3.99	1.79	1.86	1.24	1.10
Total K (mg.kg^{-1})	983	1257.15	1142.86	1051.43	868.57
Available (mg.kg^{-1})	80.90	113.86	66.92	149.81	141.82
Ca^{2+} (Cmol.kg^{-1})	0.60	2.50	1.60	1.46	1.08
Mg^{2+} (Cmol.kg^{-1})	0.29	0.86	0.81	0.71	0.53
K^+ (Cmol.kg^{-1})	0.17	0.26	0.55	0.77	0.89
Na^+ (Cmol.kg^{-1})	0.05	0.15	0.20	0.20	0.30
CEC (Cmol.kg^{-1})	9.45	6.45	6.18	5.33	4.86
SEB (Cmol.kg^{-1})	1.11	3.77	3.16	3.14	2.80
Soil saturation rate	12	58	51	59	58

Table 20. Soil Physical properties of the experiments fields at Sandogo, in 2021

Location	**Upper slope**	**Lower slope**			
Crop sowed	Groundnut	Sorghum			
Depth (cm)	0-15	0-17	17-43	43-84	84-120
Sand (%)	70.59	62.75	58.82	60.78	64.71
Clay (%)	15.69	27.45	29.41	28.43	25.49
Silt (%)	13.72	9.8	11.77	10.79	9.8
Textural class	LS	SCL	SCL	SCL	SCL
pF 2.5	18.81	22.31	25.78	23.58	20.98
pF 3.0	16.51	17.79	21.82	18.13	16.57
pF 4.2	8.02	10.13	14.14	13.21	12.83

LS=Loamy sand; **SCL**=Silty clay loam.

4.1.5. Effects of treatments on soils properties.

4.1.5.1. Effects of ridge tillage, stone rows, and *zaï* on soil chemical properties

Under sorghum, the results reveal three statistically different homogeneous groups. Z and Z_SR form the first group. The second group contains the SR treatment and RT represents the third group. Treatments significantly influenced total carbon ($p<0.0001$), total nitrogen ($p<0.0001$), and available phosphorus ($p<0.0001$) contents, and pH values ($p<0.0001$). The highest carbon, nitrogen and phosphorus contents and pH values were found in the *zaï* (C=0.572%, N=0.053%, P5.860 ppm, pH=5.77), and *zaï* + stone rows (C=0.580%, N=0.053%, P=5.980 ppm, pH=5.80) treatments followed by the stone rows (C=0.436%, N=0.045%, P=3.316 ppm, pH=5.51) treatment. On the other hand, the lowest nutrients content and pH values were observed in the ridge tillage (C=0.297%, N=0.033%, P=2.016 ppm, pH=5.25) treatment. The *Zaï* (Z), *Zaï* associated to stone rows (Z_SR) and Stone rows (SR) treatments significantly improved Carbon (C), Nitrogen (N), available phosphorus (P) and mean pH values of soils collected at harvest compared to the Ridge tillage (RT) treatment (Figure 19, 20).

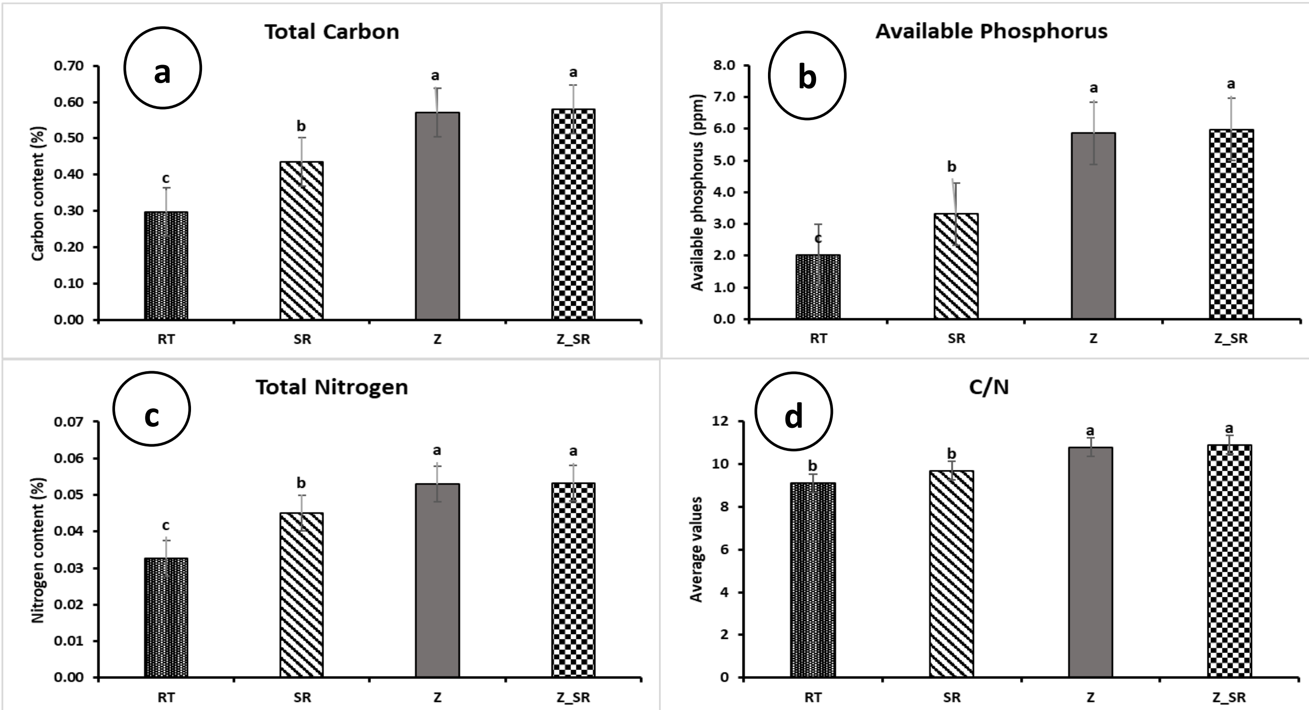

Figure 19. Effects of treatment C **(a)** , N **(c)**, P **(b)** content, and C/N **(d)** under Sorghum. (**RT** = Ridge tillage; **SR** = Stone rows; **Z** = *Zaï*; **Z_SR** = *Zaï* + Stone rows; The histograms correspond to the means; the means with same letter do not differ significantly at the 5% level; **n** = 5).

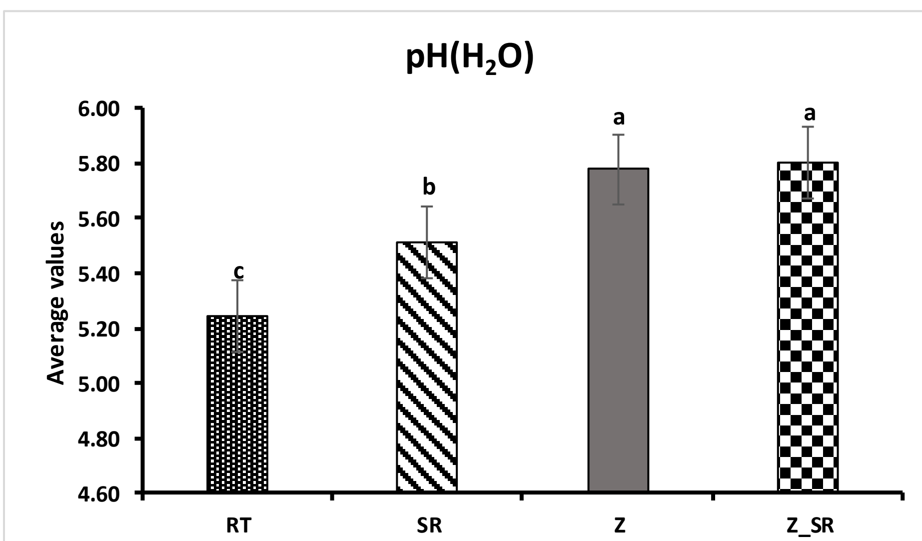

Figure 20. Effects of treatments on soil pH (average±standard error) under sorghum. (**RT** = Ridge tillage; **SR** = Stone rows; **Z** = *Zaï*; **Z_SR** = *Zaï* + Stone rows; the histograms correspond to the means; the means with same letter do not differ significantly at the 5% level; **n** = 5)

Under groundnut, the Z, Z_SR and SR treatments positively influenced C, N, P and pH values. Treatments significantly affected the variation in total carbon ($p<0.0001$), total nitrogen ($p<0.0001$) and available phosphorus ($p<0.0001$), and pH values ($p<0.0001$). The analysis of Variance (ANOVA) of the C, N, and P results shown three statistically different homogeneous groups: Z and Z_SR form the first group. The second group contains the SR and RT represents the third group. The ANOVA of pH results reveal two statistically different homogeneous groups. Z and Z_SR form the first group. The second group contains the SR and RT treatments.The highest C, N, P content, and pH values were recorded under the Z and Z_SR treatments, which form a homogeneous group. The lowest nutrients content and pH values were recorded with RT treatment (Figure 21, 22). However, C/N ratio was not influenced ($p=0.417$).

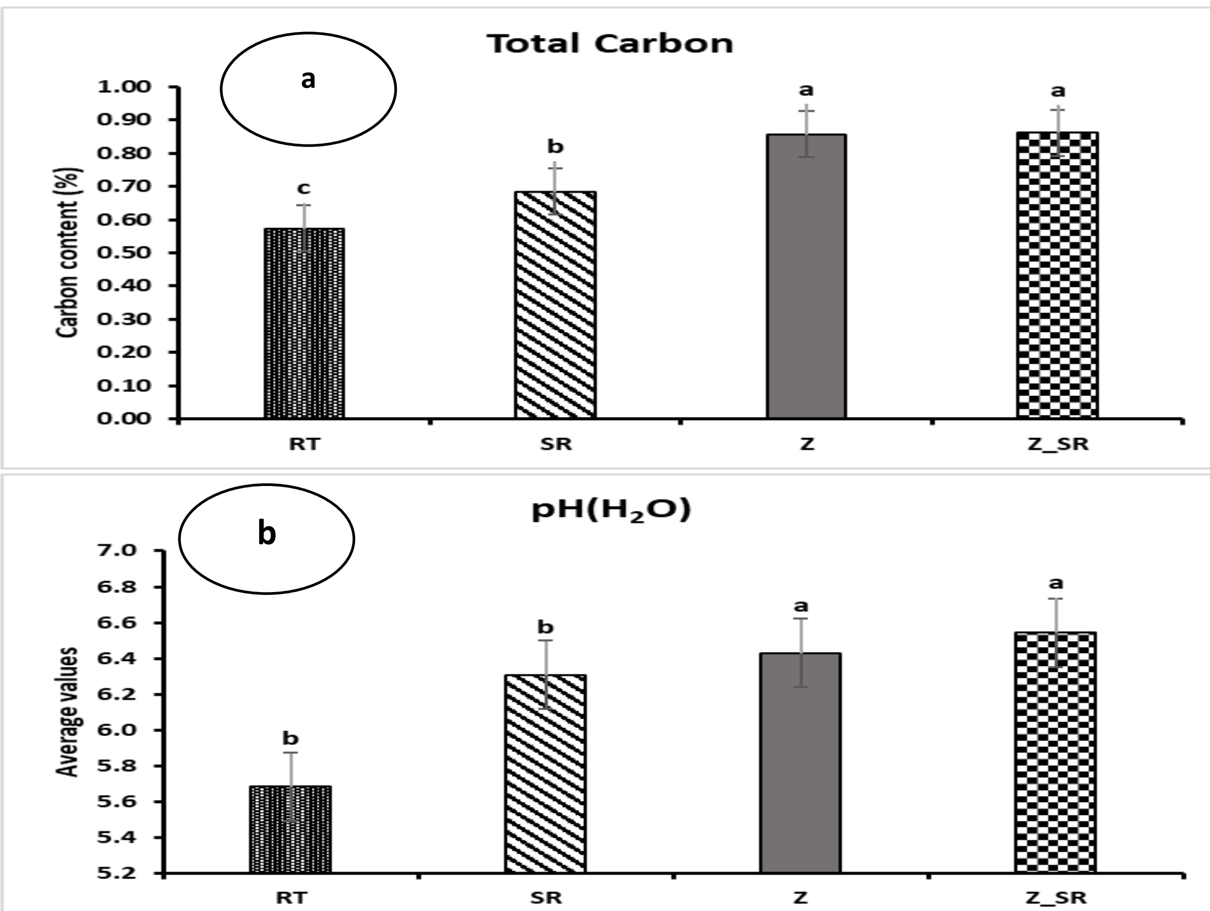

Figure 21. Effects of treatments on soil C **(a)** content, and pH value **(b)**, under Groundnut (**RT** = Ridge tillage; **SR** = Stone rows; **Z** = *Zaï*; **Z_SR** = *Zaï* + Stone rows; The histograms correspond to the means; the means with same letter do not differ significantly at the 5% level; n = 5)

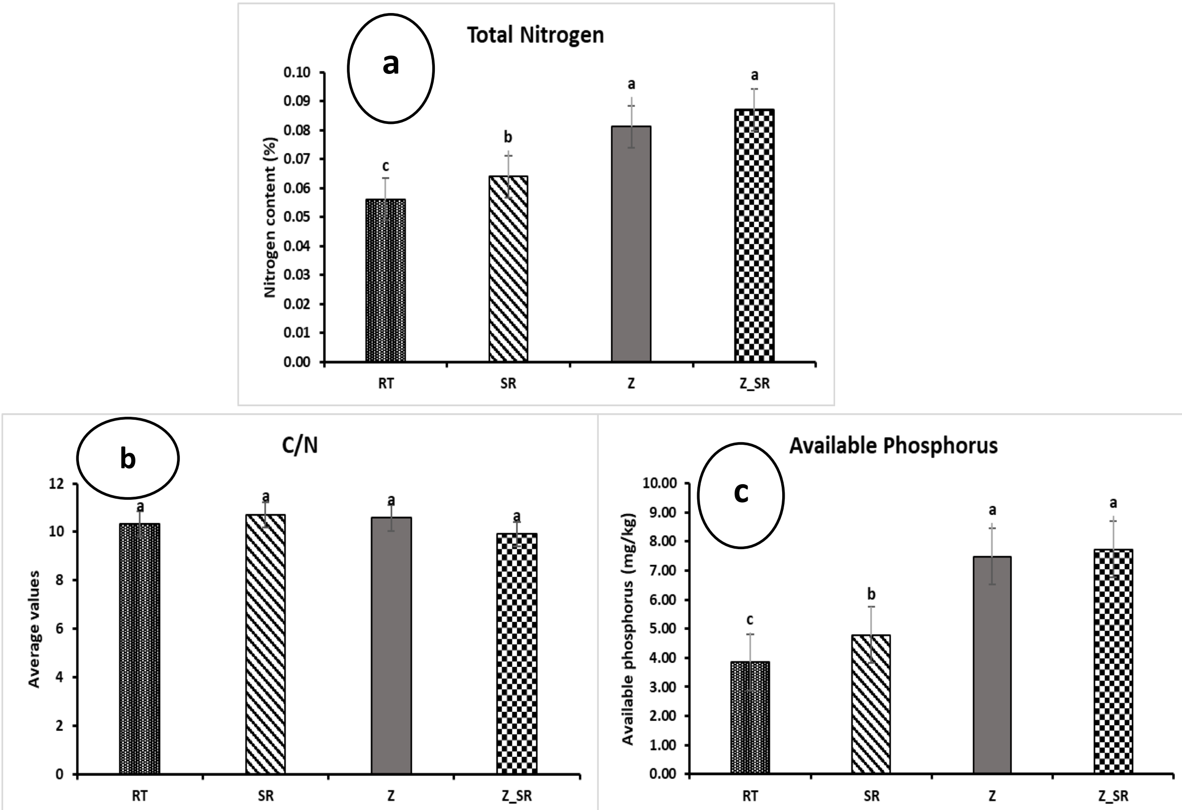

Figure 22. Effects of treatments on soil N **(a)** , C/N **(b)**, and P **(c)**, under Groundnut (**RT** = Ridge tillage; **SR** = Stone rows; **Z** = *Zaï*; **Z_SR** = *Zaï* + Stone rows; The histograms correspond to the means; the means with same letter do not differ significantly at the 5% level; n = 5)

4.1.5.2. Effects of *zaï*, stone rows, and ridge tillage on soil moisture content

Soil moisture content under groundnut (Figure 23) cultivation significantly varied along the treatments ($p<0.0001$). Moisture levels ranged from 22.47±1.12 to 26.93±1.36 on day 60, from 23.20±0.51 to 26.47±0.87 on day 70, and from 22.07±0.72 to 25.27±1.16 on day 80. The SR, Z, and Z_SR treatments significantly improved moisture content compared to the RT These improvements were +3.25% under SR, +15.40% under Z, and 19.85% under Z_SR on day 60 after sowing, -5.73% under SR, +14.96% under Z and +14.09% under Z_SR on day 70 after sowing, and -6.07% under SR, +12.37% under Z and +14.50% under Z_SR on day 80 after sowing. The *zaï* and *zaï* associated with stone rows had a greater impact on the variation of moisture levels in soil under Groundnut cultivation. The ridge tillage and stone row treatments recorded the lowest moisture content levels.

