2015

Sorghum Yield and Zai Holes in Goundi, Burkina Faso

Justin Gelb
Michigan Technological University

Follow this and additional works at: https://digitalcommons.mtu.edu/etds
Part of the Agriculture Commons, and the Environmental Sciences Commons

SORGHUM YIELD AND ZAI HOLES IN GOUNDI, BURKINA FASO

By:

Justin Gelb

A THESIS

Submitted in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

In Forestry

MICHIGAN TECHNOLOGICAL UNIVERSITY

2015

This thesis has been approved in partial fulfillment of the requirements for the Degree of MASTER OF SCIENCE in Forestry.

School of Forest Resources and Environmental Science

Thesis Advisor: *Blair Orr*

Committee Member: *David Flaspoler*

Committee Member: *Ron Gratz*

School Dean: *Terry Sharik*

Contents

Abstract

The purpose of this study was to determine if there was a difference in sorghum yield between the Mossi zai hole and the Gourounsi zai hole, specifically examining the effects of manure and soil water conservation. A study field was created with six different treatments: (1) control with traditional management (no zai holes), (2) traditional management with manure, (3) Mossi zai holes with no manure, (4) Mossi zai holes with manure, (5) Gourounsi zai holes with no manure, and (6) Gourounsi zai holes with manure. Soil moisture readings were taken after each rainstorm (about weekly), soil properties were analyzed before planting and after harvest and above ground biomass was weighed at harvest.

Manure was the only variable that significantly increased crop yield. This is different from the original hypothesis; zai holes were thought to be the main driver of increased crop yield in Sahelian West Africa. Zai holes did not have a significant effect on soil moisture.

Chapter 1: General Introduction

I was placed in the village of Goundi with the outrageous expectation of planting 5000 trees per year. This was incredibly daunting. When I arrived in Burkina Faso I felt that I had somewhat of an understanding of how the ecosystem worked from my course work at Michigan Tech. I soon realized I was wrong.

Upon arriving in my village I learned that trees may not be what the people needed. I spoke with many farmers, held meetings, talked to my counterpart, and learned what projects my host organization had undertaken. I discovered that soil fertility was one of the main constraints in my village. I learned that there have been years of poor crop yield and people were going hungry for longer periods than they had in the past.

The zai hole is a soil water conservation method that was taught to my Peace Corps group during pre-service training. While in Goundi, I noticed that there were some farmers who practice this method of water harvesting. I began to enquire as to why and how they did it. It turned out that in Goundi the zai holes were used differently than in other parts of Burkina Faso. After seeing that there was a variation in the different types of zai holes, it led me to question whether one zai technique was more productive than the other.

Purpose

The purpose of this study was to determine if there was a difference in sorghum yield between the Mossi zai hole and the Gourounsi zai hole, specifically examining the effects of manure and soil water conservation. Working with my host organization, I was able to create a study field with six different treatments, both types of zai holes were studied with and without manure additions, there were also control treatments with and without manure additions. My counterpart and I hypothesized that treatments with zai holes would have a larger sorghum yield.

Food insecurity has been an increasing issue in Goundi as well as Burkina Faso as whole for the past century. Soil fertility and soil moisture are the greatest constraints for the Burkinabe farmer. Irrigation and chemical fertilizers are beyond the means of a village level farmer. Local technologies have been used to aid in soil water conservation but a sustainable means for increasing soil fertility has yet to be determined. Increased grain yields and food security must be attainable on the village level.

Structure of Thesis

This thesis documents the research on zai holes, a potential method to increase farm yields. Chapter two gives a general background of Burkina Faso; political history, ecological zones, demographics and general geography are discussed. The study took place in the Sanguié province of Burkina Faso. Chapter three describes the study site characteristics. In this section rainwater harvesting, manure usage, and zai holes are discussed in depth.

Chapter four discusses the methodology used for this study. All six different types of zai treatments are presented. Soil moisture readings are described. Field preparation is discussed as well as the crop choice. Chapter five outlines basic data. Soil moisture meter correlation values, a description of variables, univariate statistics and precipitation data are presented.

Chapter six is the results and discussion section. This chapter presents and describes the findings of this study. The statistical analyses are explained. Effect of manure, soil moisture and soil nutrients on crop yield and soil fertility are discussed. These data are compared with other studies. Finally in chapter seven conclusions and implications are drawn. Solutions are argued for sustainable farming in Goundi and the greater Sahelian ecosystem.

Chapter 2: Background

Description of Burkina Faso

Burkina Faso is situated in the heart of West Africa with no coastline. Burkina Faso is roughly the size of Colorado, 274,200 square km in size (CIA, 2013) Figure (2.1). Burkina Faso shares borders with six countries: Ghana, Togo, Benin, Niger, Mali and Cote d'Ivoire (Figure 2.2). Ouagadougou, the capital, is located in the Plateau-Central Region.

Figure 2.1. Burkina Faso in relation to Africa. Map by D-maps.com (http://d-maps.com/carte.php?num_car=25458&lang=en)

Figure 2.2. Burkina Faso in relation to West Africa, map by D-maps.com (http://d-maps.com/carte.php?num_car=36688&lang=en)

Government of Burkina Faso

Burkina Faso is an independent republic, constructed from civil law based on the French system. The Burkinabe government is unicameral, made up of a 127 member national assembly; each member serves a five-year term. In 1991 there was constitutional reform, bringing the country closer to democracy (Peace Corps, 2014).

The former president, Blaise Compaoré, held power from 1987 until October of 2014. Compaoré took power from former president Thomas Sankara in 1987 in a military coupe d'état. Before the coup d'état there was one ruling political party, the Congrès pour la Démocratie et le Progrès or CDP. After Compaoré was ousted there was a temporary parliament in place. The current president is Michel Kafando, a former diplomat. Kafando took power after a two-week period when the military of Burkina Faso had taken over control of the country following the power vacuum left by the former president. During this two-week period Lieutenant Colonel Isaac Zida attempted to discard the constitution of Burkina Faso, turning the country into a military state. The United Nations and the African Union responded to this by giving Zida two weeks to instate a civilian as president. When Kafando was appointed president, Zida was still able to keep a seat as Prime Minister with his own cabinet (Al Jazeera, 2014).

Figure 2.3. Independence Day celebration in Koudougou, Photo by Justin Gelb

Administrative Divisions

Burkina Faso is divided into 13 regions: Boucle du Mouhoun, Cascades, Centre, Centre-Est, Centre-Nord, Centre-Ouest, Centre-Sud, Est, Hauts-Bassins, Nord, Plateau-Central, Sahel, Sud-Ouest (Figure 2.4). The Centre region has the largest percentage of the population at 11.1% and the Cascades region with the lowest percent at 3.8% (Recensement Général de la Population et de l'Habitation [RGPH], 2006). Furthermore, regions are split into provinces, Burkina Faso has 45 administrative provinces.