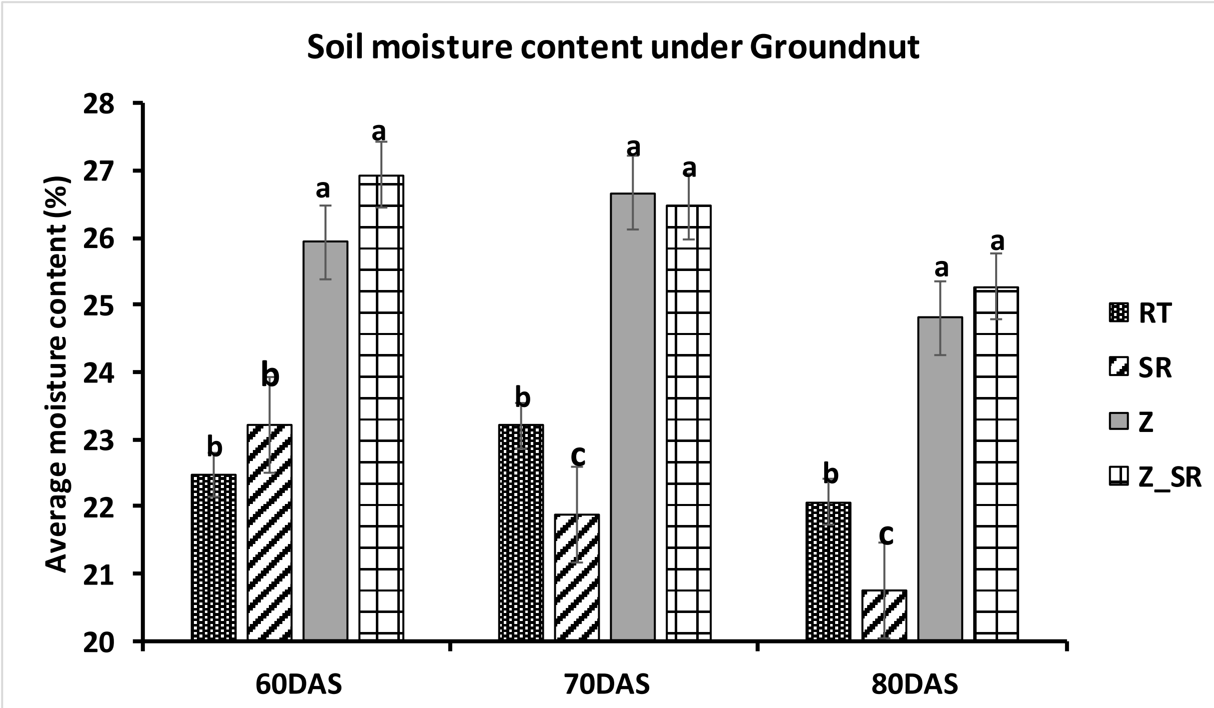

Figure 23. Soil moisture content varaiability under Groundnut cultivation. **(RT =** Ridge tillage; **SR =** Stone rows; **Z =** *Zaï*; **Z_SR =** *Zaï* + Stone rows; The histograms correspond to the means; the means with same letter do not differ significantly at the 5% level**; n =** 5**; DAS=** Days after sowing**)**

Under Sorghum cultivation (Figure 24), soil moisture content cultivation significantly varied along the treatments ($p<0.0001$). Moisture levels ranged from 33.67±1.94 to 41.60±1.55 on day 60, from 33.07±1.48 to 38.67±1.18 on day 70, and from 30.60±0.98 to 37.67±0.67 on day 80. The SR, Z, and Z_SR treatments significantly improved moisture content compared to the RT These improvements were +5.73% under SR, +22.16% under Z, and 23.55% under Z_SR on 60 DAS, + 0.39% under SR, +16.33% under Z and +16.93% under Z_SR on 70 DAS, and + 5.46% under SR, +23.10% under Z and +22.87% under Z_SR on 80 DAS. The *zaï* and *zaï* associated with stone rows had a greater impact on the variation of moisture levels in soil under Sorghum cultivation. The ridge tillage and stone row treatments recorded the lowest moisture content levels. Moisture contents varied downwards from 60 DAS to 80 DAS, but treatments including *zaï* always remained wetter than treatments consisting only of SR and RT.

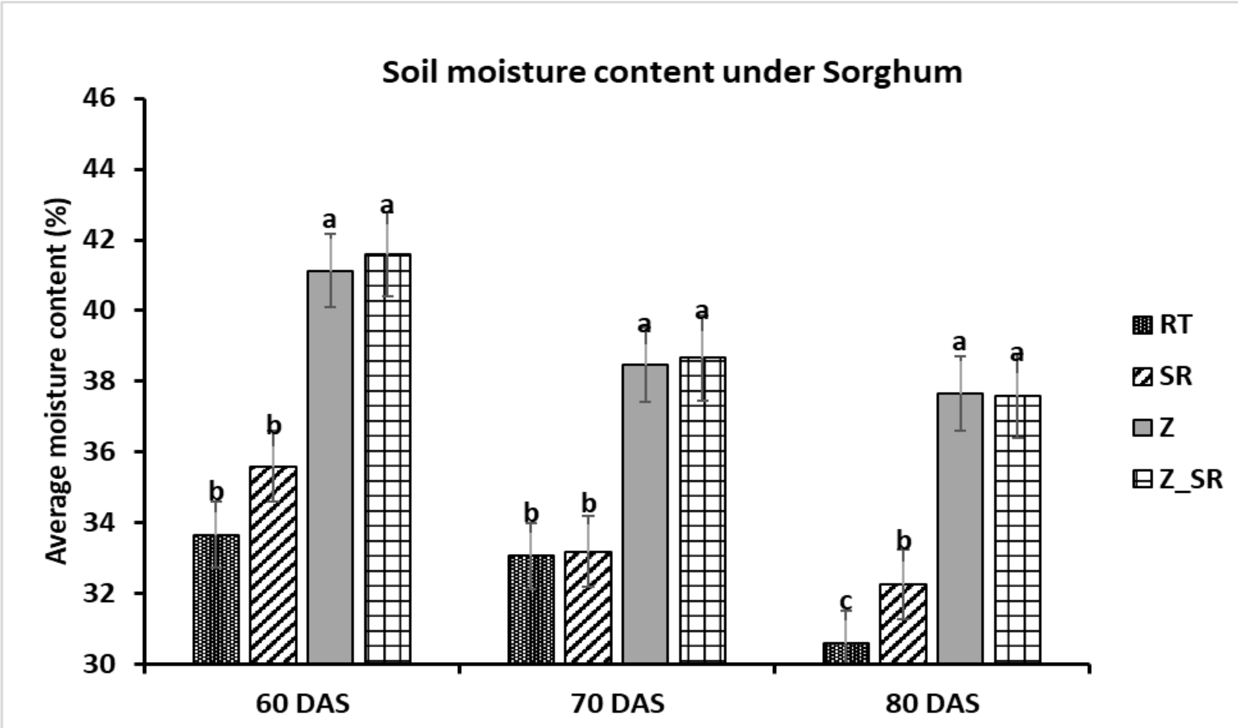

Figure 24. Soil moisture content (average±standard error) variability under sorghum (**RT** = Ridge tillage; **SR** = Stone rows; **Z** = *Zaï*; **Z_SR** = *Zaï* + Stone rows; The histograms correspond to the means; the means with same letter do not differ significantly at the 5% level; **n** = 5; **DAS**= Days after sowing)

4.1.5.3. Effects of stone rows and zaï on soil carbon dioxide release variability

Under Groundnut cultivation, analysis of variance reveals differences in cumulative CO_2 emissions in 2021 (P=0.0131). Two homogeneous groups are shown : the first group is formed by the soils under SR treatment (5203.33 ppm); the second group is formed by soils under RT (2620 ppm), Z (2752 ppm), and Z_SR (3307.33 ppm) treatments. The highest clearance was recorded in the stone rows soil (Table 21) and the ridge soil had the lowest cumulative CO_2 release. Thus, outside of the zaï pits, soil respiration does not differ from that of the ridges and stone rows. In 2022, the treatments did not show differences in influence of CO_2 release (P=0.76).

Under sorghum cultivation, the treatments significantly influenced the CO_2 release of the soils. Analysis of variance reveals two homogeneous groups with the SR treatment recording 4070 ppm and occupying the first group. The second group is made up of the RT, Z, and Z_SR treatments, which recorded 2965.3 ppm, 2978.7 ppm, and 2924 ppm respectively.

Table 21. Dynamic of soil carbon dioxide release under sorghum & groundnut

Treatment	**Sorghum (means± stdev)**		**Groundnut (means± stdev)**	
	2021	**2022**	**2021**	**2022**
RT	2965.3±83.32**b**	1819.47±55.94**b**	2620±319.56**b**	2352.00**a**
SR	4070±61.96**a**	2235.33±43.94**a**	5203.33±393.03**a**	2863.332**a**
Z	2978.7±45.62**b**	1829.33±25.97**b**	2752±245.82**b**	2826.00**a**
Z_SR	2924±69.58**b**	1804.67±17.73**b**	3087.33±205.80**b**	2720.00**a**
P-value	<0.0001	<0.0001	0.0131	0.76
Signification	***	***	*	NS

RT= Ridge tillage, **SR**= Stone rows, **Z**= *Zaï*, **Z_SR**= *Zaï* associated with Stone rows. **n**=5; **stdev =** standard deviation, means with the same letter are not significantly different at threshold 5%.

4.1.5.4. Effects of stone rows and zaï practices on soil macrofauna variability

The inventory carried out allowed the identification of forty-five (45) species under the four (4) treatments applied to groundnut. These identified species belong to twelve (12) orders and thirty-four (34) families. In both seasons, there was no significant difference in the number of macrofauna between the treatments. In 2021, the Shannon diversity index showed that RT and Z had the richest macrofauna community with IS = 1.3863 each. These treatments are followed by SR, Z_SR with IS values of 0.9404 and 0.6365 respectively. In 2022, the Shannon diversity index shows that the ridge tillage stimulated macrofauna richness (H'=2.8804). It is followed by *zaï* associated with stone rows (2.8704), stone rows (2.5943) and zaï with H'=2.4904 (Table 22).

Table 22. Shannon Diversity Index and Equitability Index of macrofauna under groundnut

Treatment	**RT**		**SR**		**Z**		**Z_SR**	
	2021	2022	2021	2022	2021	2022	2021	2022
H'	1.3863	2.8804	0.9404	2.5943	1.3863	2.4904	0.6365	2.8704
IE	0.5438	0.6000	0.2714	0.5434	0.5438	0.5278	0.2814	0.5886

H'= Shannon diversity index, **IE**= Equitability index, **RT**= Ridge tillage, **SR**= Stone rows, **Z**= *Zaï*, **Z_SR**= *Zaï* associated with stone rows.

Under sorghum cultivation, the inventory carried out revealed forty-two (42) species belonging to ten (10) orders and twenty-two (22) families. In 2021, the Shannon diversity index showed that Z had the richest macrofauna community with IS = 2.0059. This treatment was followed by the SR, RT, Z_SR treatments with IS values of 1.9587, 1.7591, and 1.7507 respectively (Table 23). In 2022, RT had more macrofauna diversity with IS = 2.3706. It was followed by the Z_SR, Z, and SR treatments with values of 2.2489, 2.0802, and 2.0146 respectively.Insects are represented by four (04) orders: Isoptera, Hymenoptera, Coleoptera, and Hemiptera. Three (03) species of earthworms belonging to the order Haplotaxida, family Octochaetidae (*Dichogaster affinis*), Acantthodrilidae (*Milsonia inermis*), and Lumbricidae (*Lumbricus terrestris*) were found.

Table 23. Shannon Diversity Index and Equitability Index of macrofauna under Sorghum

Treatment	RT		SR		Z		Z_SR	
	2021	2022	2021	2022	2021	2022	2021	2022
H'	1.7591	2.3706	1.9587	2.0146	2.0059	2.0802	1.7507	2.2489
IE	0.3883	0.3536	0.4769	0.3713	0.4073	0.3703	0.3436	0.2712

H'= Shannon diversity index, **IE**= Equitability index, **RT**= Ridge tillage, **SR**= Stone rows, **Z**= *Zaï*, **Z_SR**= *Zaï* associated with stone rows.

4.1.5.5. Effects on termites, ants, and earthworms

On the groundnut experimental site, three (3) species of termites were recorded (Table 24). These are the following species: *Microtermes upembae*, *Odontotermes mukimbunginis* and *Macrotermes sp.* These termites were essentially mushroom termites and were recorded on soils under the stone rows treatment.

Table 24. Species and number of termites in groundnut experimental site

Treatment	Species	Number/m² ± stdev	
		2021	**2022**
SR	*Microtermes upembae*	22±3.13	
	Odontotermes mukimbunginis	3±0.45	
	Macrotermes sp.		12.8±1.79
RT	-		
Z	-		
Z_SR	-		

RT= Ridge tillage, **SR**= Stone rows, **Z**= *Zaï*, **Z_SR**= *Zaï* associated with stone rows, **stdev** = standard deviation

Likewise, three (3) species of ants were recorded (Table 25). Theses species are: *Pogonomyrmex sp.*, *Monomorium pharaonis*, and *Camponotus pennsylvanicus.* The Tramp ants (*Monomorium pharaonis*) remained the most numerous.

Table 25. Species and number of ants in groundnut experimental site

Treatment	Species	Number/m² ± stdev	
		2021	2022
RT	*Monomorium pharaonis*		13±1.79
SR	*Monomorium pharaonis*		10±1.34
Z	*Monomorium pharaonis*		3±0.45
	Pogonomyrmex sp.		3±0.45
SR_Z	*Monomorium pharaonis*	6±0.89	19±2.17
	Camponotus pennsylvanicus		3±0.45

RT= Ridge tillage, **SR**= Stone rows, **Z**= *Zaï*, **Z_SR**= *Zaï* associated with stone rows **stdev** = standard deviation

On the sorghum experimental site, during the two years of testing, twelve (12) species of termites were recorded (Table 26). These species were as follows: *Acanthotermes acanthothorax*, *Cubitermes sp.*, *Macrotermes bellicosus*, *Macrotermes sp.*, *Microtermes sp*, *Microtermes upembae*, *Odontotermes fuller*, *Odontotermes garambae*, *Odontotermes mukimbunginis*, *Odontotermes sp.*, *Odontotermes syostedti*, and *Trinervitermes sp*. In 2021, the RT and Z_SR treatments recorded the highest number of termites. *Microtermes upembae*, and *Microtermes sp.* are the most encountered species. In 2022, the RT and SR treatments had more termites than the Z and Z_SR. *Microtermes upembae*, *Macrotermes sp*, and *Microtermes sp* were the most encountered with a total of 227, 99, and 38 respectively.

Table 26. Species and number of termites in Sorghum experimental site

Treatment	Species	Number/m² ± stdev	
		2021	2022
RT	*Microtermes upembae*	38±2.88	26±3.05
	Odontotermes fulleri	6±0.55	
	Macrotermes sp.		67±9.39
	Cubitermes sp.		10±1.34
	Macrotermes bellicosus		6±0.89
	Acanthotermes acanthothorax		6±0.89
	Microtermes sp.		38±5.37
	Odontotermes mukimbunginis		3±0.45

SR	*Microtermes upembae*	19±2.17	74±6.31
	Odontotermes fulleri	6±0.89	
	Macrotermes sp.		32±3.46
	Odontotermes syostedti		10±1.34
Z	*Microtermes upembae*	3±0.45	64±4.24
	Odontotermes mukinbunginis		10±0.89
	Odontotermes garambae		3±0.45
Z_SR	*Microtermes upembae*	3±0.45	64±4.06
	Microtermes sp.	32±4.47	
	Odontotermes garambae	13±1.79	10±1.34
	Odontotermes sp.	10±1.34	
	Trinervitermes sp.		13±1.79

RT= Ridge tillage, **SR**= Stone rows, **Z**= *Zaï*, **Z_SR**= *Zaï* associated with stone rows, **stdev** = standard deviation.