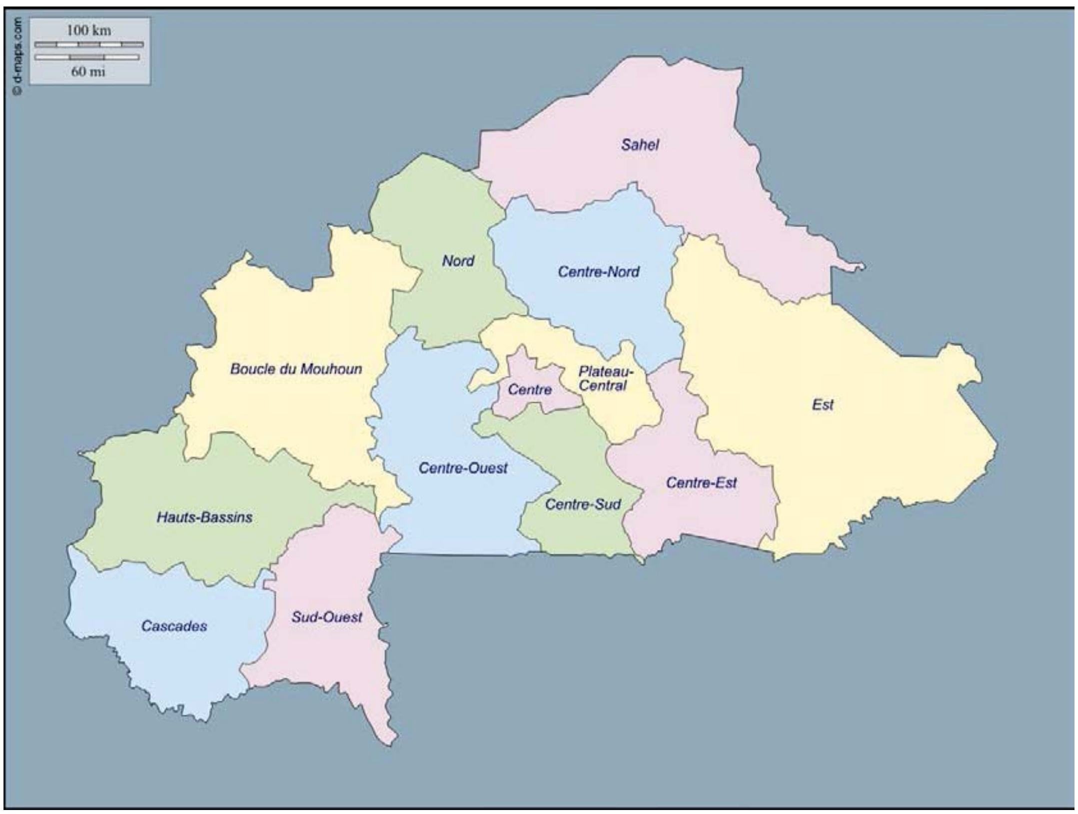

Figure 2.4. Administrative regions of Burkina Faso, map provided by d-maps. (http://dmaps.com/carte.php?num_car=34384&lang=en)

History

Prior to the French occupation of Burkina Faso in the 1890s, the country was comprised of one major kingdom ruled by the Voltaic Mossi, in the northern region of the country. The Voltaic Mossi had a specific political and social identity where warriors, craftsmen, farmers and chiefs were split in to groups based on hierarchy, with a centralized seat of power. The southern and western region of the country was occupied by a different group of people known as the Mandé. This group of people was made up of many different ethnic groups such as the Birifor, Bobo, Bwa, Dioula, Gourounsi, Lobi, and Senoufo groups who spoke different languages. During the pre-colonial period trans-Saharan trade was common. Gold, slaves and agricultural products were typical items that were bartered. Through the same routes, Islam was spread (Speirs, 1991).

French occupation began in the late 1890s when Burkina Faso was known as Upper Volta. The French occupation put a stop to trans-Saharan trade and attempted to force Burkina Faso into a cash crop economy. The French continued to oppress the people of Upper Volta by recruiting people for the military as well as imposing taxation and forced labor. By 1919 the French reconstituted Burkina Faso as well most other parts of West Africa into a region called Haut-Sénégal-Niger, which is made up of the current states of Burkina Faso and Mali. Then in 1932 the region was again divided up into Haut Volta, Mali and Niger (Speirs, 1991).

By 1946 the first Voltaics were being elected to the French National Assembly. This sparked the creation of various political parties in Upper Volta, the strongest being the Rassemblement Démocratique Africain or the RDA. The RDA was responsible for many strikes and demonstrations. By 1960 the Upper Volta was unified behind the RDA and gained independence with Maurice Yameogo as the first president. Yameogo held the presidency until 1966, when he was overthrown. This is when the salaries of civil servants had dropped below comfortable levels and the economic divide in urban and rural populations become increasingly large. This led the fourteen-year rule of General Lamizana. During his time in office two attempts were made to overthrow Lamizana. In 1980, the third coupe d'état succeeded. This coup d'état was due to corruption, decreased standard of living, political polarization and loss of military loyalty. Colonel Saye Zerbo followed shortly after, proclaiming that he would disband corruption although he had no real ideas for social change (Speirs, 1991).

By 1982 Zerbo had already been ousted from office, in part because of the large gap he was creating between the urban and rural populations. At this time the Upper Volta was putting all resources for agricultural development into cotton, a cash crop, and ignoring the country's need for food crops. Food security had become a more important issue because of a drought in the 1970s. Upper Volta continued to rely on foreign aid; the country was generating little if any money and food for itself. The development approach at this time was solely top down, only benefiting the people in office and of higher class, making it difficult for people on the village level to obtain the subsidies they needed (Speirs, 1991).

Thomas Sankara took power in 1983 with the boldest reform the country had ever seen; Sankara changed the name of Upper Volta to Burkina Faso meaning the Land of the Upright People. This name comes from the two most common local languages in the county, Mòoré and Dioula, in an attempt to reunite its people. Sankara pushed out all foreign aid, with the goal of organizing peasants and workers, claiming development should happen from within. This attempt at a socialist revolution did not last long, even though Sankara had implemented village level schools and health clinics. By 1987 he was killed in another coup d'état (Speirs, 1991).

Blaise Compaoré took power after the coup d'état. Compaoré was one of Sankara's main compatriots. Sankara's death was described as an accident. There was no investigation into his death until Compaoré fled office. After Compaoré took power in to 1987, he continued to lead the country until 2014, when he was finally ousted after many years of altering the constitution and lack of national development. Michel Kafando is the current temporary president of Burkina Faso, elections are scheduled for the end of 2015 to elect a permanent president.

People

The official language of Burkina Faso is French, generally spoken in cities and by the more educated population. Burkina Faso is made up of over

40 different ethnic groups who speak more than 60 different languages. The largest ethnic group is the Mossi, who are about 40% of the population. The Mossi reside in the central part for Burkina Faso, Ouagadougou is the ancient center of their empire. Tuaregs (Figure 2.5) and Fulani are the main ethnic groups in the northern part of Burkina Faso. These ethnic groups are nomadic and traditionally do not farm. The Gourounsi reside in central western Burkina Faso, where this study took place. The eastern part of the country is made up of mainly Gourmantché people. The southwest part of Burkina Faso is made up of many ethnic groups such as the Bobo, Senufo, Lobi, Mande and Bwa (CIA, 2013).

Figure 2.5. Tuareg man, Photo by Justin Gelb

Religious Practices

Burkina Faso's population is about 60% Islamic, 19% Catholic, 15.3% animist, and 4.2% Protestant (CIA, 2013). Islam and Christianity are the most common religious practices although most Burkinabe will practice one of these religions but keep some, if not all, of the traditional beliefs. Belief in witchcraft and sorcery is also common. People often blame poor rains, sickness, floods and even death on sorcery or other supernatural causes (CIA, 2013).

Figure 2.6. Traditional animist funeral mask demonstration, Photo by Justin Gelb

Ecological regions of Burkina Faso

Burkina Faso is comprised of three ecological regions: the Sahel in the north, the Sudan Savanna (Figure 2.7) in the central region and the Northern Guinean in the southern. The main difference in these ecological regions is the amount of rainfall they receive each rainy season. In the Sahel, the rainy season is short, with no more than 400mm of rain per year; vegetation is typically small stunted shrubs and thorny acacias. In the Sahel, agriculture is difficult with low rains and poor soil fertility; most people who inhabit this region are of the nomadic Tuareg and Fulani, ethnic groups who do not farm. The Sudan Savanna receives 500-1000mm of rain annually. As the average rainfall increases the vegetative diversity grows. The Sudan Savanna is characterized by a parkland ecosystem, seasonal cultivation is possible, finger millets and sorghum (*Sorghum bicolor*) are the most common crops, and maize [corn] is seldom grown due to its higher need for water (FAO, 1977). There is low tree density (10-40%) and there is a high concentration of farmland. Trees become larger and less thorny, *Vitellaria paradoxa*, *Parkia biglobosa*, *Adansonia digitata,* and *Faidherbia albidia* become more common. In the southwest part of the Burkina Faso the annual rainfall increases to 1000-1400mm of rain per year and tree diversity grows to include species such as *Erythrophluem suaveolens, Detarium senealense, Khaya senegalensis* and *Afzielia africana* (Timberlake et al, 2010). This is characterized as the Northern Guinean Savanna (FAO, 1977).

Figure 2.7. Typical Sudanian landscape, Photo by Justin Gelb

Sanguié province

The Sanguié Province is located in the Sudan Savanna ecosystem zone, in Centre-Ouest region of Burkina Faso with a population of 297,230 (Recensement général de la population et de l'habitation, 2006). The Sanguié is located just outside of the Mossi plateau. The provincial capital Reo is located 120km north of Ouagadougou. The Gourunsi are the traditional inhabitants of this province. All other ethnic groups who live in the Sanguié have migrated from other parts of Burkina Faso. The Sanguié is known for its production of garden produce, and is one of the few places in Burkina Faso where vegetables are grown regularly.

Chapter 3: Study site

The study site was located in the village of Goundi (12°12’56”N, 2°29 17W) located in the Sanguié province in the Centre-Ouest region of Burkina Faso. The Sanguié province is on the western edge of the ancient Mossi kingdom. This province is populated by the Gourounsi ethnic group. The Gourounsi speak an entirely different language than the Mossi and have different cultural norms than their neighbors.

Goundi is located about 112km west of the capital Ouagadougou and 12km west of the Burkina Faso’s third largest city Koudougou. Goundi is in the Northern Sudanian ecological region and receives between 700-900mm of rain per year. One of the busiest roads runs through Goundi. This road is one of the major arms of commerce linking three of Burkina Faso’s cities together (Ouagadougou, Koudougou and Dedougou) and also allows for the flow of trade from neighboring Mali and Cote d'Ivoire.

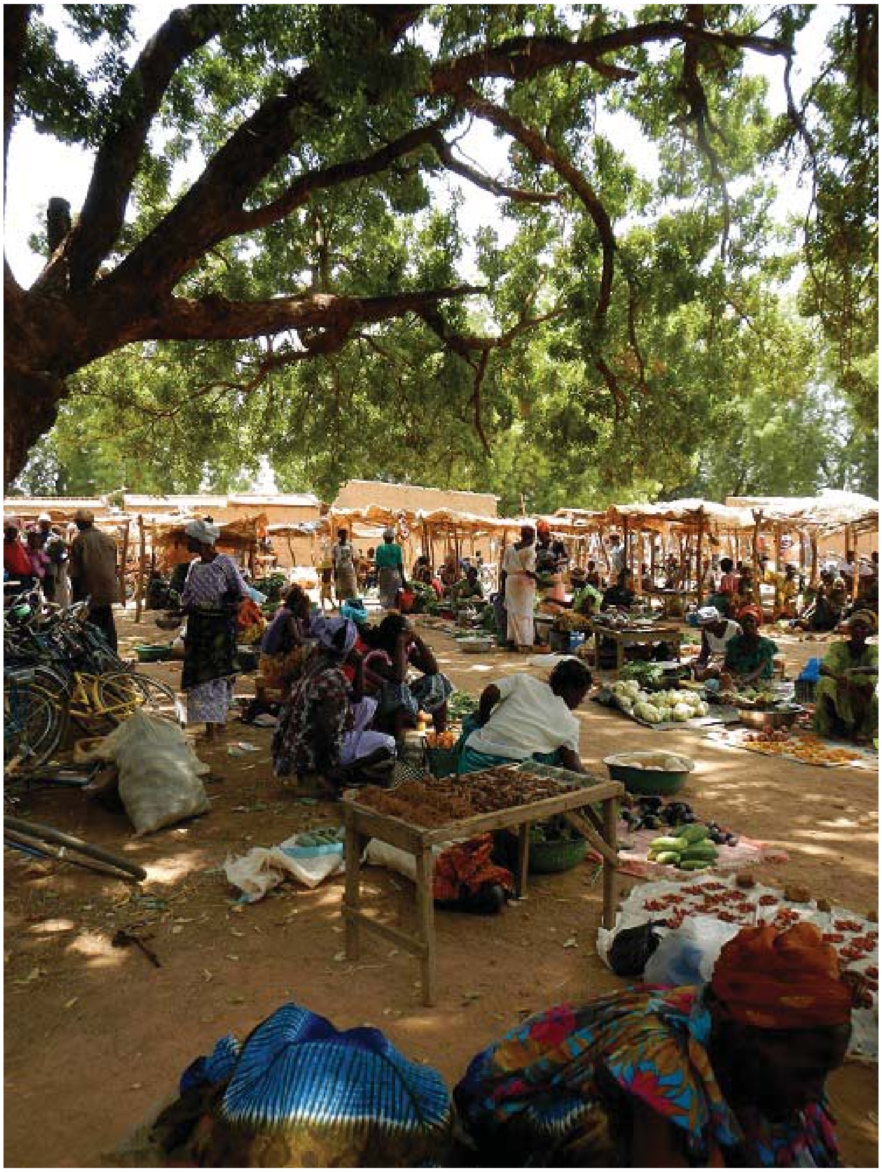

Figure 3.0. Market day in Goundi, Photo by Justin Gelb

The study took place in an agricultural vocational school within Goundi called the Centre de Promotion Rurale (CPR). The CPR is a regional school that accepts children from the Centre-Ouest region of the country. Students live at this school for two years while learning new agricultural techniques to eventually bring back to their communities.

Figure 3.1. Students working at the CPR school garden, Photo by Justin Gelb

Farming System

The population is made up of subsistence farmers who grow upland cereal crops such as millet and sorghum. In some areas farmers will also grow maize and rice in lowland areas that typically have a higher water table. Sweet potatoes are also grown two to three months of the year.

Goundi is different from most villages in Burkina Faso because of the amount of gardening that happens throughout the year. Onions and cabbage are the most widely produced vegetables and these can be found year round in the village market. Other vegetables grown throughout the year include eggplant, local eggplant, hot peppers, bell peppers, garlic, cucumbers, tomatoes, carrots, green beans, squash and pumpkin. All garden crops must be watered two to three times a day by hand (Figure 3.2). Farmers throw a ten liter bucket down a well and hoist it back up many times over the course of about two hours.

Figure 3.2. Watering onions in Goundi, Photo by Justin Gelb

Livestock is a crucial aspect of life in Goundi, most families will have various animals around their homesteads. Pigs and donkeys are the common animals eaten for food, although families usually have chickens and goats as well. Donkeys are used as beasts of burden until they become too old to function. Then they are sold at the market to be butchered. Animal husbandry is haphazard at best; most animals are left to roam. In the wet season people attempt to keep their animals tied up. This usually lasts for a month, then animals escape causing crop damage. Livestock in Goundi is used similar to insurance. Families will keep a pig or goat around for long periods of time until they need to money that this animal will produce. This can be problematic because a family can go on feeding the animal for months, if not years, before butchering the animal. When a family waits this long, the animal has already reached its maximum size and they will lose money by delaying bringing the animal to market.

Upland cereals and legumes are the two types of field crops grown in Goundi. Upland cereals consist of, sorghum (figure, 2.11), millet (*Eleusine coracana*) (figure, 2.13) and rarely maize (*Zea mays*). The legumes that are grown are black eyed peas (*Vigna unguiculata*), petits pois de terre (*Vigna subterranea*) and peanuts [groundnuts] (*Arachis hypogaea*). Gender roles dictate that men are responsible for the cereal crops and women take care of the legumes. Sorghum is the most common cereal. Villagers favor sorghum because an ancient custom states the village chief must taste the grains of millet before the rest of the village does to determine if it is ready to eat. Sorghum is not treated this way and families can harvest and eat sorghum when the please. Maize is grown by some families. It is much more water and nutrient demanding and usually requires some external input that cannot be provided by the average family.

Figure 3.3. Sorghum (*Sorghum Bicolor)*, Photo by Justin Gelb

Figure 3.4. Millet (*Eleusine coracana*), Photo by Justin Gelb

Figure 3.5. Traditional grain storage, Photo by Justin Gelb

Goundi for the most part is a subsistence agricultural system. Farming is the only means most people have to obtain food. Garden vegetables act as a cash crop. Almost all people sell the majority of their vegetable produce. Unfortunately the money made form garden crops does not last longer than three to five months. Markets are variable as well. It is possible for 50kg sacks of onions to fluctuate more than US$100 in one season. When there is disposable income it is normally used to buy sacks of grain to help support the family.

Shifting cultivation is the common mode of farming in Goundi. This also known as slash and burn farming. Traditionally in Goundi a farmer will clear a piece of land using machetes and burn (figure, 3.6), then farm the field for three to five years. The farmer would then clear another patch of land and repeat the process.

Lack of an understanding of family planning has led to an exponential increase of population in Goundi and in the rest of Burkina Faso. This means that arable land is at premium and farmers can no longer fallow their fields. It is not uncommon to find a farmer in Goundi who has been be growing sorghum in their field for over a decade with no rotation or fallowing. Due to poor farming practices, farming intensification and increased populations food insecurity in Goundi is a chronic issue. Poor soil fertility and lack of moisture are the greatest constraints to crop yield.

Figure 3.6. Burning crop residues after clearing, Photo by Justin Gelb

Rain Water Harvesting

Rain water harvesting is not a new concept in Burkina Faso or in Goundi for that matter. Rock lines and zai holes have been the topic of many studies Burkina Faso and West Africa. The goal of these water harvesting techniques is to conserve soil moisture. Increased soil moisture increases crop yield using inputs that are available to the subsistence farmer (Fox et al, 2005; Fox and Rockstrijm, 1999; Grey, 2005; Roose et al, 1999).