As for ants, eight (8) species were inventoried. These are the following: *Camponotus pennsylvanicus, Camponotus sp., Camponotus vagus, Formica rufa, Messor barbarous, Messor galla, Monomorium pharaonis*, and *Pogonomyrmex sp.*. In 2021, RT and Z_SR treatments recorded a many ants. In 2022, Z and Z_SR recorded more ants than RT and SR. *Camponotus pennsylvanicus, Monomorium pharaonis. Pogonomyrmex sp.*, and *Camponotus sp* were the highest number of encountered with total values of 109, 99, 64, and 42 respectively (Table 27).

Table 27. Species and number of ants in Sorghum experimental site

Treatment	**Species**	**Number/m^2 ±** stdev	
		2021	**2022**
RT	*Formica rufa*	3±0.45	
	Camponotus vagus	19±2.68	
	Messor galla		3±0.45
	Monomorium pharaonis		35±4.92
	Camponotus sp.		19±1.30
SR	*Pogonomyrmex sp.*		13±1.79
	Camponotus sp.		22±3.13
	Monomorium pharaonis		3±0.45

	Camponotus pennsylvanicus		3±0.45
Z	*Messor barbarus*	3±0.45	
	Monomorium pharaonis		13±1.30
	Pogonomyrmex sp.		29±4.02
	Camponotus pennsylvanicus		67±6.94
Z_SR	*Monomorium pharaonis*	6±0.89	42±3.71
	Pogonomyrmex sp.		22±3.13
	Camponotus pennsylvanicus		38±3.29

RT= Ridge tillage, **SR**= Stone rows, **Z**= *Zaï*, **Z_SR**= *Zaï* associated with stone rows, **stdev** = standard deviation.

Concerning earthworms, only three (3) species were inventoried (Table 28). These are the species *Dichogaster affinis*, *Milsonia inermis*, and *Lumbricus terrestris*. In 2021, the SR, Z, and Z_SR treatments recorded earthworms with identical numbers. In 2022, the SR and Z treatments stimulated the development of a large number of earthworms. The species *Dichogaster affinis* and *Milsonia inermis* were the most encountered with total values of 128 and 54 respectively.

Table 28. Species and number of earthwormss in Sorghum experimental site

Treatment	**Species**	**Number/m^2** ± stdev	
		2021	**2022**
RT	*Dichogaster affinis*		16±1.00
	Milsonia inermis		3±0.45
SR	*Lumbricus terrestris*	3±0.45	
	Dichogaster affinis		48±3.46
Z	*Lumbricus terrestris*	3±0.45	
	Dichogaster affinis		48±3.32
	Milsonia inermis		51±7.16
Z_SR	*Lumbricus terrestris*	3±0.45	
	Dichogaster affinis		16±1.22

RT= Ridge tillage, **SR**= Stone rows, **Z**= *Zaï*, **Z_SR**= *Zaï* associated with stone rows, **stdev** = standard deviation.

4.1.6. Soil chemical properties, and yields variabilities of groundnut and sorghum

Analysis of the correlations showed a positive correlation (Figure 27) between groundnut yields (pods, straw, 100-pods, pods/pit, and nodules) and soil chemical parameters (organic carbon, total nitrogen, available phosphorus, pH). In addition, Sorghum yields were strongly correlated to soil chemical parameters (organic carbon, total nitrogen, available phosphorus, pH). Indeed, Figures 25 and 26 show that the higher carbon, nitrogen and available phosphorus contents as well as the pH value, influence the higher yields of groundnut and sorghum. However, these results show a non-significant dependence between pod weight per pit and pH value (rho==0.38, p= 0.0746). The Z and Z_SR treatments recorded higher carbon, nitrogen and phosphorus contents and pH values than the RT and SR treatments. This resulted in higher grain and straw yields for sorghum. Principal component analysis also revealed this association between yields and soil chemical properties as influenced by the treatments. Thus, grain yields, carbon content, assimilable phosphorus content, RT, Z and Z_SR treatments are highly correlated (correlations of 0.96, 0.95, 0.96, 0.99, 0.98, 0.99 respectively) under sorghum production. Under groundnut production, PCA results also confirmed this strong association between Pod Yields, Haulm Yields, Carbon, Phosphorus, RT, Z, and Z_SR (correlations of 0.91, 0.92, 0.96, 0.97, 0.98, 0.99 respectively). However, for both sorghum and groundnut, the correlation between soil chemistry, yields, and RT treatment was negative. The RT treatment is therefore not able to increase the nutrient content necessary to boost crop yields.

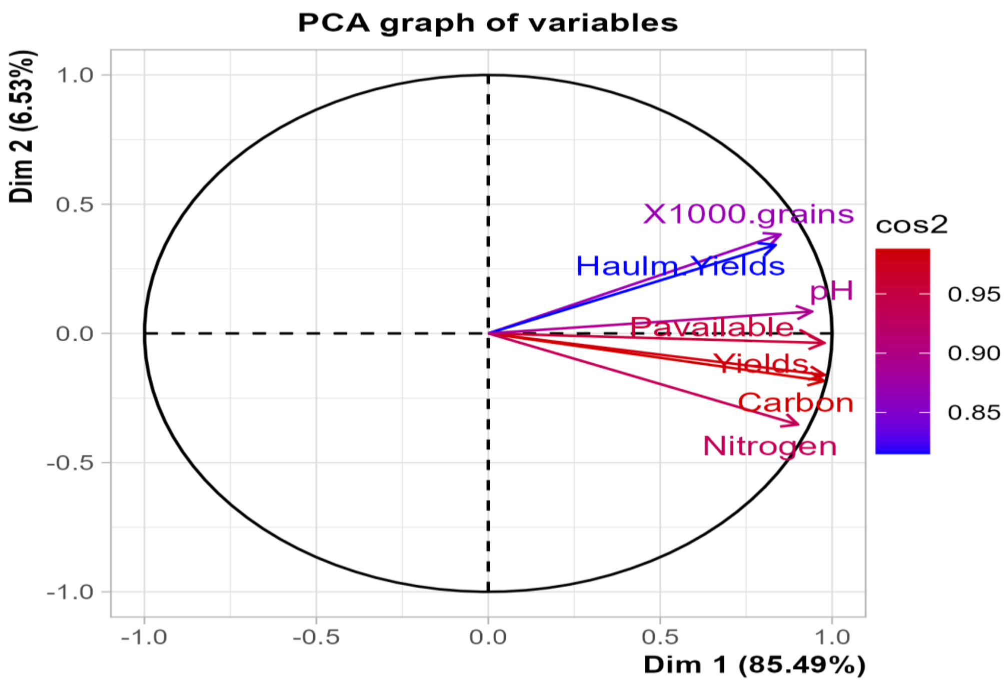

Figure 25. Ranking of soil parameters and sorghum yield characteristics. The first axis represents 85.49% and the second axis 6.53% of the total variance

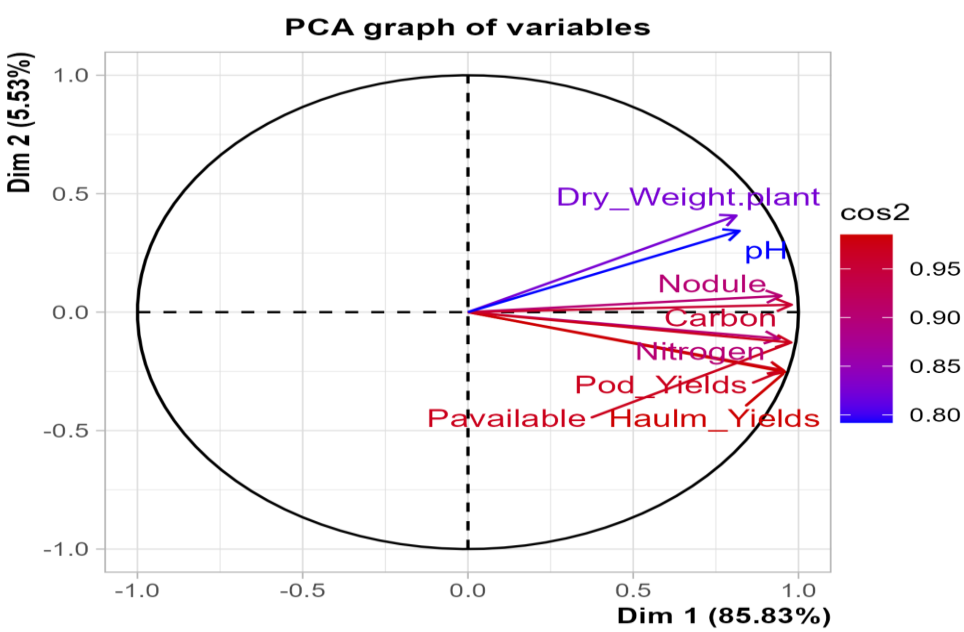

Figure 26. Ranking of soil parameters and groundnut yield characteristics. The first axis represents 85.83% and the second axis 5.53% of the total variance

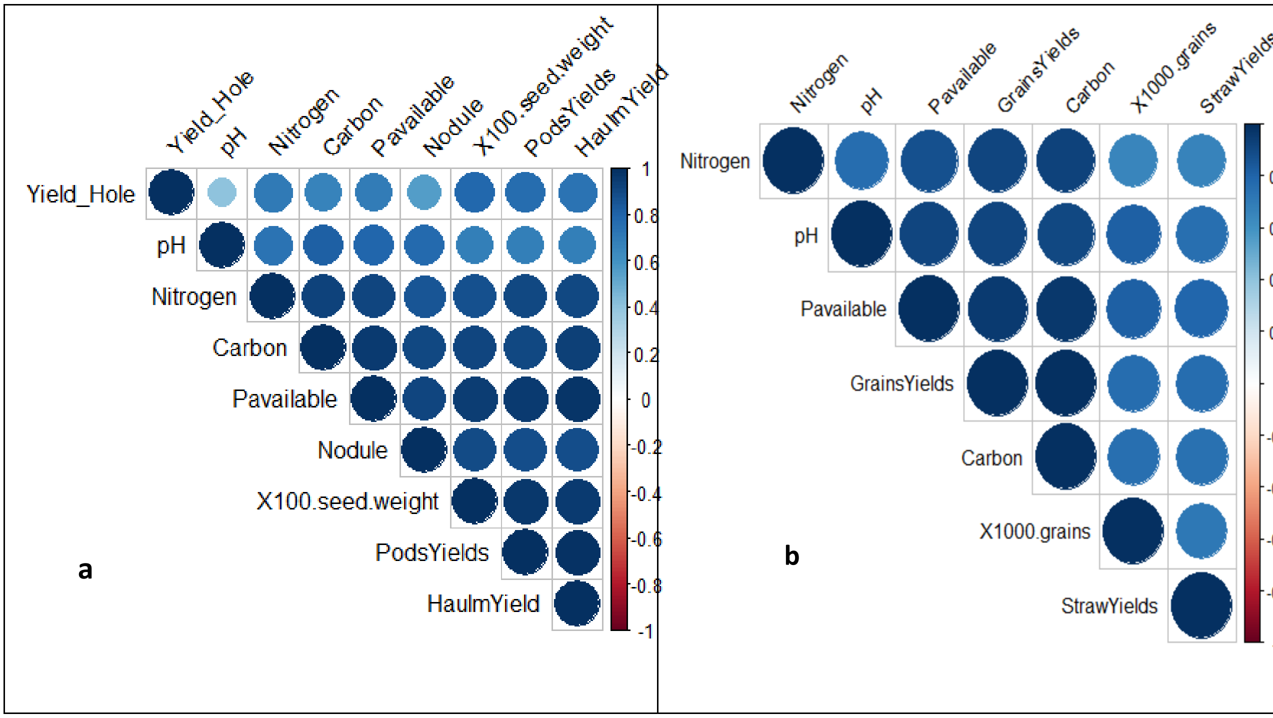

Figure 27. Correlogram of chemical parameters and crop yields (**a** = groundnut, **b** = sorghum). Positive correlations are shown in blue and negative correlations are in red. The intensity of the colour and the size of the circles are proportional to the correlation coefficients. To the right of the correlogram, the colour legend shows the correlation coefficients and the corresponding colours.

4.1.7. Soil moisture content evolution and yield variability of groundnut and sorghum

Positive correlations were observed between sorghum grain yields, groundnut pods, and soil moisture content (Figure 28, 29). These correlations were significant for sorghum grain yields from 60 days after sowing ($P<0.0001$) to 80 days after sowing ($P<0.0001$). In groundnut, these correlations were significant on pod yields from 60 DAS ($P<0.0001$) to 80 DAS ($P<0.0001$). These correlations are positive and indicate that the increase in soil moisture levels under sorghum and groundnut production influences a significant increase in the yields of these crops. Thus, the water factor remains limited to the development of these crops. Therefore, increasing the water capacity of the soils under the Z, Z_SR, and SR treatments will help to break this barrier which is often influenced by short drought sequences.

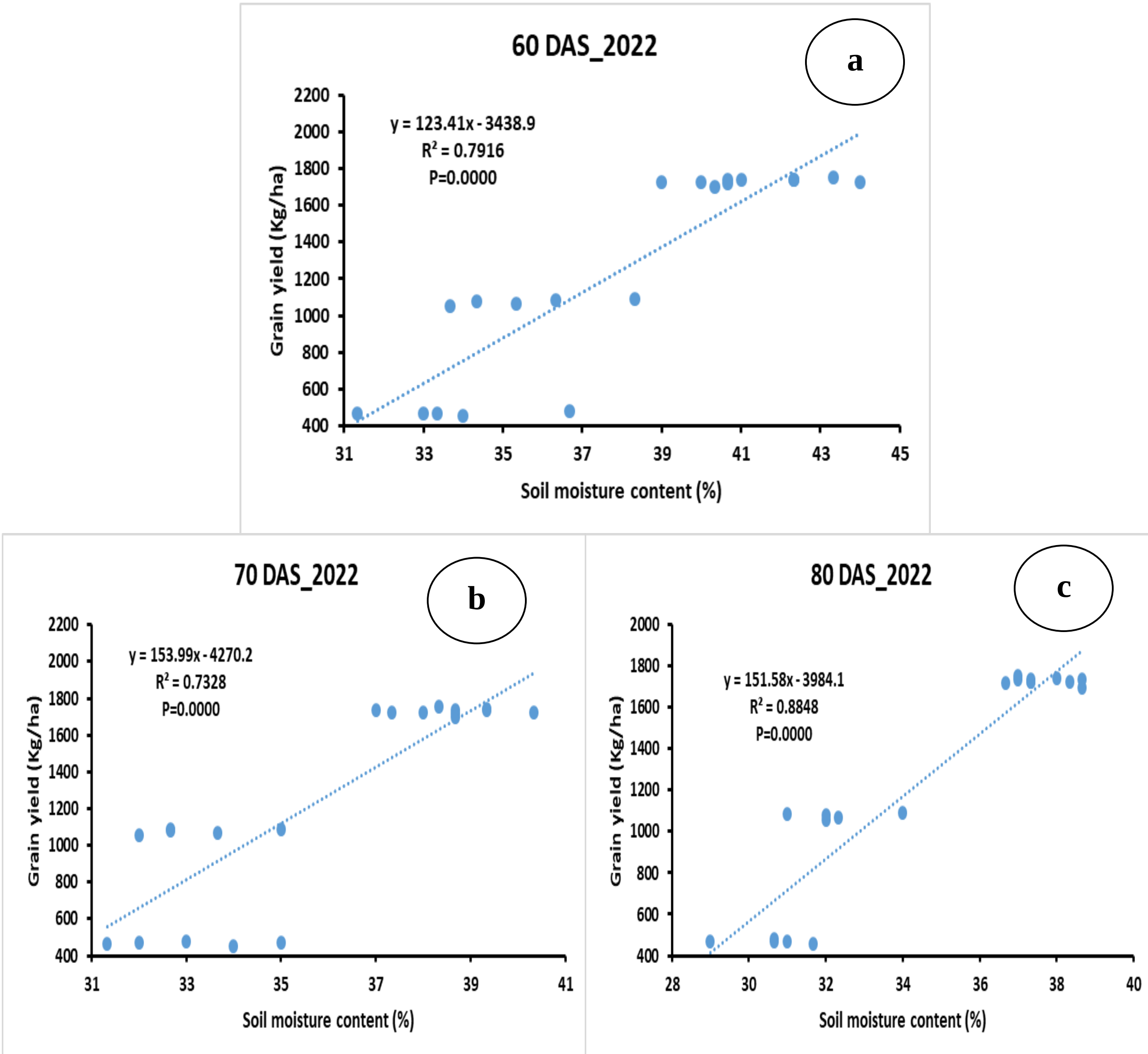

Figure 28. Regression between soil surface moisture and grain yields of sorghum at 60 DAS (**a**), 70 DAS (**b**) , and 80 DAS (**c**) (**DAS** = Days after sowing)