Rock lines and zai holes are the prevailing water harvesting methods in Burkina Faso. The rock line is fairly common throughout the county. This involves moving rocks about 10-20 cm in diameter to create a permeable barrier around a farmer's field which slows water runoff and allows for infiltration. Rock lines are fairly uniform throughout Burkina Faso. Rock lines have been shown to increase a farmer's yield significantly within the first year of implementation (Reij et al, 2005). Rock lines are arguably more sustainable than zai holes because they last for many generations, although the amount of labor required to initially construct rock line is beyond the means of most farmers. Rocks used to construct rock lines typically come from a site that is far from the farmers' field. Development efforts the help construct rock lines incorporate trucks to haul rock from different locations. If the farmer does not have access to these types of resources, rock line construction can be almost impossible.

Zai Holes

Zai holes are a type a planting pit first seen in the northern region of Burkina Faso in the Yatenga Province. The term zai originates from the Mossi word zaïégré, which translates to wake up early and prepare the seed bed. Zai holes are typically 20-40cm in diameter and 10-15cm deep (Figure 3.7). Zai holes were originally dug by poor farmers in the Yatenga province, who were given poor or non-arable land to farm. Zai holes were dug once at the beginning of the rainy season and in theory used again in subsequent years. The goal of zai holes in the Yatenga are to capture rain water, conserve moisture, and capture organic matter brought in by Harmattan Winds (Essama, 2005; Roose et al, 1999).

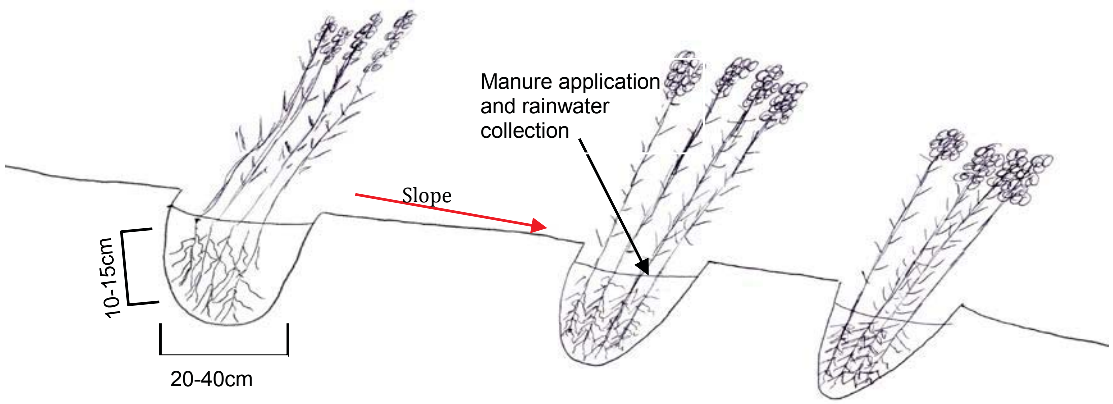

Figure 3.7. Basic zai hole structure

The Yatenga Province, where zai holes originated, is in the northern region of Burkina Faso where water is more limited than other parts of the country. The main goal of the zai hole is to harvest rain water and increase moisture availability, although the application of organic matter is crucial to increased plant yields (Essama, 2005). Water is the most limiting factor in Sahelian and Sudanian Africa. Zai holes attempt to assuage moisture constraints by harvesting rain water runoff by increasing water use efficiency (Fox and Rockström, 1999).

Beyond increasing water infiltration, zai holes increase organic matter content of the soil. Zai holes may be filled with organic matter to encourage termite colonization. Termites help the decomposition of organic matter and help increase soil nutrients (Bayala et al, 2012). Extended use of zai holes have also been known to increase soil fertility on land thought to be unusable. Yields can increase up to four hundred percent with the use of the zai practice (Sawadogo, 2011).

Figure 3.8. Digging zai holes, Photo by Justin Gelb

In Goundi zai holes are a common practice but the people in this village have a different practice when planting in zai holes. During the beginning of each rainy season farmers will dig zai holes in sorghum or millet fields. These holes are filled with compost or manure and then seed is planted. The biggest difference in the Goundi or Gourounsi zai hole compared to the Yatenga or Mossi zai, is the cultivation process. The Gourounsi farmers will close each hole with a hand hoe during cultivation. Once the hole is closed it no longer retains water as effectively.

Manure

Ungulate manure and organic fertilizer are crucial in any farming system in Burkina Faso. Soil in Burkina Faso is typically poor and farmers do not have the capital to buy chemical fertilizers (McClintock and Diop, 2005; Nyamangara et al 2004). Farmers apply manure to their fields to help increase nutrients and nutrient holding capacity.

Manure has been shown to increase soil nutrients such as nitrogen potassium and phosphorus in semi-arid West Africa. In this region of the world soil tends to be sandy with little nutrient holding capacity (Esse et al, 2001). Low cation exchange capacity (CEC) is common in sandy soils, which make nutrient absorption in the soil difficult (Brady and Weil, 2002). Manure additions in sandy soil can increase CEC allowing the soil to have a higher nutrient holding capacity (Bationo and Buerkert, 2001).

On the village level soil fertility is one of the greatest constraints when attempting to increase crop yield. The use of manure and organic compost is a likely solution to help increase millet and sorghum yields, although crop residues and manure are normally used in gardens or fields used to grow cash crops (Abdoulaye and Sanders, 2005). Farmers in Goundi and in the rest of Burkina Faso prioritize other crops such garden vegetables and other cash crops such as cotton.

Manure usage and water conservation are two of the greatest constraints in West Africa. The purpose of this study is to understand how manure and zai holes effects sorghum yield on the village level, using only techniques seen by local farmers. Treatments were developed in an attempt to understand the best possible way of improving crop yield and food security on the local level.

Figure 3.9. Making compost, Photo by Justin Gelb

Chapter 4: Methods

In this study six different treatments were used to determine the effectiveness of zai holes on soil moisture retention and manure use on sorghum yield. In the Northern Region of Burkina Faso the Mossi People have been using zai holes for many generations. The Mossi zai is recommended to farmers in Goundi by extension agents. The village of Goundi is occupied by a different ethnic group, known as the Gourounsi, who, despite recommendations from extension agents, use a different type of zai hole. The Mossi zai was primarily for water conservation, where the Gourounsi zai focused more on the incorporation of manure into the soil. This study compared the Mossi zai and the Gourounsi zai using six different treatments:

1. Control plot with traditional hoeing and no manure additions,
2. Control plot with traditional hoeing and manure additions,
3. Mossi zai with no manure additions,
4. Mossi zai with manure additions,
5. Gourounsi zai with no manure additions,
6. Gourounsi zai with manure.

The objective of this study was to determine how these zai treatments affect sorghum yield with inputs available to the local farmer. The initial idea to create this study was formed by holding Peace Corps meetings about general village needs with smallholder farmers of Goundi to determine what they would find interesting. Using participatory method insures that that community will have a vested interest in the outcome of a development project (Lilja and Bellon, 2008).

This study attempted to replicate what the local subsistence farmers do in the field, the only difference being the zai hole treatment. In the village of Goundi many farm inputs such as irrigation, chemical fertilizers and animal draft power are not available to the average farmer. In this study none of these resources were used. In this way farmers could see how these different treatments could improve crop yield with locally available tools and resources (Earnshaw, 2011; Satterlee et al, 2009).

Location

All treatments were located in a one-quarter hectare field that was located in the village of Goundi and supplied by the Centre de Promotion Rurale (CPR). The field was land allocated by the CPR and was used as a demonstration for all of the students who attend the school. The field was part of a larger two-hectare field previously used for planting various food crops such as sorghum, millet, sesame, peanuts and black-eyed peas. The field was enclosed within a chain-link fence. The plot where the study took place had peanuts growing the previous year and sorghum the year before that. Crop rotations such as this are optimal in areas such as this but are becoming a less common farming practice.

Water harvesting methods

This study focused on two different types and zai holes, the more common Mossi zai, first seen in the northern region of Burkina Faso, which is hand weeded, and the Gourounsi zai which is weeded with a hand hoe. The primary goal of the Mossi zai is to harvest rainwater and prevent runoff. This method was first used by farmers who were only allocated land with poor soil fertility and used as a method of soil and water conservation. As the population of Burkina Faso has grown land fertility has been slowly decreasing and this type of zai hole has been publicized by agricultural extension agents throughout Burkina Faso (Reij, 1989). The Mossi zai is typically dug once and then used for multiple years. Fields with Mossi zai hole are weeded by hand and the space around the hole is weeded using a traditional hand hoe. Gourounsi zai holes are re-dug every year and when the first weeding occurs the holes are closed with hand hoes. This method appears to be used more in conjunction with the application of manure or compost (Figure 4.1).

Figure 4.1. Digging zai holes and preparing field, Photo by Justin Gelb.

Experimental Design

In this trial five 3 x 6 meter plots were assigned for each of the six treatments in complete randomized block design (Figure 4.2). There were five plots for each of six treatments: (1) a control with traditional management (no zai holes), (2) traditional management with manure, (3) Mossi zai holes with no manure, (4) Mossi zai holes with manure, (5) Gourounsi zai holes with no manure, and (6) Gourounsi zai holes with manure. Thus, the study was designed to capture the impact of both manure and water through the use of zai holes on sorghum yield.

6	1	4	5	1	3
6	6	2	4	2	5
1	3	1	2	6	4
2	5	6	1	4	3
5	3	4	3	2	5

Figure 4.2. Randomized block design: (1) a control with traditional management (no zai holes), (2) traditional management with manure, (3) Mossi zai holes with no manure, (4) Gourounsi zai holes with manure, (5) Mossi zai holes with no manure, and (6) Gourounsi zai holes with manure. Each block is 3 x 6 meters and the entire trial area covers 15 x 36 meters.

Soil samples

Soil samples were taken before planting and after harvest. A composite soil sample was collected from each plot with a hand hoe and analyzed by the National Bureau of Soil in Ouagadougou. The soil was analyzed for percent clay, percent silt, percent sand, organic matter, carbon, nitrogen, C/N, phosphorus, potassium, calcium, magnesium, sodium, the sum of bases, CEC, and total base saturation. Soils samples were taken before planting, then once more after harvest. The soils data collected was soils texture; percent clay, silt, slit (Bouyoucos, 1962). Total organic matter and carbon were analyzed using the Walkley-Black test (Walkley and Black, 1934). Nitrogen and potassium were analyzed using the Kjeldahl method (Kjeldahl, 1883). Phosphorus levels were determined using the Bray test (Bray and Kurtz, 1945). Using a thiourea agent, cation exchange capacity, sum of bases, and base saturation was determined as well the composition of each of the following elements: calcium (meq/100g), sodium (meq/100g), magnesium (meq/100g), and potassium (meq/100g) (Pleysier and Juo, 1980).

Planting and field Preparation

Working with the students and the teachers of the CPR I was able to delineate the 15 x 36 meter parcel which we then divided into 30 3 x 6 meter plots. Each plot was marked to note which treatment the plot would be placed in the plot. All zai holes were dug before planting and bovine manure additions from the CPR were incorporated in appropriate treatments. A full wheelbarrow (about 0.17 cubic meters per plot or 38 tons per hectare) of manure was used on each of the plots that required manure additions. The manure density found in the study falls within commonly reported ranges for moist manure (Malgeryd, 1994; Thirion et al, undated). In the two treatments that did not have zai holes (1, 2) the soil was tilled before planting, this helped incorporate the manure into the soil in treatment two. The soil in treatment one was also tilled to keep the planting medium consistent. In treatments four and six about one large handful (0.002 $meters^3$) of manure was placed in each hole, totaling the volume of one wheelbarrow per plot. Manure was applied three days before planting. All plots were planted with the three-month sorghum of the Kapelga variety. The seeds were sown in each plot at a 50cm X 80cm spacing. Seeds were planted using a traditional hand hoe, using this hand hoe a small pocket about 10cm in diameter and 5cm in depth was dug in each treatment. Ten seeds were placed in each pocket and the soil was then closed. Once the seeds began to germinate each pocket with leaflets was thinned to three plants. Seven percent of the planting pockets had less the three plants germinate these pockets were reseeded.

Figure 4.3. Delineating plant spacing, Photo by Justin Gelb

Weeding

Each plot was weeded twice in the style that fit the type of treatment (Figure 4.4), Mossi zai treatments were weeded by hand, Gourounsi zai treatments were weeded with a hand hoe, and control treatments were also weeded with a hand hoe. Weeding for each treatment was based on how each ethnic group traditionally cares for their fields. The first weeding occurred four weeks after planting and the second weeding occurred eight weeks after planting.

Figure 4.4. Weeding zai treatments, Photo by Justin Gelb

Moisture measurements

There were eight weeks during this trial when moisture measurements were taken. The soil in Burkina Faso hardens when dry. With the types of moisture meters that were used, measurements were only possible after a rainstorm. Therefore measurements were only taken when the soil was moist. A digital Inspect USA meter was used to measure soil moisture close to the surface at 20 cm while a Lincoln analog meter was used to measure deeper soil moisture at 60 cm. During each measuring period soil moisture for five plants were measured per plot and each location near the plant was measured three times, an upslope, on the contour, and downslope measurement was taken 10cm from each plant, resulting in 900 measurements per measurement day. Students at CPR helped take all field measurements, the goal was to ensure that each student would be able to learn about rainwater harvesting. All measurements were taken while I was present to ensure the data was obtained consistently and recorded correctly. A rain collection gauge was also placed at the study site in order to measure rainfall events. After every rainfall the millimeters of rainfall were written down and then totaled at the end of the season. This rainfall data were also compared to regional weather station data, to determine if there was a large difference in the area.

Harvest

Harvest took place 15 weeks after planting. Obtaining grain yield was the original intent of this study, however due to low rainfall and delayed harvest this was not possible before the trial ended. In lieu of grain yield, above ground biomass was weighed immediately after harvest (Figure, 4.5). Several studies indicate that there is a significant relationship between grain and total above ground biomass (Piper and Kulakow, 1993; Sarig et al, 1987).

Figure 4.5. Above ground biomass, photo by Justin Gelb.

Statistical Analysis

Data was analyzed using the SAS® (SAS Institute, 2012) statistical program. An analysis of variance (ANOVA) was used to compare cardinal data against categorical data. The other SAS processes used were PROC UNIVARIATE, PROC MEANS and PROC GLM. Soil moisture meter readings were compared using PROC CORR. Pre and post soil test means were compared using paired t-tests, significance was tested at $P<0.05$. Significance and P values are reported in the results and discussion sections.

Chapter 5: Data

Data were collected for the variables shown in Table 5.1 (page 45). This table shows all variables that were used in this study. Each variable is accompanied by its appropriate description.

Two moisture meters used this in this study. The Lincoln analog meter (referred to as the *deep* soil meter) was longer and measured moisture deeper in the soil (60.96 cm), while the Inspect USA digital meter measured soil (referred to as the *shallow* soil meter) at shallower depths (20.32 cm). The deep soil readings are positively significantly correlated with the shallow readings (Table 5.2).

Table 5.2, correlation of deep and shallow meter readings

Date	R	p
06/17/2014	0.7676	0.001
06/28/2014	0.8191	0.001
07/08/2014	0.8130	0.001
07/19/2014	0.6292	0.001
08/05/2014	0.4359	0.016
08/13/2014	0.8378	0.001
08/20/2014	0.8922	0.001
09/03/2014	0.8342	0.001

Univariate statistics are listed for each cardinal data point (table 5.3). Each rain event was recorded, 76mm was the largest rain event of the season (table 5.4). Total season rain was 731.5mm while the total rainfall recorded at the regional weather station located in the city of Reo 12km north of Goundi was 770.22mm.