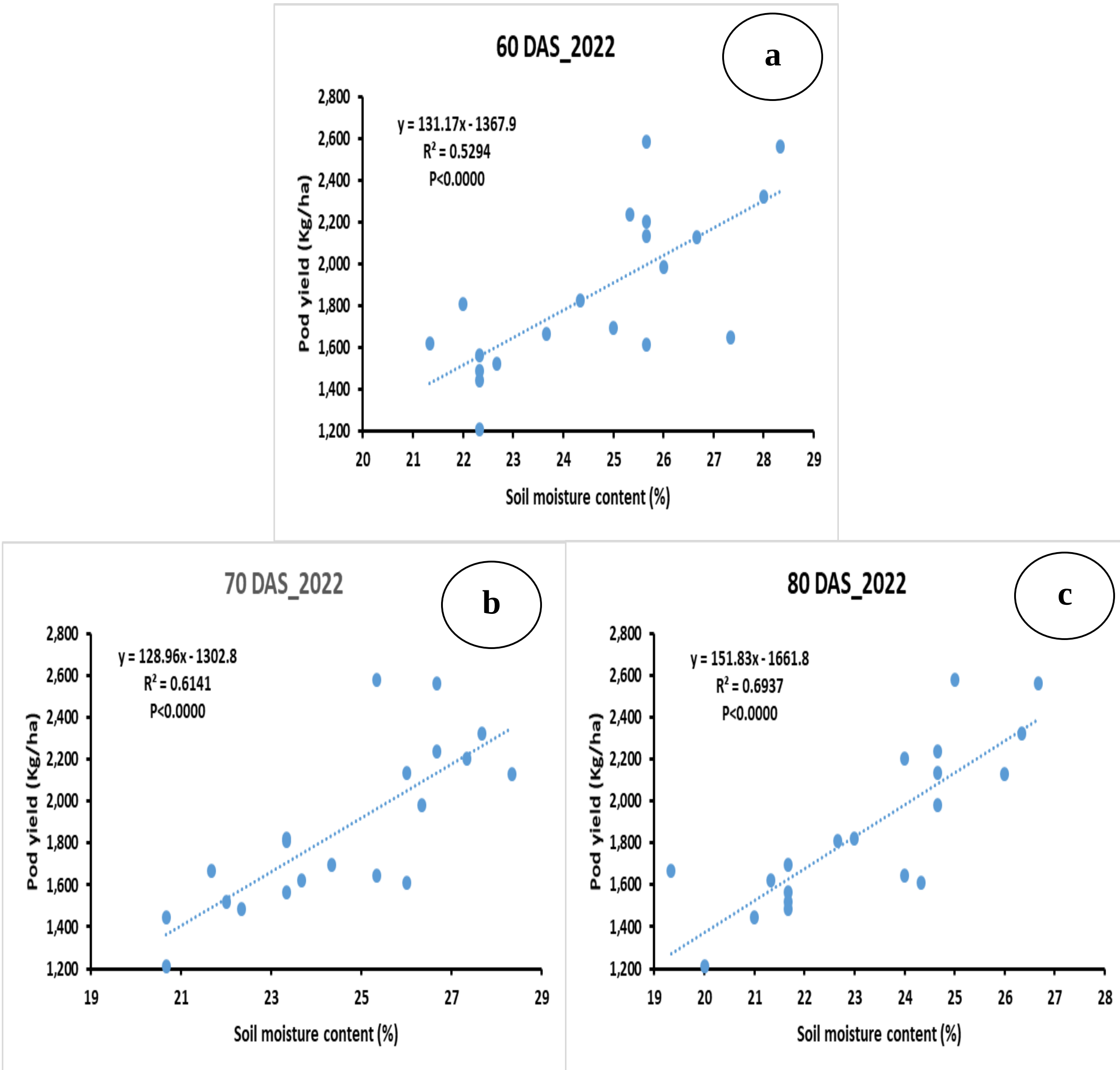

Figure 29. Relationship between soil moisture and pods yield of the groundnut at 60 DAS (**a**), 70 DAS (**b**), and 80 DAS (**c**) (**DAS** = Days after sowing)

4.1.8. Effects of *zaï*, stone rows, and ridge tillage on agronomic parameters of groundnut

4.1.8.1. Effects on pods loads, nodules, leaves, and branches

The results showed that the four treatments influenced the numbers of the pods, nodule, leaves, and branches (Table 29). The best values were obtained on the *zaï* and *zaï* combined with stone rows. Thus, these techniques significantly improved pod formation (p=0.0061), nodulation (p<0.0001), leaf formation (p=0.0015), and branch formation (p=0.0137), compared to ridge plowing and stone row alone. Consistent with the latter parameters, nodular dry weight was significantly influenced by *zaï* and *zaï* combined with stone rows (p=0.0008).

For the number of pods per plant, the *zaï* and *zaï* techniques combined with the stone rows gave the best values with an average of 25. The ridge and stone rows techniques recorded the lowest results, averaging 17. As for the number of leaves, branches, and nodule weight, two groups were found. The first group is made up of *zaï, zaï* + stone rows and stone rows. The second group is ridging with values of 0.0411 grams of dry nodule/plant, 31 leaves/plant, and 5 branches/plant. However, three groups are presented on the number of nodules. The *zaï* and *zaï* techniques combined with stone cordons constitute group 1. The cordon and ridge techniques form the second and third groups respectively with values of 70 and 58 nodules per plant.

Table 29. Effects of treatment on growth parameters of the groundnut

Treatment	Pod load/Plant	Nodule number/Plant	Nodule dry weight (g/plant	Leaf number/Plant	Branch number/Plant
RT	17.92±1.42**b**	58.48±14.30**c**	0.0411±0.01**b**	31.20±2.78**b**	5.24±0.17**b**
SR	17.24±1.60**b**	70.40±11.84**b**	0.0672±0.02**a**	37.56±2.77**a**	5.92±0.30**a**
Z	25.44±5.95**a**	84.76±15.88**a**	0.0893±0.01**a**	39.80±1.08**a**	6.08±0.66**a**
Z_SR	25.24±5.21**a**	87.88±14.09**a**	0.0886±0.02**a**	40.20±5.05**a**	6.32±0.58**a**
P-value	0.0061	<0.0001	0.0008	0.0015	0.0137
Signification	**	***	***	**	*

RT= Ridge tillage, **SR**= Stone rows, **Z**= *Zaï* pit, **Z_SR**= *Zaï* pits combines to stone rows. n=5; **stdev =** standard deviation, mean with same letter are not significantly different at threshold 5%.

4.1.8.2. Effects on the yields and seed weight

Yield variations according to soil management are presented in Table 30. Except for the weight of 100 pods in 2021, statistical analysis reveals two homogeneous groups. *Zaï* and *zaï* combined with stone rows constitute the first group. The second group is made up of ridges and stone rows. The first group has the highest values while the second group has the lowest values. Pod yields vary from 392 kg/ha (Ridge tillage) to 1126 kg/ha (*zaï* + stone rows) in 2021, and from 1645 kg/ha (Ridge tillage) to 2161 kg/ha (*zaï* + stone rows) in 2022. This trend is also noted in the weight of 100 pods, only in 2022, and the importance of pods per seed hole. Biomass yields follow the same trend and vary from 586 kg/ha (Ridge tillage) to 2011 kg/ha (*zaï* + stone rows) in 2021 and from 1134 kg/ha (Ridge tillage) to 1753 kg/ha (*Zaï*) in 2022. Pod yields in 2022 are about 1.9 to 4 times higher than in 2021. Haulm yields almost doubled in 2022 for the stone rows (1.9 times) and ridge tillage (1.9 times) techniques. In contrast, for *zaï* and *zaï* associated with stone rows the dry haulm in 2021 remained higher than in 2022 (Table 31). This increase in values in 2022 remains similar for the 100-pod weight and the weight per hole.

Table 30. Pods yield and 100-Seed weight of Groundnut

Treatment	**Pod yield (kg ha^{-1})**		**100-Seed Weight (g)**	
	2021	**2022**	**2021**	**2022**
RT	392.54±3.96**b**	1645.31±28.15**b**	69.78±.3.49**c**	91.56±1.23**b**
SR	397.48±.4.35**b**	1641.95±17.20**b**	75.84±1.86**b**	94.02±2.44**b**
Z	1124.65±.3.76**a**	2122.32±38.02**a**	90.38±1.91**a**	112.90±2.64**a**
Z_SR	1126.67±.5.11**a**	2161.96±36.52**a**	88.76±1.87**a**	111.98±4.65**a**
P-value	0.0001	<0.0001	<0.0001	<0.0001
Signification	***	***	***	***

RT= Ridge tillage, **SR**= Stone rows, **Z**= *Zaï* pit, **Z_SR**= *Zaï* pits combines to stone rows. n=5; **stdev =** standard deviation, means with the same letter are not significantly different at threshold 5%.

Table 31. Haulm yield and pods weight per seed-hole of Groundnut

Treatment	**Pod weight (g/seed hole)**		**Straw yield (kg ha^{-1})**	
	2021	**2022**	**2021**	**2022**
RT	2.93±0.23**b**	15.101±1.37**b**	586.57±32.93**b**	1134.43±11.76**b**
SR	3.60±0.57**b**	13.705±1.79**b**	596.23±98.05**b**	1176.78±70.63**b**
Z	9.45±1.09**a**	19.112±3.21**a**	1917.02±89.54**a**	1753.28±77.33**a**
Z_SR	10.33±0.88**a**	19.836±3.07**a**	2011.79±144.39**a**	1686.87±79.46**a**
P-value	<0.0001	0.0028	<0.0001	<0.0001
Signification	***	**	***	***

RT= Ridge tillage, **SR**= Stone rows, **Z**= *Zaï* pit, **Z_SR**= *Zaï* pits combines to stone rows. n=5; **stdev =** standard deviation, means with the same letter are not significantly different at threshold 5%.

4.1.9. Effects of *zaï*, stone rows, and ridge tillage on agronomic parameters of sorghum

4.1.9.1. Effects on the grains and haulm yields and 1000 grains weight

Table 32 shows the overall effects of treatments on the grain yield, straw yield , and 1000-grain weight of sorghum. Grain yields were significantly increased in 2021 (p<0.0001) and 2022 (p<0.0001) under the SR, Z, and Z_SR treatments compared to ridge tillage. In 2021, this increase was 36.57% by SR, 337.48% by Z, and 332.67% by Z_SR. However, in 2022, this increase was 130% by the SR, 271% by the Z, and 268% by the Z_SR. In 2021, the increase in 1000 grain weight was 6.39% by SR, 22.02% by Z, and 17.09% by Z_SR. In 2022, the increase was 7% by SR and 16% by Z and Z_SR. The same trend was noted in straw yields by all three treatments and in both seasons. Thus, SR stimulated an increase of 10.99%; Z by 139.84%, and Z_SR by 92.74% compared to RT in 2021.

Table 32. Effects of treatments on grains yields and 1000-grains weight of Sorghum**.**

Treatment	Grains Yield (kg ha^{-1})		1000-Grains Weight (g)	
	2021	2022	2021	2022
RT	380.38±9.67^{c}	467.55±8.22^{c}	19.40±.0.97^{b}	18.48±1.55^{b}
SR	519.47±.8.99^{b}	1075.06±14.32^{b}	20.64±1.50^{b}	19.79±0.81^{ab}
Z	1664.09±.23.46^{a}	1736.32±11.53^{a}	23.67±2.14^{a}	21.48±1.34^{a}
Z_SR	1645.77±.20.86^{a}	1723.28±15.85^{a}	22.74±1.13^{a}	21.44±0.81^{a}
P-value	<0.0001	<0.0001	0.0014	0.0023
Signification	***	***	**	**

RT= Ridge tillage, **SR**= Stone rows, **Z**= *Zaï* pit, **Z_SR**= *Zaï* pits combines to stone rows. n=5; **stdev =** standard deviation, means with the same letter are not significantly different at threshold 5%.

Table 33. Effects of treatment on straw yields

Treatment	Straw Yield (kg ha^{-1})	
	2021	2022
RT	2038.00±719.81^{c}	2920.00±783.96^{b}
SR	2262.00±688.60^{c}	3118.00±1012.73^{b}
Z	4888.00±507.81^{a}	5644.00±631.29^{a}
Z_SR	3928.00±.895.08^{b}	4856.00±907.02^{a}
P-value	<0.0001	0.0002
Signification	***	***

4.1.9.2. Effects on the growth parameters

Overall sorghum plant height growth varied significantly along treatments in 2021 (P=0.0087) and 2022 (p<0.0001). The highest increases were found in the *zaï* and *zaï* combined with stone row treatments. This is followed by the SR and RT treatments. Similarly, collar diameters varied significantly between treatments in 2021 (p=0.0015) and 2022 (p=0.0005). Large collar diameters were recorded under the *zaï* and *zaï* combined with the stone rows. The *zaï* and stone rows influence the achievement of edaphic conditions necessary for the development of sorghum plants. This is reflected in the higher vertical and horizontal growth values of the sorghum plants. However, the values observed in 2022 are higher than those in 2021 (Figure 30a and 30b). This is due to the variation in rainfall between 2021 and 2022.

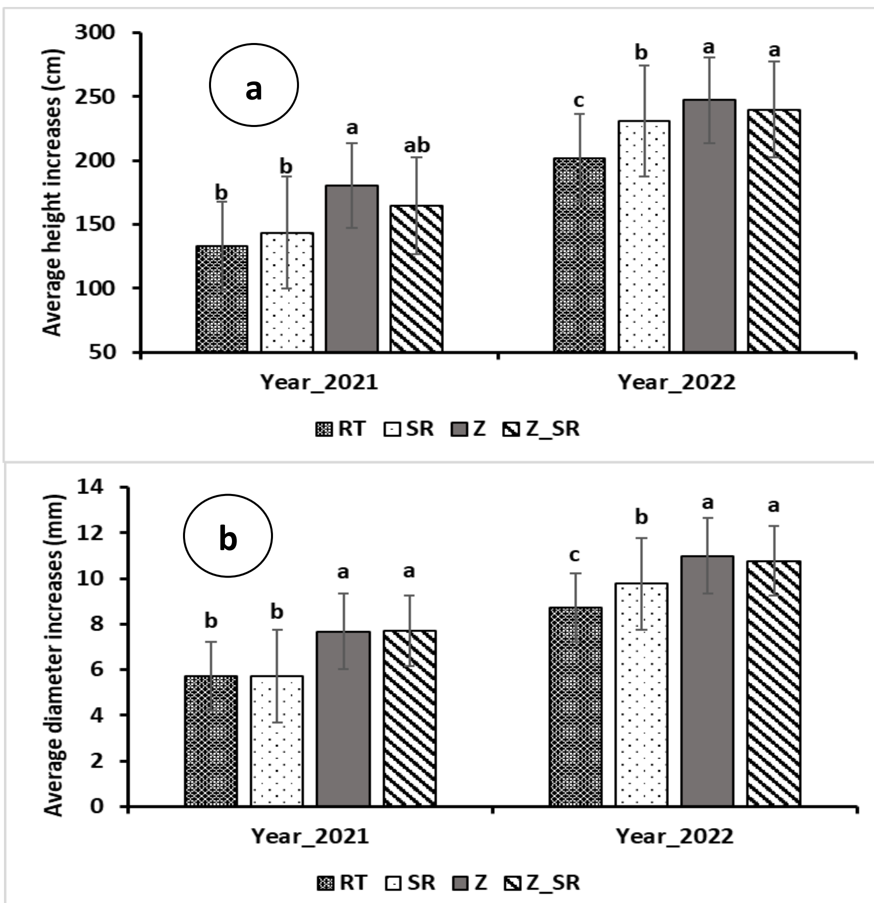

Figure 30. Variability of the height **(a)** and diameter at collar **(b)** of sorghum. **(RT =** Ridge tillage; **SR =** Stone rows; **Z** = *Zaï*; **Z_SR** = *Zaï* + Stone rows; The histograms correspond to the means; the means with same letter do not differ significantly at the 5% level; **n** = 5).