Table 5.1 Description of variables used in this study

Variable	Description
TREATA	Dummy variable where 1= control treatment with no manure
TREATB	Dummy variable where 1 =control, with manure
TREATC	Dummy variable where 1 =Mossi zai, no manure
TREATD	Dummy variable where 1 =Mossi zai, with manure
TREATE	Dummy variable where 1 =Gourounsi zai, no manure
TREATF	Dummy variable where 1 =Gourounsi zai, with manure
MANURE	Dummy variable where 0 =no manure Dummy variable where 1 =manure
ZTREATM	Dummy variable where 0 =regular planting Dummy variable where 1 =Mossi zai Dummy variable where 2 =Gourounsi zai
D6X17P	6/17/2014 shallow soil moisture reading (%)
D6X17A	6/17/2014 deep soil moisture reading
D6X28P	6/28/2014 shallow soil moisture reading (%)
D6X28A	6/28/2014 deep soil moisture reading
D7X8P	7/8/2014 shallow soil moisture reading (%)
D7X8A	7/8/2014 deep soil moisture reading
D7X19P	7/19/2014 shallow soil moisture reading (%)
D7X19A	7/19/2014 deep soil moisture reading
D8X5P	8/5/2014 shallow soil moisture reading (%)
D8X5A	8/5/2014 deep soil moisture
D8X13P	8/13/2014 shallow soil moisture reading (%)
D8X13A	8/13/2014 deep soil moisture reading
D8X20P	8/20/2014 shallow soil moisture reading (%)
D8X20A	8/20/2014 deep soil moisture reading
D9X3P	9/3/2014 shallow soil moisture reading (%)
D9X3A	9/3/2014 deep moisture reading
YIELD	Above ground biomass (kg)
CLAY 1	Clay pretest (%)

Table 5.1, (continued) Description of variables used in this study

Variable	Description
CLAY 2	Clay posttest (%)
LOME 1	Silt pretest (%)
LOME 2	Silt posttest (%)
SAND 1	Sand pretest (%)
SAND 2	Sand posttest (%)
TOTOGM 1	Total organic matter pretest (%)
TOTOGM 2	Total organic matter posttest (%)
CARTOT 1	Total carbon pretest (%)
CARTOT 2	Total carbon posttest (%)
NTOT 1	Total nitrogen pretest (%)
NTOT 2	Total nitrogen posttest (%)
CXN 1	Carbon: nitrogen ratio pretest
CXN 2	Carbon: nitrogen ratio posttest
PPPM 1	Phosphorus parts per million pretest
PPPM 2	Phosphorus parts per million posttest
KPPM 1	Potassium part per million pretest
KPPM 2	Potassium part per million posttest
CA 1	Calcium meq/100g of exchangeable bases pretest
CA 2	Calcium meq/100g of exchangeable bases posttest
MG 1	Magnesium meq/100g of exchangeable bases pretest
MG 2	Magnesium meq/100g of exchangeable bases posttest
K 1	Potassium meq/100g of exchangeable bases pretest
K 2	Potassium meq/100g of exchangeable bases posttest
NA 1	Sodium meq/100g of exchangeable bases pretest
NA 2	Sodium meq/100g of exchangeable bases posttest
SOB 1	Sum of bases pretest
SOB 2	Sum of bases posttest
COE 1	Cation exchange capacity pretest
COE 2	Cation exchange capacity posttest

Table 5.1, (continued) Description of variables used in this study

Variable	Description
TS 1	Base saturation pretest
TS 2	Base saturation posttest

Table 5.3, Univariate statistics

Variable	Mean	Std Dev	Minimum	Maximum
YIELD	17.18	7.74	3.60	29.80
D7X8P	21.78	7.08	16.06	45.53
D6X17P	20.49	7.22	14.48	47.07
D6X17A	5.13	1.90	2.27	9.40
D6X28P	20.03	6.47	14.77	40.88
D6X28A	5.45	1.67	3.53	9.33
D7X8A	5.66	1.80	3.13	9.87
D7X19P	17.37	3.16	13.48	25.53
D7X19A	5.04	1.19	3.60	7.87
D8X5P	8.23	3.36	0.59	13.44
D8X5A	2.96	1.00	1.60	5.27
D8X13P	15.81	3.86	11.59	31.31
D8X13A	4.05	1.30	1.87	7.20
D8X20P	19.69	6.54	14.13	40.21
D8X20A	5.47	1.76	2.47	9.60
D9X3P	18.01	5.04	12.37	37.46
D9X3A	4.40	1.75	2.07	8.40
CLAY1	24.38	9.50	13.73	45.10
CLAY2	25.23	7.73	17.65	43.14
LOME1	21.56	3.41	15.68	29.41
LOME2	21.83	3.25	15.68	29.41
SAND1	54.05	8.04	37.25	66.67
SAND2	52.94	7.21	37.25	62.75
TOTOGM1	0.90	0.19	0.64	1.28
TOTOGM2	1.11	0.13	0.75	1.31
CARTOT1	0.52	0.11	0.37	0.74
CARTOT2	0.64	0.07	0.43	0.76
NTOT1	0.04	0.01	0.02	0.06
NTOT2	0.07	0.01	0.04	0.09
CXN1	14.50	2.29	11.00	18.00
CXN2	9.50	1.46	7.00	14.00

Table 5.3, (continued) Univariate statistics

Variable	Mean	Std Dev	Minimum	Maximum
PPPM1	687.47	94.82	523.00	898.00
PPPM2	860.17	713.65	441.00	4521.00
KPPM1	266.43	68.72	176.00	415.00
KPPM2	537.03	126.61	330.00	816.00
CA1	3.40	1.12	2.05	5.93
CA2	2.68	0.89	1.54	5.52
MG1	1.48	0.39	1.01	2.38
MG2	1.67	0.56	0.82	2.83
K1	0.25	0.13	0.01	0.55
K2	0.27	0.24	0.08	1.29
NA1	0.06	0.03	0.03	0.14
NA2	0.05	0.01	0.03	0.08
SOB1	5.20	1.57	3.27	8.46
SOB2	6.17	8.41	3.24	50.40
COE1	5.89	1.77	2.92	8.81
COE2	9.58	15.30	5.24	90.40
TS1	88.33	8.42	61.00	98.00
TS2	67.77	7.12	53.00	84.00

Table 5.4, Precipitation in Goundi Burkina Faso for the 2014 rainy season

Date (month/day)	Precipitation (mm)
4/9	10.0
4/10	0.5
5/10	10.0
5/14	1.5
5/25	10.0
5/30	1.0
6/1	4.0
6/5	41.0
6/11	30.0
6/12	15.0
6/13	2.0
6/14	0.5
6/16	13.0
6/17	4.0
6/28	76.0
6/29	25.0
7/2	24.0
7/3	9.0
7/4	22.0
7/7	7.5
7/18	22.0
7/24	34.0
7/31	4.0
8/4	4.0
8/5	18.0
8/8	21.0
8/10	12.0
8/11	3.5
8/12	22.0
8/14	3.0
8/16	18.0
8/17	11.0
8/20	52.0
8/22	10.0
8/27	10.0

Table 5.4, (continued) Precipitation in Goundi Burkina Faso for the 2014 rainy season

Date (month/day)	Precipitation (mm)
9/1	28.0
9/2	5.0
9/2	15.0
9/3	7.5
9/5	7.5
9/6	2.5
9/14	29.0
9/15	13.5
9/19	10.0
9/23	15.0
Total	731.5

Chapter 6: Results and Discussion

Manure use had a statistically significant impact on yield (F=52.44, Pr <F=0.0001) The zai treatment did not influence yield (F=0.95, Pr<F=0.40) or moisture retention (Tables 6.1 and 6.2). This is interesting because almost all research indicate that for zai holes, soil moisture is the primary variable that increases yields (e.g. Bayala et al, 2012; Sawadogo, 2011; Zougmoré 2003). In this study manure is the most important aspect of the planting methods.

The next section describes the yield increases associated with manure application. The soil moisture section describes the possible reason for lack of soil moisture influence of zai holes on yield. Finally the effect of the manure on soil nutrients will be discussed. Using this information a determination will be made on the effectiveness of zai holes and manure usage on sorghum yield.

Manure and zai treatments

Manure is the only statistically significant treatment in this study (F=52.44, Pr <F=0.0001) (Figure 6.1). Manure was the most important aspect of this trial, which was different from the initial hypothesis. The control treatment with manure has a greater biomass yield than all of the treatments without manure (Figure 6.2). The extra labor needed to dig zai holes is not justified in the current farming system used in Goundi. With this

understanding manure collection is paramount in the weeks before planting and in this trial the application methods were statistically similar.

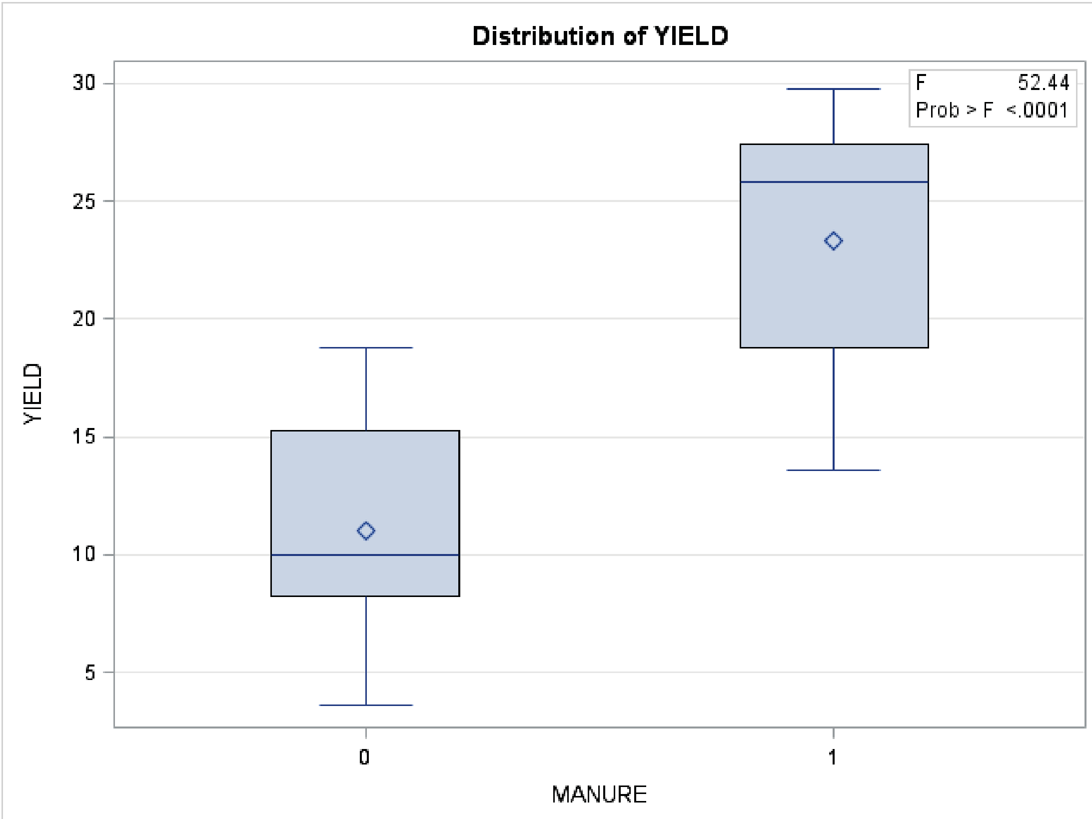

Figure 6.1. ANOVA test results of treatment yields with and without manure usage. 0= above ground biomass yield (kg) in treatments without manure 1= above ground biomass yield (kg) in treatments with manure applications. Treatments with manure applications have significantly higher yields (F=52.44, Pr <F=0.0001) than treatments without manure.

Manure increases soil nutrients and soil nutrient holding capacity, this is represented in the three treatments with manure use. Two out of the three treatments using manure show a statistically significant different yield than all non-manured treatments (F=12.36, Pr>F=<0.0001) (Figure 6.2).

In semi-arid West Africa water is typically seen as the largest constraint to crop growth. In this study the manure had a larger role in overall biomass yield. Fox and Rockstrijm (1999) found similar results, zai holes influenced crop yield only a third as much as organic fertilizer did by itself. This further bolsters the argument that manure and compost may be more effective than water harvesting methods.

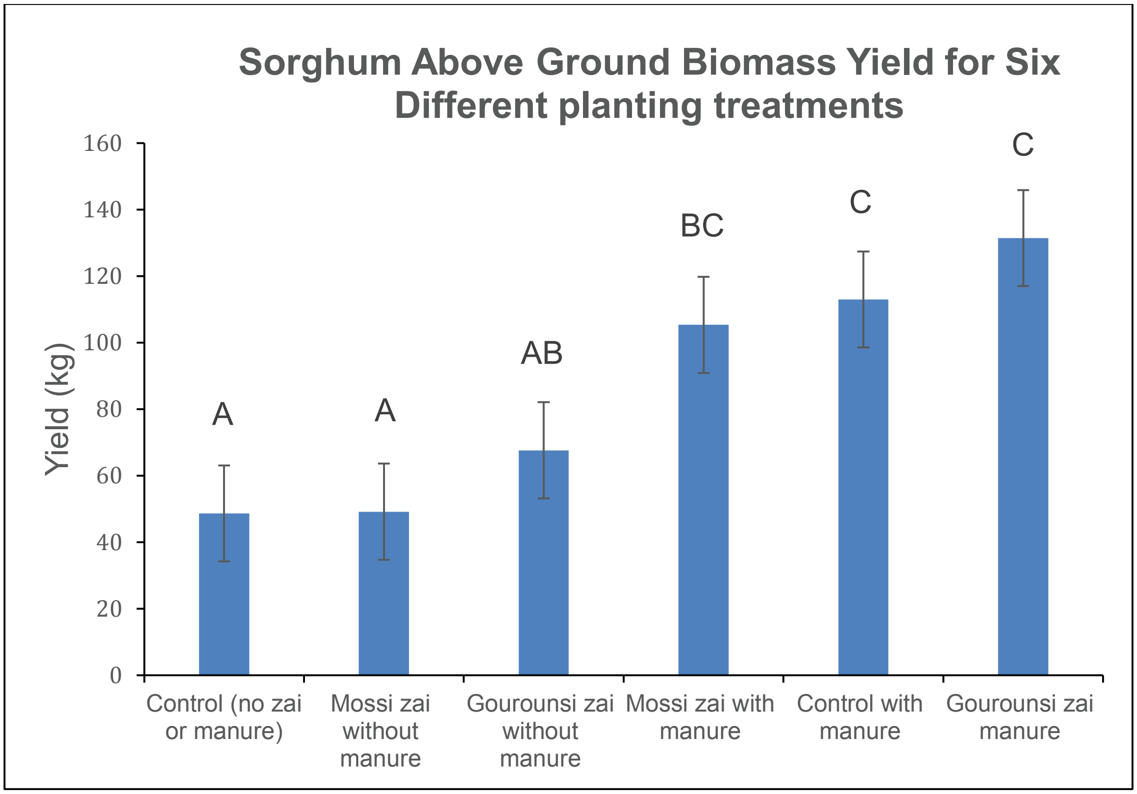

Figure 6.2 Sorghum yield in relation to zai treatment. Identical letters indicate no statistically significant difference among treatments (F=12.36, Pr >F=0.0001; alpha=0.05 for Tukey's HSD test)

Soil moisture

The Gourounsi zai that is seen around Goundi is a traditional practice and may have evolved from the Mossi zai; Goundi is near a large Mossi city. The annual precipitation for Goundi is 700-900mm which is about 200mm higher then where the Mossi zai originated in the Yatenga region of Burkina Faso. In areas with lower rainfall it has been noted that the zai technique increases crop yield and helps to reclaim degraded land. Zai treatments in the Yatenga are usually implemented concurrently with rock lines and organic matter applications are usually implemented as well (Reij et al, 2005). In a village where rainfall is not as much of a constraint, soil water conservation may not be as important as organic fertilizers. Farmer select crops with regard to water demand. Sorghum is an appropriate crop choice in Goundi because it requires less water than other cereal crops such as maize.