4.2. Discussion

4.2.1. Socio-economic indigenous drivers of soil and water conservation practices used to cope with climate change in the Plateau Central region of Burkina Faso

4.2.1.1. Socio-economic characteristics of respondents

The results of the survey showed that the majority of farmers in *Kourwéogo* and *Oubritenga* provinces were men (89.63%). Most of them aged less than 60 years old (80.74%). These results corroborate those authors (Danquah et al., 2019; Adebiyi et al., 2019; Garba et al., 2020; Traoré et al., 2021), who found more males (72.6%, 75%, 85.7% and 98.02%) than females among the respondents in Ghana, Mali, Benin, and Niger respectively and whose ages ranged from 21-60, 27-57 years in Ghana and Benin respectively. This higher proportion of men is explained by the fact that the function of chief of the farm is traditionally reserved for men (Diaby et al., 2020), who are more likely to be allowed to speak than women. The few women are in most cases widows or the householder is absent. Therefore, with this rank of age, they were able to give credible information on the agro-pedological characteristics, the current environmental situation and how to manage the land and cope with climate change and its negative impacts. The literacy rate in our study area was 57.78% on average (9.63% have primary and secondary education, other forms of education represent 48.15%). This rate of literate respondents is in contrast to the results of authors (Asare-Nuamah and Botchway, 2019; Diaby et al., 2020) from Ghana and Mali. In fact, this rate is below that of Ghana (75.4%) and above that of Mali (35%). So the literacy rate is on average in this part of Burkina Faso. The level of education influenced the ability of farmers to use *zaï* and stone rows techniques to adapt or mitigate the negative effects of climate change. This could be explained by their access to information through mass media (Kaboré et al., 2019), increased likelihood of adaptation to the effects of climate change, their awareness of accessibility, understanding, acceptance and belief in climate change information and improved technologies. Farmer's level of education has been found to have a significant relationship with intensive knowledge of climate change (Kone et al., 2022). Thus, education contributes to fight against global changes including climate. Membership in to a local organization significantly influenced the practice of *zaï* pits and stone rows, as it increased the chances of practicing *zaï* pits or stone rows. It also permitted the member to be informed and gain knowledge about soil and water conservation techniques applicable in the area, depending on the channels used to share information and experiences.

The number of agricultural equipment owned by the farmer also appeared to be a determinant of techniques practiced for the recovery of degraded soils for adaptation to climate change in the area. This result is consistent with that of Kaboré et al. (2019), who found that ownership of small agricultural tools such as picks and shovels had a strong impact on the practice of *zaï*, stone rows and the construction of manure pits in the north-central region of the country. The possession of cattle statistically conditioned the practice of *zaï*. This would be due to the reuse of cattle waste in *zaï* pits. It is therefore necessary to empower farmers with educational skills and knowledge, and to support them to organize themselves and access small-scale farming equipment.

4.2.1.2. Agro-pedological characteristics

In the present study sites, out of a total of 135 farmers surveyed, 133 reported producing sorghum, 96 pearl millet, 133 cowpea and 83 groundnut. Sorghum and pearl millet remained the main cereal crops in the region, despite the promotion of other cereals such as rice and maize by the government and some non-governmental organizations. This is because sorghum and millet are more drought resistant and require less fertilization than maize and rice, which are less resistant to drought and low fertilization. Nationally, the fertilization of sorghum and pearl millet are 87 and 91 kg.ha-1 compared to 129 and 123 kg.ha-1 for maize and rice respectively (MAAHMA, 2021). In sorghum and pearl millet fields, the cultivation techniques adopted are ridge ploughing (89.07%) and stone rows (70.20%). The *zaï* is not widely used by farmers in this area. This rate of adoption of stone rows is comparable to those obtained by Kaboré et al. (2019) and (Sigué et al., 2018).

Crop residues were mainly used for fodder (42-98.46%), domestic energy (47.37-51.13%), composting (30-55.79%), potash production (14.91-39.77%) and sale (9.92-58.23%). Sanou et al. (2016) had already mentioned the use the major part of crop residues as fodder, supplementary feeding and domestic energy production. The sale of crop residues also played an important role, with legumes leading the way (cowpea 37.69%, groundnut 58.23%). They were the most sold and eaten by animals because they were abundantly available in the dry season and their total nitrogen content respectively were 12.47% and 12.46% (Sanou et al., 2016). This sale of crop residues could also be explained by the proximity of the study area to the urban centers such as Ouagadougou and Ziniaré. Thus, awareness raising and training on post-harvest management of residues and their processing to increase their benefit would be very important in this area.

4.2.1.3. Environment and soil management situation

The results showed that the respondents had a good perception of the degradation of natural resources. This degradation was perceptible in the land, vegetation, fauna and soil. According to the respondents, the degradation of the soil, which translates into a drop in fertility, was attributable to factors such as (a) climate change (climate variability), (b) soil erosion, (c) wood cutting, (d) use of pesticides, (e) poor fertilization, (f) long-term monoculture, (g) non-use of organic fertilizer, (h) failure to follow the advice of the extension services, (i) lack of rituals before the start of the season, (j) collection of aggregates for urbanization, (k) population growth, (l) failure to protect the bush and (m) failure to return crop residues. These same causes were revealed by the work of (Ouattara et al., 2022) and Kaboré et al., (2019) in studies carried among the populations of the Centre-West, North Central, North, South-Eastern and East regions of Burkina Faso. Of all factors that reduce agricultural soil fertility, erosion, drought sequences, aggregate collection and the non-use of organic fertilizer were the most important in this part of the country. It is true that erosion and drought remain phenomena observed throughout the territory and are natural. However, the collection of aggregates and the non-application of organic fertilizer could be explained by the concern about being able to pay for food during the food gap period by selling aggregates, the competition for raw materials and the lack of means to produce organic fertilizer in quantity.

The majority of farmers in the study area had become aware of the degradation of the quality of agricultural soils. To cope with this situation, certain water and soil conservation techniques such as *zaï*, stone rows, assisted national regeneration, mulching, ridge tillage and the use of organic manure were practiced. However, according to them, the technique that best conserved the soil against water erosion remained the stone rows (76.30%), *zaï* (11.11%), and assisted national regeneration (10.37%). This showed their knowledge and attention to these techniques in the area. This soil conservation function had been mentioned by (Zougmoré et al., 2014b). Also, stone barriers and *zaï* had a strong impact on the development of vegetation cover (Savadogo et al., 2016). Then, stone rows reduce runoff and soil erosion, while the *zaï* improves water retention (sponge effect of the soil) and leads to an enrichment of organic material in the soil. Less erosion, more soil water and humus are favorable for plant growth and improve the microclimatic conditions, which are in turn also favorable for plant growth (there are several interactions and feedbacks between soil, water, climate, flora, and fauna, which could be explained in more detail. However, the practice of stone rows and *zaï* techniques remained very difficult due to unavailability and transport of raw materials (rubble, organic fertilizer), lack of small equipment, and lack of knowledge of the *zaï* practice.

In the provinces of *Kourwéogo* and *Oubritenga*, climate change was manifested through disaster risks: reduced and irregular rainfall, late start of the rainy season, early cessation of rainfall, higher frequency of dry sequences, water stagnation sequences, locust attacks and strong winds. These results coincide with those of Kaboré et al., (2019) in the Central-Northern and South Western regions of the country. Frequent average (8-14 days) and major (15 days) ordinary rainfall breaks have been reported in the Sudanian and Sahelian zones of West Africa (Salack et al., 2014). In addition, the sudden cessation of rains before the end of the rainy season constituted one of the major agroclimatic constraints to rained agricultural production, as it causes the shortening of the subsequent vegetative growth period. Declines in yields and grain production of more than 60% were attributed to these climatic anomalies. This in turn hindered social and economic development.

4.2.1.4. Determinants of the adoption of *zaï* and stone rows techniques

The determinants that conditioned the adoption of the *zaï* and stone rows techniques in the present study were age, level of education, membership to a local farmers' organization, number of cattle and small trading.

The age

In the provinces of *Kourweogo* and *Oubritenga*, the age of the respondents was found to be significantly associated with the use of stone rows. Producers aged 40-50 years practise more stone rows. This could be explained by their age group. Indeed, young people are more willing to use erosion control as a soil conservation strategy than older people, because this technique requires physical effort. Also, these results corroborate those of Adams et al. (2021), who found that in Ghana farmers around 50 years old were more willing to use new agricultural technologies. According to him, the older the farmers are, the more they participate and/or adopt improved agricultural technologies as they gain more experience.

The level of education.

Education had a significant impact on the adoption of the *zaï* practice. Most of the formal and informal educated farmers practiced the *zaï* technique. These results corroborate those of some authors on the adoption of agricultural techniques, among others (Afouda et al., 2020; Napon et al., 2020; Sawadogo et al., 2022). This could be explained by the understanding and openness of the educated to innovations (Yabi et al., 2016b). Furthermore, education improves the technical efficiency of households due to their much greater propensity to adopt new and more productive agricultural techniques (Sawadogo et al., 2022). Thus, increasing the level of education in all its forms could increase the rate of adoption of *zaï* in this study area.

Membership to a local farmers' organization.

Membership in a local farmers' organizatoin was a determining factor in the adoption of *zaï* and stone rows techniques. This result was similar to those obtained by (Mwangi and Kariuki, 2015) on the adoption of other agricultural practices. Because they belong to an organization that can be supported by NGOs, they will have access to transportation and construction equipment for the techniques and can be trained in soil restoration activities. They are also able to ask each other for help in carrying out activities that are considered difficult for one person alone. Also, local organizations stimulated their members to adopt agroecological techniques through training on agricultural techniques, knowledge sharing and innovations (Sigué et al., 2018; Iyabano et al., 2021). (Jaza et al., 2020) found that farmers who had attended training or restitution meetings were more likely to adopt environmental protection practices than those who had not. Thus, with the synergy of action of different NGOs towards local farmers' organizations under their supervision, soil management techniques to adapt to the adverse effects of climate change can be widely adopted.

Number of cattle

The number of cattle available in the household significantly influenced the adoption of agricultural technologies by different actors in rural areas in the context of climate change. Afouda et al. (2020) highlighted this correlation. According to these authors, the number of cattle in the household strongly increased the probability of adoption. Indeed, the possession of cattle facilitated the adoption of *zaï*. This could be explained by the fact that owning cattle allowed farmers to have dung for the production of organic manure that could be used to enrich the *zaï* pits. Furthermore, (Danne and Musshoff, 2017) found that herd size significantly affected the decision of agro-pastoralists to participate in land degradation reduction programmes. Thus, cattle ownership accompanied by training could be a source of recovery of degraded soils in this part of the country.

Small trading

Small trading was identified as a restraining factor in the decision to adopt the *zaï* technology. The results indicated that producers who traded at the same time had a low level of zaï practice. This finding contrasts with that reported by (Sigué et al., 2018) who found that farm income correlated positively with the adoption of the microdose technique. It could be that these farmers were more interested in their trade during the period of digging zaï pits.

4.2.1.5. Partial conclusion

The indigenous drivers of the adoption of stone rows and *zaï* practices by farmers in four municipalities of the Plateau Central region have been identified and analysed. The results showed that the socio-economic drivers of the adoption of these soil and water conservation techniques (stone rows and *zaï*) are age, level of education, membership to a local farmers' organization, ownership of cattle and the practice of small trade, with the practice of the small trading limiting the practice of zaï technology in these localities. The level of education, membership to local farmers’ organization and ownership of cattle were positively correlated with the adoption of *zaï*. As for the adoption of stone rows, age and membership to a local farmers’ organization positively influenced it. In terms of policy and intervention strategies of partners in the area, these results required a synergy of actions in order to maintain the adoption of these techniques for an effective adaptation to the disastrous effects of climate change. This would improve soil quality in the region.

4.2.2. Agronomics constraints and potentialities of the soils of experimental sites

The results of the soil pit descriptions revealed two types belonging to the iron and/or manganese sesquioxide soil class. According to the CPCS (1967) classification, these are superficially indurated leached tropical ferruginous soils and speckled and/or concretional leached tropical ferruginous soils (useful depth > 60 cm). According to the (WRB, 2014) classification, these soils correspond to Plinthosols epipetric and Lixisols gleyic, respectively. Constrained by nutrient availability and rooting conditions, the indurated leached tropical ferruginous soil is marginally suitable for sorghum and maize; moderately suitable for pearl millet, cowpeas, groundnuts, and sesame; and permanently unsuitable for rice. The leached tropical ferruginous soil with stains and concretions is marginally suitable for sorghum, maize, millet, cowpea, groundnut, and sesame, the constraint being related to oxygen availability and the risk of flooding. On the other hand, it is moderately suitable for rice, with the limitation being nutrient availability. The useful depth of the indurated leached tropical ferruginous soil is less than 40 cm. So below suitable to moderately suitable depths for sorghum (60-100 cm) and groundnut (60-100 cm). The armoured appearance associated with the low cation exchange capacity (6.45) and the low sum of exchangeable bases (3.77) plus a very acidic pH (5.22) constitute a blockade for the good development of these crops. The optimum pH for these crops varies from 5.5 to 8 (BUNASOLS, 1990). The pH is a determining factor for the availability or assimilability of mineral elements by the plant, especially phosphorus (Rahman and Ranamukhaarachch, 2003), affecting both the absorption and desorption of phosphorus for the plant. Thus, the acidic pH combined with the low assimilable phosphorus and medium nitrogen content remains an obstacle for these crops. This is because this nitrogen could enhance plant growth, thus creating a concentration gradient and increasing the demand for P (Mowo, 2000) which is low in the soil. As for the leached tropical ferruginous soil with stains and concretions, it is marginally suitable for sorghum and groundnuts. This constraint is linked to the availability of oxygen and the risk of flooding. Indeed, the drainage is moderate with a silty-sandy texture. This risk of flooding, which would affect soil aeration, is due to the presence of silt on the surface layer of the soil.

In partial conclusion, two types of soil belonging to the same soil class were involved in this study. These are the tropical ferruginous leached soil and the tropical ferruginous leached soil with stains and concretions, all of which belong to the iron and manganese sesquioxide soil class. The major constraints of these soils are the low useful depth limited by induration, the very high gravelly load and the loam texture which slows down the speed of water infiltration.

4.2.3. Effects of *zaï*, stone rows, and ridge tillage on soil properties under sorghum

4.2.3.1. Effects on soil carbon, nitrogen, available phosphorus, and pH

The C, N, and P content of soils under sorghum was improved under Z, Z_SR, and SR compared to soils under RT. According to our study, the Z, Z_SR, and SR treatments increased organic carbon, total nitrogen, available phosphorus, and pH values. This increase in carbon would be due to the addition of cattle manure at the time of establishment and to the return of a small part of the plant through the roots, as they are the main carbon depositor in the soil (Allmaras et al., 2004; Wilhelm et al., 2004). Moreover, some authors found that the roots of sorghum can accumulate up to 14% of the total carbon capture in the above-ground and below-ground biomass (Andress, 2004; Wilhelm et al., 2004). According to the study by (Cai et al., 2019), the application of manure promotes the increase of soil organic carbon contents, pH, and nutrients content. Therefore, we can conclude that *zaï* associated with cattle manure and the return of sorghum roots contribute to increasing soil carbon content.

Soil N levels were also improved under Z, Z_SR, and SR compared to those sampled under RT. This result is logical due to the urea supply and the return of roots coupled with the increase in organic matter in the *zaï*. Indeed, the organic matter reduces the inflow rate and improves the soil's water retention. This retention avoids the nitrogen transport in depth by water (Fatondji et al., 2011).

Available phosphorus levels are higher under the Z, Z_SR, and SR treatments compared to the RT treatment. These treatments are therefore beneficial to the improvement of the soil's available phosphorus content. These results corroborate those of Getare et al. 2021 who found that *zaï* combined with manure increased the levels of available phosphorus in the soil. In our case, this improvement in available phosphorus levels is attributable to the interaction of *zaï*, manure, and NPK mineral fertilizer. This remarkable effect is explained by the fact that the amendment by the application of manure improves the physicochemical properties of the soil and the nutrient cycle by reinforcing the enzymatic and microbial activities of the soil. This will trigger the process of bioavailability of phosphorus for plant uptake (Ali et al., 2019) and provide phosphorus in the soil through the content of inorganic orthophosphates in manure.

Concerning pH, the Z, Z_SR, and SR treatments stimulated higher pH values than the RT treatment. This dynamic is similar to that of carbon, nitrogen, and available phosphorus. Thus, the Z, Z_SR, and SR treatments positively influence the improvement of soil acidity. The higher pH values under these treatments could be attributed to the manure that increased the organic matter content of these soils. However, the alkalinity of organic matter as a result of the decarboxylation of organic anions and ammonification of organic nitrogen stimulates the increase of soil pH and neutralizes its acidity (Rukshana et al., 2014; Cai et al., 2019).

4.2.3.2. Effects on soil moisture content

Our results showed a significant increase in soil moisture content under *zaï* and *zaï* associated with stone rows, confirming the key role of *zaï* pits in improving soil water retaining capacity on degraded soils. Indeed, the highest moisture levels were recorded on soils under *zaï* and under *zaï* associated with the stone rows. This is because the *zaï* pits collect water and retain moisture. The addition of organic manure would increase the soil organic carbon content, which improves porosity and water holding capacity (Annabi et al., 2011) and contribute to conserve soil moisture content. In the SR treatment, even with ridging, moisture levels remain lower in the *zaï*. This suggests that even with organic fertiliser and ridging, which should reduce water transport of fertiliser, *zaï* pits would be more efficient in storing and retaining water.

4.2.3.3. Effects on soil respiration

A significant cumulative release of CO_2 was obtained on soil under SR. This was due to the application of organic fertiliser. The organic manure increases the organic matter content and raises the soil pH. However, pH and organic matter influence the biological activity of the soil. In addition, tillage such as flat plowing and ridging would contribute to lowering the soil bulk density (Serme et al., 2015). This situation is manifested by an improvement in soil moisture and aeration, thus inducing a good development of microorganisms. Then the mineralisation of organic matter will be accelerated and the amount of CO_2 released will depend on the microbial population, their diversity, and the metabolic enzymes secreted.

4.2.3.4. Effects on soil macrofauna dynamic

Under sorghum growing, the soil engineers were inventoried. Then, twelve (12) species of termites, eight (8) species of ants, and three (3) species of earthworms were indentified. Isopterans were represented by the mushroom termites (*Acanthotermes acanthothorax, Macrotermes bellicosus, Macrotermes sp., Microtermes sp., Microtermes upembae, Odontotermes fuller*, *Odontotermes garambae, Odontotermes mukimbunginis*, *Odontotermes sp., Odontotermes syostedti*), harvesters or foragers (*Trinervitermes sp.*) and humivores (*Cubitermes sp.*). The genus Odontotermes (72), Microtermes (361), and Macrotermes (105) were best represented in all treatments. Whatever the year and the treatment, mushroom termites are the most common. Thus, the development of fungus gnats is acceptable under sorghum production. The RT, SR, and Z_SR treatments recorded more termites than the Z treatment. The presence of mushroom termites could be explained by the contribution of manure. cow dung manure is a lignocellulosic biomass (Ashekuzzaman and Poulsen, 2011). However, according to some authors (Maldague, 2003; Zaremski et al., 2009), termites feed mainly on cellulose. Furthermore, this situation could be explained by the adaptability of termites, which is sometimes favored by the symbiotic relationship they maintain with certain fungi, facilitating the degradation of food (Guedegbe et al., 2008). As for the ants, the genera Camponotus (170), Monomorium (99), and Pogonomyrmex (64) are the most represented. The genera Messor (6) and Formica (3) were the least encountered. This leads us to hypothesize that the combination of soil management techniques, manure, and mineral fertilization, soil type, and crop provides a favorable environment for ant populations. The application of treatments on sorghum was also favorable to the growth of earthworms. The species recorded are anecitic (*Dichogaster affinis* and *Lombricus terrestris*) and endogenous (*Millsonia inermis*) worms. The most common species is *Dichogater affinis* followed by *Milsonia inermis*. D. affinis feeds mainly on soil taken from the 0-10 cm horizon and sometimes deeper, while *Milsonia inermis* feeds on organic fractions taken from the soil at a depth of 30 cm where they live. The presence of this earthworm population could be explained by the incorporation of manure (Traore et al., 2012). Thus, our results let us know that the treatments associated with the type of soil and the culture stimulate good development of the engineers of the soil, which are the termites, the ants, and the earthworms. However, the conditions are better for termites and ants than for earthworms. This leads us to hypothesise that the existence of ants is an obstacle to the development of termites or earthworms.

On the other hand, the number of individuals of three soil engineers remained higher in 2022 than in 2021. This can be explained by soil moisture. Indeed, soil moisture stimulates the appetite of invertebrates.

4.2.4. Effects of *zaï*, stone rows, and ridge tillage on soil properties under groundnut

4.2.4.1. Effects on soil carbon, nitrogen, and available phosphorus content, and pH

Under groundnut, the Z, Z_SR and SR treatments positively influenced C, N, P and pH values. The highest values are recorded under the Z and Z_SR treatments, which form a homogeneous group. Under groundnut growing, the analysis of our results reveals that the treatments have significantly influenced the contents of C, N, P and pH values. The Z, Z_SR, and SR treatments positively affected C, N, P, and pH values compared to the RT treatment. This is due to manure, chemical fertilizers, *zaï* pits, and biomass input from groundnut. Indeed, the fall of groundnut biomass provides the soil with huge amounts of organic matter after their mineralization (Tanoh et al., 2022) and can provide important nutrients to the soil including C, P, and N, basic elements of plant tissues as well as exchangeable soil cations such as Ca^{2+}, Mg^{2+}, K^{+}, and Na^{+}. In addition, Fatondji et al. (2011) had mentioned the reduction of nitrogen leaching by the accumulation of organic matter by *zaï* pits. In addition, the decomposition of the manure provided would increase the organic matter content. This increase in the organic matter would contribute to improved soil organic carbon content, fertilizer element contents, and higher pH values (Cai et al., 2019). *Zaï* pits combined with manure and micro-dose fertilizer on groundnut could be a form of adaptation to the adverse effects of drought sequences

4.2.4.2. Effects on soil moisture variability

The results showed a significant increase in surface soil moisture within the seed-hole compared to ridge tillage and stone rows. These results show that *zaï* pits play an important role in soil moisture quality. The Z and Z_SR record the highest moisture levels. That situation is due to *zaï* patches that have been amended with organic fertilizer and increased fine particles caused by the soil engineers (Roose et al., 1993). This mixture of organic manure and fine soil limits water losses by filtration as well as evaporation losses. The low water content noted on the ridge-plowed soils could be explained by runoff due to the lack of organic inputs. Indeed, organic matter increases the water retention capacity of the soil (Koull and Halilat, 2016). In addition, it is this organic manure supply associated with ridging that has led to higher moisture in stone strips than in ridge plowing.

4.2.4.3. Effects on soil carbon dioxide release variability

Soil is an essential link in the global carbon cycle as it contains 70% of biospheric organic carbon (Lamade, 1996). Soil carbon has two main origins: carbon from the senescence of plant biomass, which is taken from the atmosphere and assimilated photosynthetically, and carbon from the activity of soil microorganisms. One of the best ways to estimate the dynamics of decomposition and carbon fluxes related to these processes is to measure the release of CO_2 from the soil, called "soil respiration". The measurement provides interesting information on the activities of soil microorganisms and the root of the root compartment, which are very difficult to measure directly. Our results showed a significant difference between soil CO_2 release under the four treatments in 2021 and not significant in 2022. In 2021, the SR treatment recorded more cumulative CO_2 than the other treatments. Then, the stone cordon arrangements stimulated higher carbon dioxide release than the other treatments. This is explained by the organic manure input and the ridging which increased the organic matter content of the soil, as organic inputs and tillage condition the dynamics of the soil's biological activity potential (Some et al., 2016; Dabré et al., 2017). Thus, organic inputs, ridging and stone cordons positively influence soil biological activity.

4.2.4.4. Effects on soil macrofauna variability

A multitude of soil management practices exist. However, the essential element of all these practices remains the maintenance of soil quality. Invertebrates are very sensitive indicators of soil quality and fertility (Bachelier, 1978b; Lavelle et al., 2006b) and the current unsustainability of agricultural systems worldwide is partly due to the disappearance of these invertebrates (Lavelle et al., 2006). Organisms described as soil engineers, such as termites, ants, and earthworms, play a role as soil conditioners through their bioturbation actions and their effects on the physical parameters of the soil (Bachelier, 1978). Our study allowed us to inventory certain groups of these invertebrates according to soil and water conservation techniques. Three (3), species of termites and three (3) species of ants were encountered. No earthworms were identified. Only the SR treatment recorded termites. Ants were more numerous in the SR, RT, and Z_SR treatments. The groundnut crop may not be conducive to the development of earthworms. The families of termites and ants encountered are Termitidae and Formicidae. These families feed more on foods rich in cellulose and lignin. Their presence can be explained by the availability of additional food constituted by the cellulose and lignin brought by the organic matter (Traore et al., 2012) resulting from the contribution of organic manure.

4.2.5. Partial conclusion

Zaï, stone rows and zai combined with stone rows significantly influenced soil properties under groundnut and sorghum. *Zaï* and *zaï* combined with stone rows form a homogeneous group and stood out as the treatments that, together with the enhancement of their performance by the application of organic manure and micro-dose mineral fertilisers, improved the organic matter content of the soil. This raised pH values compared to baseline and ridge tillage values. Increasing organic matter content combined with the retaining ability of the *zaï* and stone rows increased soil moisture levels. The combined action of mineral fertilisers and improvements in pH, organic matter content and the captive capacity of the *zaï* and stone rows resulted in an increase in total nitrogen and available phosphorus. The addition of organic matter to the stone rows improved the edaphic and environmental conditions that allowed the development of micro-organisms and resulted in a clear increase in the biological activity of these soils compared to the soils under *zaï* and ridges. Indeed, the outside of the *zaï* pits is not conducive to the development of living soil organisms. This was confirmed by the presence of earthworms and termites in soils under stone rows. Thus the additional inputs of organic matter (cattle manure), N and P through mineral fertilisers and decompositions of sorghum roots and groundnut biomass combined with the retention and amelioration of fine soil particles by the *zaï* and stone rows, improved the biological, chemical and physical properties.

4.2.6. Effects of *zaï*, stone rows, and ridge tillage on agronomic parameters of groundnut

The results show that the treatments had a significant impact on pods, nodules, weight of dry nodules, leaves and branches. The pods load was higher with the Z and Z_SR treatments compared to the control, which is the ridge tillage and more practiced in the area. In addition, the SR, Z and Z_SR treatments stimulated more nodule formation, more drier nodule weight, more leaves and branchs formation than the ridge tillage. These increases in the pods load under Z and Z_SR, the number of nodules, the weight of drier nodules, the number of leaves and the number of branches under the SR, Z and Z_SR treatments show that groundnut responds better to these techniques compared to ridge tillage at the hupper-slope for its nodulation and vegetative development. An improvement in water and chemical conditions could justify this increase. Indeed, the *zaï* pits and the stone rows contribute to improve the rate of water infiltration in the soil and the content of fine soil and fertilizing elements necessary for the nutrition of the plant. The work of (Zongo, 2017; Guébré, 2021) showed a significant effect of *zaï* with organic fertilizer on the nodulation capacity of the cowpea. As groundnut is also a legume, it is possible that these significant effects of *zaï* positively influence the nodulation capacity of groundnut.

Besides, the results of our study showed that zaï, stone rows and *zaï* combined with stone rows had significant effects on pod and straw yields and on 100-pod weight and pod weight per plant. These treatments stimulated these different parameters compared to ridge tillage. The Z and Z_SR treatments stimulated more pod and straw production and more pod filling. The *zaï* and the stone cordons, by improving the soil parameters, contributed to improve these different plant parameters. According to Oduor et *al.* (2021), *zaï* holes improve soil chemical properties and according to Partey et al. (2018), *zaï* increases water infiltration and reduces water evaporation. These actions contribute to increased yields and weights of groundnut pods and straws. These results are confirmed by surface moistures, which are higher in *zaï* and stone cordons than in ridge tillage. The reduction of runoff and the improvement of soil water retention capacity by *zaï* (Wouterse, 2007; Partey et al., 2018) may have provided or retained nutrients necessary for groundnut development and productivity

4.2.7. Effects of *zaï*, stone rows, and ridge tillage on agronomic parameters of sorghum

The results indicated that Z, Z_SR and SR treatments had significant effects on grain yields, straw, thousand grain weight, height growth and diameter at the collar compared to RT treatment. Our work corroborates several authors (Saba et al., 2017; Ouédraogo et al., 2020) and confirms the key roles of *zaï*, stone rows and microdose as well as their association on the physical, chemical and biological fertility of the soil significantly impacting sorghum yields and growth. Indeed, *zaï*, stone rows, *zaï* combined with stone rows and manure reduces runoff, reduces evaporation, facilitates infiltration, improves water retention capacity and concentrates organic matter (Zougmoré et al., 2014b) and thus improves crop growth and development, increasing grain yields and water and nutrient use efficiency. Furthermore, the Z and Z_SR treatments gave significantly higher yields and growths than the SR and RT treatments. This is because the *zaï* pits and stone rows along the contour lines collected water and fine soil and reduced runoff, thus improving soil moisture (Fatondji et al., 2009). However, sorghum yields and growth in 2022 are still higher than those in 2021. This is due to the irregularity of the rains observed in 2021. Indeed, sorghum yields are considerably influenced by water availability in quantity and time (Ouédraogo et al., 2020; Guébré, 2021).The improved water and chemical properties are the result of organic fertilizer inputs and the breaking of the surface crust, which allowed for better water penetration (Zongo 2017: Kimaru-Muchai et al., 2021). Also, *zaï* favors the increase of carbon and nitrogen content of the soil (Dabre et al.,, 2017). Thus the addition of micro-dose fertilizers associated with good water retention capacity has boosted sorghum yields.

4.2.8. Partial conclusion

The results of our study showed that zai pits and zai pits associated with stone rows had positive effects on nodulation by improving soil pH, carbon, nitrogen and phosphorus contents. This successful nodulation positively stimulated groundnut vegetative development and yields. The addition of nitrogen (urea and NPK), potassium (NPK), phosphorus (NPK) and manure to the zai pits and stone rows increased the availability of nutrients in the soils, thus stimulating sorghum vegetative development and yields. Based on our results, the addition of manure and mineral fertilizers in microdose form to zai pits and zai pits combined with stone rows are more competitive climate-smart combinations for improved groundnut and sorghum production and soil management.

CHAPTER FIVE: CONCLUSION AND RECOMMENDATIONS

5.1. Conclusion

The main objective of this study was to determine the influence of *zaï*, stone rows and ridge tillage and their combination on soil health and agronomic performance of groundnut and sorghum in order to contribute towards the intensification of sustainable agricultural production in the Sudan-Sahelian zone of Burkina Faso. Base on the results we can conclude that in the Plateau Central region, farmers are using *zaï* and stone rows practices to cope with climate change adverses following age, level of education, membership in to local organization, ownership of cattle, and practice of the small trade.

In addition, *zaï*, *zaï* combined with stone rows, and stone rows improved soil biological, chemical and physical properties by increasing the number of soil engineers (ants, earthworms, termites), le quantity of CO_2 release, nutrients content (total carbon, total nitrogen, available phosphorus), pH-H_2O values, and moisture content under groundnut and sorghum cultivation.

Also, *zaï*, stone rows, and their combination improved groundnut and sorghum yields performances by increasing groundnut growth (leaves, branches, nodules), sorghum growth (height, collar diameter), groundnut yields (pod and haulm yields, 100-pods weight, pods load, weight of pods/hole), and sorghum yields (grain and straw yields, 1000-grains weight).

Then, our study hightlited that *zaï* and stone rows improved soil productivity, yields and growths of groundnut and sorghum. However, we suggest the following perspectives:

- to continue the studies by digging *zaï* pits every year to see the influence of the practices on soil biology by putting out the link between macrofauna, microfauna and the dynamic of carbon and nitrogen in short and long terms.
- to test the responses of groundnut to *zaï* and stone rows in combination with microdosing with two plants per hole on other type of soil in order to highlith the link nitrogen fixation, soil fauna, capacity of nodulation, soil moisture content, and yields optimizing.
- to test the responses of groundnut and sorghum to *zaï* and stone rows mixed with poultry dung as organic manure at different rates to determine the optimum rate for soil properties improvement and yields increasing.

5.2. Recommendations

At the end of the present study, we may recommend:

- farmers to combine stone rows with *zaï* in order to strengthen the soil properties for an optimal increase in groundnut, and sorghum yields.
- farmers to grow groundnuts under *zaï* on upperland with shallow soils
- policymakers and non-governmental organisations to support farmers in the implementation of *zaï* and stone row techniques at a large scale, while thinking about mechanisation. This support should be mainly human (by helping them to organise themselves into groups or associations) and technical (by supporting them in training and the procurement of equipment and quality inputs).

The limits of this study were:

- experimental conditions: As the experiments were conducted on the farm, we were faced with the late installation of the trials in the first year due to obtaining the raw materials for the facilities, protection against animal divagation and respecting the dates of the operations due to natural weather issue and social events.
- the small sample size of the survey population: as the research budget was not sufficient, we limited ourselves to four villages and small number of samples. .
- the short duration of the trial: as we were blocked by the pandemic of covid-19 to set up our experimental devices and the limitation of the budget, we are limited to conduct the experimentation for two consecutive years instead of 3 years.
- the non-collection of some of the studied factors: plant physiological parameters, chemical analysis of biomass, air and soil temperature, bulk density, deeph soil moisture and soil microfauna were not measured.

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ANNEXES

Annex 1. Questionnaire for the individual survey

FICHE D'ENQUETE SUR LES DETERMINANTS SOCIO-ECONOMIQUE, AGRONOMIQUE ET ENVIRONNEMENTAL D'ADOPTION DES CES/DRS ENDOGENES

Objectif : Evaluer les déterminants endogènes de l'adoption des pratiques de conservation des eaux et des sols dans le plateau central au Burkina Faso.

Action : analyser et comprendre les déterminants endogènes de l'adoption des pratiques de conservation des eaux et des sols dans quatre villages de la région du plateau central.

Numéro de la fiche………………Date :……../……./………./

I. Identification/localisation de l'enquêté(e)

Province	Kourwéogo /___/ Oubritenga /___/
Commune	Boussé /___/ Laye/___/ Dapélogo /___/ Zitenga /___/
Village	
Nom et prénom de l'enquêté	
Ethnie	
Origine	Autochtone /___/ Allochtone /___/ Autres /___/
Religion	Chrétienne /___/ Musulmane /___/ Animiste /___/
Contact du ménage	

II. Socio-Economie

Sexe	Masculin /___/ Féminin /___/
Age du chef de ménage ou son répondant	
Statut matrimonial	Célibataire /___/ Marié(e) /___/ Divorcé (e) /___/ Veuf/veuve /___/
Nombre de femmes	
Quel est votre niveau d'étude	Non alphabétisé (e) /___/ Alphabétise (e) /___/ Primaire /___/ Secondaire /___/ Supérieur /___/

Etes-vous membre d'une organisation ?	Oui /___/ Non /___/ Si Oui, préciser……………………
Nombre de personnes dans le ménage	
Nombre d'actifs total du ménage	Personnes de 16 ans à 59 ans (Total=…. Hommes =……..) Personnes de 60 ans et + (Total=…. …..Hommes =……..)
Quelle est votre activité principale ?	Agriculture /__/ Elevage /___/ Artisanat /___/ Commerce /___/ Orpaillage /___/ Autres /___/ (à préciser) ……………………
Quelle est votre activité secondaire ?	Agriculture /__/ Elevage /___/ Artisanat /___/ Commerce /___/ Orpaillage /___/ Autres /___/ (à préciser) …………………….
Mur du logement du chef de ménage	Banco seul /___/ Banco et ciment /___/Ciment seul /___/ Autres /___/ (à préciser)…………………………
Nature du toit du logement du chef de ménage	En secco /___/ En banco /___/ En tôle /___/ Autres /___/ (à préciser)………………………
Type de propriété de la terre	Propriétaire terrien /___/ Emprunt /___/ Achat /___/ Don /___/
Quels sont les équipements que vous possédez (préciser le nombre) ?	Charrue /_/__/ Charette /_/__/ Semoir /_/__/ Brouette /_/__/ Rayonnaire /_/__/ Autres /___/ (à préciser)…………………….
Quels sont les animaux que vous possédez (préciser le nombre) ?	Volaille /_/__/ Ane /_/__/ Bœufs /_/__/ Moutons /_/__/ Chèvres /_/__/ Porcs /_/__/ Chiens /_/__/ Autres /___/ ………
Quelle autre activité faite vous pour subvenir à vos besoins ?	

III. Agro-Pédologie

3.1. Production du mil et sorgho

Quelle est la dynamique des rendements du mil et du sorgho au cours des 10 dernières années ?	Hausse /___/ Baisse /___/ Evolution en dents de scie /___/
Qu'est-ce qui justifie cette dynamique ?	Faible fertilité du sol /___/ Faible utilisation de fertilisant /___/ Faible technicité /___/ attaques parasitaires /___/ inondation /___/ sècheresse /___/ vents violents /___/ Autres (à préciser) /___/…..
Sur les dix dernières années quelles ont été les mauvaises dans la production agricole ? Pourquoi ?	
Selon vous, quelles ont été les causes ?	Sècheresse /___/ Inondation /___/ Autres (à préciser) /___/………

Entre le sorgho et le mil, quelle spéculation cultivez-vous le plus ?	Il y'a dix ans :
	De nos jours :
Pourquoi ce changement ?	

3.2. Technique de production de sorgho

Cultivez-vous du sorgho ?	Oui /___/ Non /___/
Superficie du sorgho	
Localisation des champs	Champs de case /__/ Champs de brousse /__/
Rendements	Champ de case :……………Champ de brousse :………………
Topographie de vos champs de sorgho	Haut de pente /___/ moyenne pente /___/ bas de pente /___/
Sur quels sols cultivez-vous le sorgho ?	
Semences utilisées	Locale /___/ Améliorée /___/
Si semence améliorée, quelles sont les variétés que vous utilisez ?	Kapelga /___/ Sariasso11 /___/ Sariasso14 /___/ Sariasso16 /___/ Flagnon /___/ Ne connais pas /___/Autres (à préciser) /___/……..
Période de préparation du sol	
Type de labour	Grattage au daba /___/ Labour à plat /___/ Labour en billon /___/
Aménagements en CES/DRS dans vos champs de sorgho	Zaï /___/ Cordons pierreux /___/ Billons perpendiculaire à la pente /___/Zaï + Cordons pierreux /___/ Demi-lunes /___/ Labour à plat + Cordons pierreux /___/ Labour en billons + cordons pierreux /___/ Paillage /___/ Autres (à préciser) /___/ ……………
Quelle est la technique de CES/DRS la plus adaptée à la culture du sorgho ?	
Matériel utilise pour le labour	Daba /___/ Traction animale /___/ Traction motorisée /___/
Utilisation du sorgho	Consommation /___/ Vente /___/ Transformation /___/ Don /___/
Période de semis	
Les opérations d'entretien	1=démariage Oui/__/ Non /__/ 2= sarclage/sarclo-binage Oui/__/ Non /__/ Nombre de fois : 3=apport de NPK Oui/__/ Non /__/ Quantité : 4=apport Urée Oui/__/ Non /__/ Quantité :

	5=Buttage Oui/__/ Non /__/ 6=Fumure organique Oui/__/ Non /__/ Quantité et nature : 7=autres (à préciser)………………………..
Utilisation de la paille (feuille + tiges)	Paillage /___/ Compostage /___/ Energie domestique /___/ Fourrage /___/ Vente /___/ Autre (à préciser) /___/………………
Utilisation des panicules	Compostage /___/ Foin /___/ Autre (à préciser) /___/....................

3.3. Technique de production du mil

Cultivez-vous du mil ?	Oui /___/ Non /___/
Superficie	
Localisation des champs	Champs de case /___/ Champs de brousse /___/
Rendements	Champ de case :……………Champ de brousse :………………
Position topographie	Haut de pente /___/ moyenne pente /___/ bas de pente /___/
Sur quels sols cultivez-vous le mil ?	
Semences utilisées	Locale /___/ Améliorée /___/
Si semence améliorée, quelles sont les variétés que vous utilisez ?	IKMP-5 /___/ MISARI-1/___/ SOSSAT-C88 /___/ Autres (à préciser) /___/ …………………..Ne connais pas /___/
Utilisation du mil	Consommation /___/ Vente /___/ Transformation /___/ Don /___/
Période de préparation du sol	
Type de labour	Grattage au daba /___/ Labour à plat /___/ Labour en billon /___/
Aménagements en CES/DRS dans vos champs de mil	Zaï /___/ Cordons pierreux /___/ Billons perpendiculaire à la pente /___/Zaï + Cordons pierreux /___/ Labour en billons + cordons pierreux /___/ Paillage /___/ Autres (à préciser) /___/ …..
Quelle est la technique de CES/DRS la plus adaptée à la culture du Mil ?	
Matériel utilise pour le labour	Daba /___/ Traction animale /___/ Traction motorisée /___/
Période de semis	
Les opérations d'entretien	1=démariage Oui/__/ Non /__/ 2= sarclage/sarclo-binage Oui/__/ Non /__/ Nombre de fois :

	3=apport de NPK Oui/__/ Non /__/ Quantité : 4=apport Urée Oui/__/ Non /__/ Quantité : 5=Buttage Oui/__/ Non /__/ 6=Fumure organique Oui/__/ Non /__/ Quantité et nature : 7=autres (à préciser)………………………..
Utilisation de la paille (feuille + tiges)	Paillage /___/ Compostage /___/ Energie domestique /___/ Fourrage /___/ Vente /___/ Autre (à préciser) /___/………………
Utilisation des panicules et glumes	Compostage /___/ Foin /___/ Vente /___/Autre (à préciser) /___/...

3.4. Technique de production du niébé

Cultivez-vous du niébé ?	Oui /___/ Non /___/
Système de culture	En association Oui /___/ Non /___/ En pure Oui /___/ Non /___/
Superficie	
Localisation des champs	Champs de case /__/ Champs de brousse /__/
Rendements	Association :……………En pure :………………
Position topographie	Haut de pente /___/ Pente moyenne /___/ Bas de pente /___/
Sur quels sols cultivez-vous le niébé ?	
Semences utilisées	Locale /___/ Améliorée /___/
Si semence améliorée, quelles sont les variétés que vous utilisez ?	KVX.61.1 /___/ KVX.396.4.5.2D/___/ KOMCALE /___/ Ne connais pas /___/ Autres (à préciser) /___/………………………
Utilisation du niébé	Consommation /___/ Vente /___/ Transformation /___/ Don /___/
Période de préparation du sol	
Type de labour	Labour à plat /___/ Labour en billon /___/ Autres /___/…………..
Aménagements en CES/DRS dans vos champs de niébé	Zaï /___/ Cordons pierreux /___/ Zaï + Cordons pierreux /___/ Labour à plat + Cordons pierreux /___/ Labour en billons + cordons pierreux /___/ Autres (à préciser) /___/ ………………….
Quelle est la technique de CES/DRS la plus adaptée à la culture du niébé ?	

Matériel utilise pour le labour	Daba /___/ Traction animale /___/ Traction motorisée /___/
Période de semis	
Les opérations d'entretien	Sarclage/sarclo-binage Oui/__/ Non /__/ Nombre :....Apport de NPK Oui/__/ Non /__/ Traitement phyto Oui/__/ Non /__/ Nombre de fois :…… Autres (à préciser)……………
Utilisation des fanes	Compostage /___/ Fourrage /___/ Vente /___/ Autre (à préciser) /___/……..
Utilisation des coques	Compostage /___/ Foin /___/ Vente /___/ Autre (à préciser) /___/…………

3.5. Technique de production de l'arachide

Cultivez-vous de l'arachide ?	Oui /___/ Non /___/
Superficie	
Localisation des champs	Champs de case /__/ Champs de brousse /__/
Rendements	Champ de case :……………Champ de brousse :………………
Position topographie	Haut de pente /___/ Pente moyenne /___/ Bas de pente /___/
Sur quels sols cultivez-vous l'arachide ?	
Semences utilisées	Locale /___/ Améliorée /___/
Si semence améliorée, quelles sont les variétés que vous utilisez ?	Fleur 11 /___/ TS-32.1 /___/CN 94C /___/ KH 149 A /___/ RMP 12 /___/ RMP 91 /___/ Autres (à préciser) /___/ ……………..Ne connais pas /___/
Utilisation de l'arachide	Consommation /___/ Vente /___/ Transformation /___/ Don /___/
Période de préparation du sol	
Type de labour	Grattage au daba /___/ Labour à plat /___/ Labour en billon /___/
Aménagements en CES/DRS dans vos champs d'arachide	Cordons pierreux /___/ Labour à plat + Cordons pierreux /___/ Labour en billons + cordons pierreux /___/ Autres (à préciser) /___/ ……………….
Quelle est la technique de CES/DRS la plus adaptée à la culture de l'arachide ?	
Matériel utilise pour le labour	Daba /___/ Traction animale /___/ Traction motorisée /___/
Période de semis	
Les opérations d'entretien	Sarclage/sarclo-binage Oui/__/ Non /__/ Nombre de fois :……. Apport de NPK Oui/__/ Non /__/ Quantité :……….. Apport Urée Oui/__/ Non /__/ Quantité :…………..

Utilisation des fanes	Fourrage /___/ Vente /___/ Autre (à préciser) /___/………..
Utilisation des coques	Compostage /___/ Foin /___/ Vente /___/ Autre (à préciser) /___/.

IV. Environnement et gestion des sols

Quelle perception faite-vous de l'état des ressources naturelles au cours des 10 dernières années dans votre village ?	Sols : Dégradés /___/ Très dégradés /___/Intacts /___/ Améliorés /___/ Végétation : Diminuée /___/ Augmentée /___/ Faune : Diminuée /___/ Augmentée /___/
Quel est le niveau de fertilité de vos sols ?	Improductif /___/ Peu fertile /___/ Fertile /___/ Très fertile /___/
Comment reconnaissez-vous cet état de fertilité ?	
Quelles sont les causes de ce niveau de fertilité ?	
Quelles sont les techniques que vous utilisez pour faire face à la baisse de la fertilité des sols?	Zaï /___/ Cordons pierreux /___/ RNA /___/ paillage /___/ demi-lune /___/ Autres (à préciser) /___/………..
Quelle est selon vous la technique qui conserve le mieux le sol face à l'érosion hydrique ?	
Quelle est la technique la plus difficile à pratiquer ? Pourquoi?	

4.1. CES/DRS endogènes et gestion des catastrophes

Quelles sont les risques de catastrophe les plus récurrentes dans votre village au cours des 10 dernières années ?	Inondation /___/ Sècheresse /___/ Attaque acridienne /___/ Vents violents /___/
Quels sont les effets de ces évènements sur la production agricole ?	Hausse des rendements /___/ Baisse des rendements /___/
Quelles sont les pratiques utilisées pour	Zaï /___/ Cordons pierreux /___/ Demi-lunes /___/ RNA /___/

faire face à ces risques de catastrophes ?	Zaï-cordons pierreux /___/ Suivie de la Météo /___/ Rites coutumières/religieuses /___/ Autres /___/…………………….……
Quels sont les savoirs locaux (mouvements des oiseaux, mouvement des insectes, apparition de certains évènements) que vous utilisez dans le cadre de la lutte contre les changements climatiques ?	

4.2. Cas particulier des cordons pierreux

Pratiquez-vous les cordons pierreux	*Oui* /___/ *Non* /___/
Quels effets des cordons pierreux avez-vous remarquez ?	Freiner l'érosion hydrique /___/ Récupérer des terres dégradées /___/ Régulariser la pente /___/ Autres /___/……………………..…………
Depuis quand, pratiquez-vous la technique des cordons pierreux ?	
Qui vous a appris la technique ?	
Est-ce que le procédé de la pratiques a changé ?	Oui /___/ Non /___/
Si Oui, expliquer ce changement	
Comme vous pratiquez la technique des cordons pierreux, où les appliquez-vous ? (lieu et position topographique)	Champ de case /___/ Champ de brousse /___/ Haut de pente /___/ Moyenne pente /___/ Bas de pente /___/
Quel sont les sols adaptés à la technique de CP ?	
Décrivez ce sol	
Comment installez-vous les cordons ?	Former des lignes droites /___/ Former des lignes gondolées /___/ Former des lignes suivant les courbes de niveau /___/

Quels sont les écartements entre les cordons ?	
Combien de jours mettez-vous pour réaliser 1 ha de cordons pierreux lorsque les moellons sont poses?	
Si vous devriez embaucher une MO extérieur pour le réaliser, à combien le payerez-vous pour un ha ?	
Apportez-vous de la fumure organique dans les cordons pierreux ?	*Oui /___/ Non /___/*
Quantité de compost/ fumier utilisée ?	*Par ha : ………… (UML= charretée)*
Si le compost devrait être acheté, quelle serait le prix par UML ?	*1= Brouette /___/* *2= Charrette /___/* *3= Autre à préciser /___/*
Impacts des cordons pierreux sur l'environnement ?	
Selon vous, qu'est ce qui freine l'adoption des cordons pierreux ?	Manque de matériel /__/ Manque de main d'œuvre /__/ Manque d'information /__/ Pénibilité du travail /__/ Autres (à préciser) ………..
Pourquoi la technique des cordons pierreux ne donne pas le même rendement de culture dans même village ?	
Quelles stratégies faut-il pour une meilleure réplicabilité de la technique de cordons pierreux dans la perspective de l'intensification de la production du sorgho et du mil ?	

4.3. Cas particulier du Zaï

Pratiquez-vous du zaï ?	*Oui /___/ Non /___/*
Quels effets du Zaï avez-vous remarquez ?	Réduire les pertes de nutriments /___/ Récupérer des terres dégradées /___/ Autres /___/…………………………………………………………
Depuis quand, pratiquez-vous la technique du Zaï ?	
Qui vous a appris la technique ?	

Est-ce que le procédé de la pratiques a changé ?	*Oui* /___/ *Non* /___/
Si Oui, expliquer ce changement	
Comme vous pratiquez la technique du zaï, où les appliquez-vous ?	Champ de case /___/ Champ de brousse /___/ Haut de pente /___/ Moyenne pente /___/ Bas de pente /___/
Sur quels sols pratiquez-vous la technique du zaï ?	
Décrivez nous ce sol	
Quels sont les dimensions de vos zaï ?	Ligne : Poquet : Diamètre : Profondeur :
Combien de jours mettez-vous pour réaliser 1 ha de zaï ?	
Si vous devriez embaucher une MO extérieur pour le réaliser, à combien le payerez-vous?	Poquet : Hectare :
Apportez-vous de la fumure organique dans vos poquets de zaï?	*Oui* /___/ *Non* /___/ Nature de la F.O :……………
Si utilisation du compost/ fumier, quelle quantité ?	*Par poquet : ……. (UML = poignet)*
Si le compost est acheté, quelle est le prix par UML ?	*1= Sac de 50 kg* /___/ *2= Charrette* /___/ *3= Autre à préciser* /___/………………
Selon vous, qu'est ce qui freine l'adoption du zaï ?	Manque de moyen de matériel /__/ Manque de main d'œuvre /__/ Manque d'information /__/ Pénibilité du travail /__/ Autres (à préciser) /__/…………….
Pourquoi la technique du zaï ne donne pas le même rendement de culture dans même village ?	
Quelles stratégies faut-il pour une meilleure réplicabilité du Zaï dans la perspective d'intensifier la production du sorgho et du mil ?	

Annex 2. Questionnaire for focus group

FICHE POUR FOCUS GROUPE

<u>Objectif :</u> Evaluation des déterminants endogènes de l'adoption des pratiques de conservation des eaux et des sols dans le plateau central au Burkina Faso.

<u>Action :</u> analyser et comprendre les déterminants endogènes de l'adoption des pratiques de conservation des eaux et des sols dans le village de Sandogo.

1. Quelle perception faite-vous de l'état des ressources naturelles (sols, eaux, végétation, …) au cours des 10 dernières années dans votre village ?

    a. **Sols :**… ……………………………………………………………………….

    b. **Eaux :**…………………………………………………………………………

    c. **Végétation :**…………………………………………………………………

    d. **Faune :**……………………………………………………………………….

2. Quelles sont les stratégies endogènes que vous avez développées pour faire face à cette situation ?..

    ………………………………………………………………………………………………
    ………………………………………………………………………………………………
    ……………………………………………………………………………

    ………………………………………………………………………………………

3. Quelle est l'impact de chaque technique et technologie ?

    a. … ………………………………………………………………………………

    b. … ………………………………………………………………………………

    c. … ………………………………………………………………………………

    d. ……………………………….. …………………………………………………

e. ……………………………………………………………………………………

4. Inconvénients de chaque technique et technologie endogènes ?

   a. ……………………………………………………………………………………

   b. ……………………………………………………………………………………

   c. ……………………………………………………………………………………

   d. ……………………………………………………………………………………

5. Selon vous, quelle est la technique adaptée à la culture du sorgho ? Pourquoi ?

……………………………………………………………………………………………………
……………………………………………………………………………………………………
……………………………………………………………………………

6. Selon vous, quelles sont les techniques adaptées à la culture du mil ? Pourquoi ?

……………………………………………………………………………………………………
……………………………………………………………………………………………………
…………………………………………………………………………………

7. Selon vous, quelles sont les techniques non adaptées à la culture du mil et du sorgho ? Pourquoi ?...

……………………………………………………………………………………………………
……………………………………………………………………………………………………
…………………………………………………………………………………

8. Qu'est-ce que vous faite de votre production de :

   a. Sorgho : ………………………………………………………………………

   b. Mil : ……………………………………………………………………………

9. Selon vous, quelles stratégies faut-il pour une meilleure réplicabilite des techniques endogènes de CES/DRS dans la perspective de l'intensification de la production du sorgho ?.......…………………………………………………………………………………
……………………………………………………………………………………………………

…………………………………………………………………………………………………
…………………………………………………………………………………………………
…………………………………………………………………………………………………
………………

10. Depuis quand, pratiquez-vous les techniques de CES/DRS ?
11. Qui vous a appris les techniques de CES/DRS ?
12. Est-ce que le procédé des pratiques de CES/DRS endogènes a changé ?......................
13. Pouvez-vous nous expliquer ce changement ?..

……
………………………………………………………………………………………………

14. Quelles sont les difficultés majeures pour la pratique de ses techniques de CES/DRS ?

…………………………………………………………………………………………………

………………………………………………………………………………………………...

………………………………………………………………………………………………...

…..……………………………………………………………………………………………

15. Quelles sont les risques de catastrophe (inondation, sècheresse, attaque acridienne, vents violents, épisode de poussière) les plus récurrentes dans votre village au cours des 10 dernières années ?........ ……………………………………………………………..
16. Quelles sont les techniques que vous pratiquez face à ces risques de catastrophe ?...........

……
………………………………………………………………………………………………

17. Quelles sont les difficultés rencontre dans ces actions contre ces risques de catastrophe ?..

……
………………………………………………………………………………………………

18. Quelles solutions proposez-vous pour faire face à ces difficultés ?.....................................

………

…………………………………………………………………………………………………

19. Quels sont les savoirs locaux (mouvements des oiseaux, mouvement des insectes, apparition de certains évènements) que vous utilisez dans le cadre de la lutte contre les changements climatiques ?...

Annex 3. Form for the description of soil profiles

Numéro de Fosse…………………	Date de description……………	Unité cartographique……………..
Auteur………………………………	…………………………………	Classification………………………
FAO…………………………………	…………………………………	WRB…………………………………
USDA………………………………	…………………………………	Local ………………………………
Localisation………………………	…………………………………	Altitude……………………………
Coordonnées GPS………………	…………………………………	…………………………………………
Position géomorphologique…….	…………………………………	Topographique environnante………
Microtopographie……………….	…………………………………	Pente………………………………
Végétation et/ou utilisation………	…………………………………	…………………………………………
Matériau parental………………	…………………………………	Drainage……………………………
Etat hydrique……………………	…………………………………	Nappe phréatique………………
Elmts grossiers en surface……….	…………………………………	Affl. Roche/cuirasse………………..
Erosion……………………………	…………………………………	Influence humaine…………………
Classification technique………...	…………………………………	…………………………………………

Horizon/ Profondeur	Couleurs (s)		Tâches			Texture	Elements grossiers (> 2mm)			Structure
	Sec	Humide	%	Sec	Humide		%	Fragments minéraux	Nodules minéraux	

Horizon/ Profondeur	Consistance			Cutans, Face de pression ou de glissement	Pores	Cimentation/ Induration	pH	Racines	Activité biologique	Transition	Echantillon
	Sec	Frais	Humide								

Notes additionnelles……………………………………………………………………………………

Numéro définitif…………………Nombre d'échantillons prélévés…………………………………………

Annex 4. Results of the soil description of the experimental sites

Profil N°1 du site de Sandogo

N° du profil : BS1

Date de description : 06/02/2021

Auteurs : ………………………………………………………..

1°/ CLASSIFICATION DU SOL

CPCS (1967) : Sol ferrugineux tropical lessivé induré peu profond

WRB (2014) :

Légende FAO (1989) :

Technique : S2/S3 arachide, niébé, mung-bean

2°/ ENVIRONNEMENT DU PROFIL

- Localisation : Sandogo/Boussé (Province du Kourwéogo)
  Lat. : 1397258
  Long. : 648463
  Alt: 312 m

- Végétation et/ou utilisation : Culture pluviale arachide. Savane parc arbustive a *Piliostigma reticulatum, Guiera senegalensis, Combretum micranthum, Combretum glutinosum, Diospyros mespiliformis, repousses de Fedherbia albida.* Tapis herbace : herbe rouge .

- Position physiographique	:	glacis, pente supérieure
- Topographie environnante	:	quasi-plate
- Microtopographie	:	présence de billons de culture dégradés
- Pente	:	faible, environ 1-2% Sud-Est_Nord-Ouest
- Matériaux parental	:	……………….
- Drainage	:	Normal
- Etat hydrique	:	sec
- Nappe	:	non atteinte
- Eléments grossiers en surface	:	Nombreux épandage de gravier de cailloux ferrugineux
- Affleurements de roches et/ou de cuirasse	:	Néant
- Erosion	:	en nappe

- Influence humaine : Culture, pâturage, habitation à proximité

3°/ DESCRIPTION MORPHOLOGIQUE DU PROFIL

0 – 15 cm : Brun (10 YR 5/3) à l'état sec, brun jaunâtre foncé (10 YR ¾) à l'état humide ; limono-sableuse ; 50% de graviers ferrugineux ; structure faiblement développée, polyédrique, sub-angulaire en éléments moyens, fins et grossiers ; consistance peu dure ; nombreux pores fins, très fins, moyens et larges ; nombreuses racines fines et très fines ; activité biologique bien développée ; transition distincte.

15 – 35 cm : Horizon fortement gravillonnaire a plus de 70% de graviers ferrugineux ; limono-argilo-sableuse ; structure faiblement développée, polyédrique, sub-angulaire en éléments fins et moyens ; consistance dure ; nombreux pores fins, très fins et moyens ; assez-nombreuses racines fines, très fines, grossières et moyennes ; activité biologique bien développée ; abrupte irrégulière.

> 35 cm : Cuirasse ferrugineuse

Profil N°2 du site de Sandogo

N° du profil : BSH

Date de description : 15/08/2021

Auteurs : ……………………………………………………………………………..

1°/ CLASSIFICATION DU SOL

- CPCS (1967) : Sol ferrugineux tropical lessivé à taches et concrétions (FLTC)
- WRB (2014) :
- Légende FAO (1989) :
- Technique : S1/S2 Sorgho ; S2/S3 Mil, Niébé, Arachide

2°/ ENVIRONNEMENT DU PROFIL

- Localisation : Sandogo/Boussé (Province du Kourwéogo)
  Lat. : 1395088
  Long. : 649908
  Alt: 320 m

- Végétation et/ou utilisation : Culture pluviale de sorgho sous savane parc à *Vitellaria paradoxa, Sclerocarya birrea, Lannea microcarpa, Balanites aegyptiaca*, avec des repousses de *Combretum micranthum, Guiera senegalensis, Acacia macrostachya* et quelques *Piliostigma reticulatum*

- Position physiographique : Glacis de pente moyenne
- Topographie environnante : quasi-plate
- Microtopographie : présence de quelques termitières rouges
- Pente : faible, environ 1% Nord-Sud
- Matériaux parental : ……………………………………
- Drainage : Imparfait
- Etat hydrique : Sec à frais
- Nappe : non atteinte
- Eléments grossiers en surface : 0-2%
- Affleurements de roches et/ou de cuirasse : Néant
- Erosion : en nappe
- Influence humaine : Culture, Pâturage

3°/ DESCRIPTION MORPHOLOGIQUE DU PROFIL

0 – 17 cm : Brun jaunâtre (10 YR 5/6) à l'état humide ; limono-sableuse ; quelques graviers ferrugineux (2%) ; structure faiblement développée, polyédrique, sub-angulaire en éléments très grossiers, grossiers et moyens ; consistance friable ; nombreux pores fins, très fins, larges, moyens et très larges ; nombreuses racines fines, moyennes et très fines; activité biologique bien développée ; transition distincte.

17 –43 cm : Jaune brunâtre (10 YR 6/8) à l'état humide; limono-argilo-sableuse ; présence d'environ 5% de graviers ferrugineux; présence de quelques poches de coprolithes ; structure faiblement développée, polyédrique, sub-angulaire en éléments grossiers, moyens et très grossiers; consistance friable; assez nombreux pores fins, moyens, très fins , moyens, larges et très larges; assez nombreuses racines fines, moyennes, très fines et grossières; activité biologique bien développée ; transition distincte.

43-84 cm : Brun foncé (7,5Y 6/8) à l'état humide ; 10-15% de taches d'oxydation brun jaunâtre (10 YR 5/8) ; argilo-limoneuse ; 10% de concrétions de fer et Ferro-manganiques ; structure faiblement développée, polyédrique, sub-angulaire en éléments très grossiers, grossiers et moyens; consistance ferme ; présence de quelques poches de coprolithes ; peu nombreux pores fins, très fins, moyens et larges ; peu nombreuses racines fines, moyennes et très fines ; l'activité biologique assez bien développée; limite graduelle.

84-120 cm : Brun foncé (7,5Y 5/6) à l'état humide ; 15% de taches d'oxydation brun jaunâtre (10 YR 5/8) ; argileuse ; 15% de concrétions de fer et Ferro-manganiques ; structure faiblement développée, polyédrique, sub-angulaire en éléments très grossiers, grossiers, moyens et fins ; consistance très ferme ; présence de quelques poches de coprolithes ; peu nombreux pores très fins, fins et moyens; rare racines très fines, fines et moyennes; l'activité biologique faiblement développée.

Annex 5. Scientific publications and communications from the thesis

Ouédraogo H, Diallo Y, Hien E, Yaméogo LP, Udo N. 2022. Socio-economic indigenous drivers of soils and water conservation practices use to cope with climate change in the region of Plateau Central in Burkina Faso. *Int. J. Biol. Chem. Sci.,* **16**(6): 2841-2856. DOI : https://dx.doi.org/10.4314/ijbcs.v16i6.29

https://www.ifgdg.org/images/pdf/2022/December2022/9261-IJBCS-articles-Oudraogo-Harouna.pdf

Available online at http://www.ifgdg.org

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Socio-economic indigenous drivers of soils and water conservation practices use to cope with climate change in the region of Plateau Central in Burkina Faso

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Scientific communication

- **14-15 december 2022:** 10th edition of the Doctoriales of the 2IE Institute under topic «Socio-economic indigenous drivers of soils and water conservation practices use to cope with climate change in the region of Plateau Central in Burkina Faso» (Ouagadougou, Burkina Faso)

Poster

- **6-9 December 2022:** WASCAL Science Symposium with the topic « Socio-economic indigenous drivers of soils and water conservation practices use to cope with climate change in the region of Plateau Central in Burkina Faso » (Ouagadougou, Burkina Faso)

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