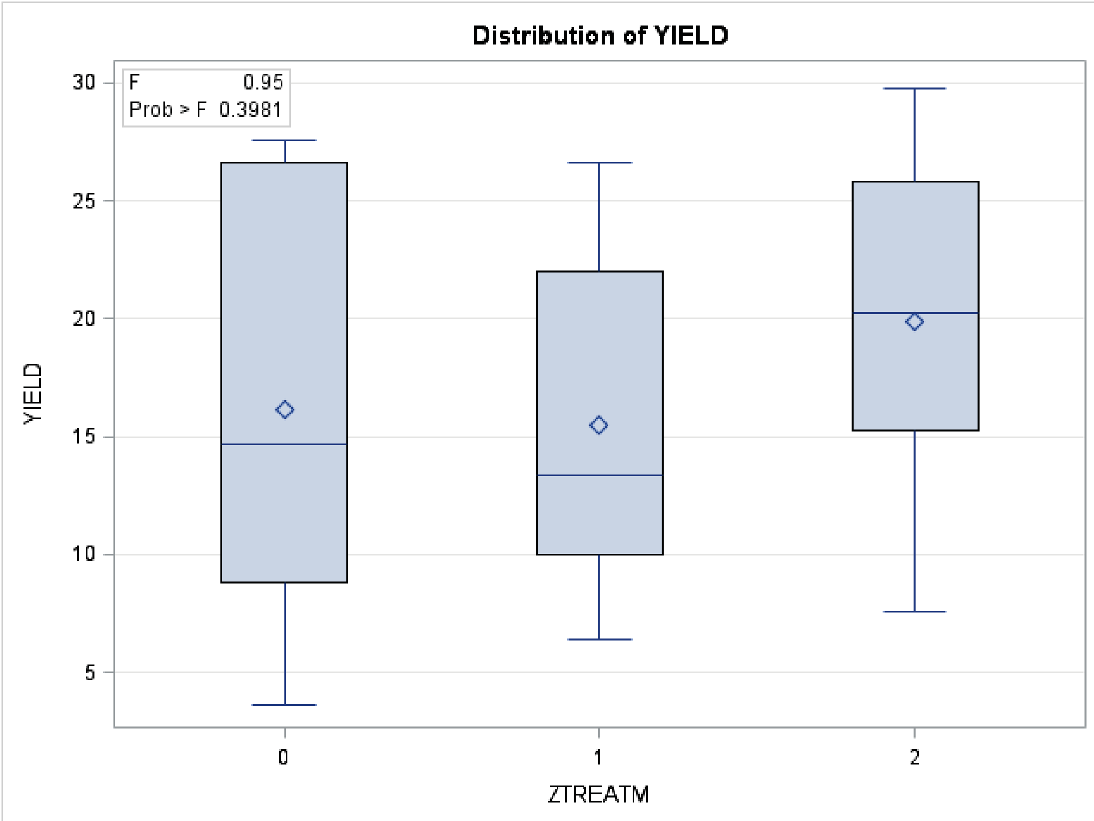

Figure 6.3. Yields with respective zai treatments using an ANOVA test for comparison. 0= above ground biomass yield (kg) control plots using traditional cultivation only 1= above ground biomass yield (kg) in treatments using Mossi zai. 2= above ground biomass yield (kg) in treatments using the Gourounsi zai. None of the zai or control treatments showed a significant difference in biomass yield (F=0.95, Pr>F=0.398).

Implementing water harvesting systems need to have a great reward; the amount of effort that is required to prepare, mandates a large payoff. Rain in Burkina Faso is variable. Farmers are being educated about soil water conservation practices throughout Burkina Faso by agricultural extension agents or non-governmental organizations (NGOs). Extension agents and NGOs emphasize soil moisture rather than organic fertilizer. If farmers are given an understanding that digging zai holes will increase their farms' yield and they do not see a payoff, this can be detrimental to the household because of additional labor inputs. Manure or compost inputs make the zai treatments pay off (Fox et al, 2005), and as this study has illustrated, the zai treatment may not be necessary to increase yield through improving soil moisture (Figure 6.1, page 52).

Tables 6.1 (shallow readings) and Table 6.2 (deep readings) show the F and p values for ANOVA tests at each measured date to determine if the soil moisture was significantly different in any of the zai treatments. On no date did the zai treatments show a significant difference in soil moisture with either meter. Throughout the study there was no significant difference in moisture retention in any of the three zai treatments. This is the opposite of what other studies have shown (Reij et al, undated). Most studies have shown that the water holding aspect of the zai is the greatest factor when increasing crop yield (Essama, 2005; Fox and Rockstrijm, 1999; Reij, 1989).

Table 6.1. Effects of zai treatments on moisture (shallow readings)

Date	F	p
06/17/2014	0.24	0.787
06/28/2014	0.20	0.821
07/08/2014	0.17	0.843
07/19/2014	1.85	0.177
08/05/2014	0.22	0.805
08/13/2014	1.76	0.192
08/20/2014	0.16	0.851
09/03/2014	0.95	0.398

Table 6.2. Effects of zai treatments on moisture (deeper readings)

Date	F	p
06/17/2014	2.30	0.120
06/28/2014	2.11	0.141
07/08/2014	1.64	0.213
07/19/2014	0.00	0.996
08/05/2014	1.49	0.244
08/13/2014	1.38	0.268
08/20/2014	0.76	0.476
09/03/2014	0.63	0.538

In this study zai management was carried out in manner as a subsistence farmer would in Burkina Faso. The moisture readings show that there is no added water retention in any of the zai treatments using current farming practices ($F=0.95$, $Pr>F=0.398$). This could be for a number of different reasons. Farmers fill the Gourounsi zai with soil during the first weeding, thus the intention of this zai was never to retain water; it is used primarily as a farming practice for manure or compost additions. The Mossi zai on the other hand is widely recognized in the northern regions of Burkina Faso because of its water and organic matter retention purposes. In this study there was no additional water retention, but manure use was extremely important. Throughout the rainy season both types of zai holes were filled up with sediment after only a few rainstorms, by the end of the rainy season it was impossible to tell if holes had actually been dug at planting.

In most case and research studies, zai holes are controlled by the researcher (Roose et al, 1999; Fox and Rockstrijm, 1999; Sawadogo, 2011);

in this study the methods that were used came from the surrounding community. The local farming system in Goundi was mimicked as much as possible. The only aspect that was changed was the manner in which the field was set up, to include all treatments. This type of experimental structure was used to determine what zai treatment would best benefit the subsistence farmer within their current farming system. In this situation the zai holes were weeded and dug according to how farmers work on their fields. This management showed that the most important aspect of these treatments was manure application. Using the farmers' traditional method of zai construction and maintenance, moisture had no effect on crop yield.

In addition, there was no statistically significant interaction effect with zai treatment and manure ($F= 0.10$, $Pr>F=0.9024$). This is to be expected since zai treatments had no statistically significant difference.

Soil nutrients

Analysis showed that manure applications significantly altered many soils characteristics. Total organic matter, carbon, nitrogen and potassium (ppm) were all significantly increased (Table 6.3). This shows the application of manure was important for the plant yield. Potassium and nitrogen are two of the most important nutrients for plant growth and grain yield (Bennett et al, 1990). This increase of soil fertility is the pathway by which the manure increases plant yield.

Nitrogen is one of the most import elements for plant growth. Manure additions are so important because these farm fields have been exhausted through many years of farming. The addition of organic fertilizer helps replenish important nutrients such as nitrogen. Zai holes are typically thought to increase organic matter while increasing soil moisture, thereby increasing crop yield. Manure increased the nitrogen and organic matter in the soil (Table 6.3).

An increase of organic matter in the farm fields will ultimately increase soil fertility over time, continuing to produce higher annual crop yields. Increased organic matter, through increased CEC, will promote a higher retention of nutrients in the soil. In fields that have been so depleted by repetitive farming with limited soil conservation practices this is important. In poor soils added nutrients may leach out of the soil, not allowing plants to obtain what is needed. Nitrogen may volatize during the growing season. In this study there was an increase of sorghum yield due to organic matter input. Conversely when soil was tested for CEC there was no significant change. No change in CEC indicate that one application of organic matter is not enough to replenish the soil. The lack of change of CEC may also be the result of sandy soil (Brady and Weil, 2002). Sandy soils make it more likely for organic matter to decompose and therefore more difficult to raise CEC through the application of manure. Short term effects of manure applied in this study, only once and at low levels, have helped increase yield but will not sustain yield.

Manure applications in this study were in the low end of what is required to increase soil fertility (Malgeryd, 1994; Thirion et al, undated). This is representative of the short-term increase of soil nutrients that were observed in this study. On farmland with higher soil fertility manure applications are typically 56 tons per hectare, and this is also with the additions of chemical fertilizer (Madison et al, undated). In this study enough manure was applied to make a difference for one season. In order for a sustainable increase of soil fertility manure applications need to be increased.

Manure is known to increase both macro and micro soil nutrients over time, such as nitrogen potassium and phosphorus (Brady and Weil, 2002). In this study there was an increase of nitrogen and potassium (Table 6.3) in post-harvest soil tests. This implies that manure did have an effect on soil fertility. However there was no significant change in the sum of cation bases, this continues to show that a solitary application of organic fertilizer may not have an influence on long term soil fertility. CEC did not increase ($Pr>F=0.26$, $t=1.17$), indicating that the organic matter, and its ability to hold additional nutrients added to the soil this season, has decomposed during the growing season.

Sawadogo et al (2008) performed a similar study in the Yatenga region Burkina Faso and found that zai holes influence crop yield, but without added organic inputs water harvesting alone is not sufficient. Organic fertilizer applications increase vital soil nutrients such as phosphorus (Sawadogo et al, 2008). There was no significant change in phosphorus levels in Goundi after the application of manure, but there was still an increase in yield. This could be attributed to the continuous use of the same farm field and lack crop rotation or the higher rainfall of the region around Goundi. However, the additional organic matter has not increased CEC over the growing season, indicating that the amount of manure added was not sufficient to build organic matter stocks in the soil.

Table 6.3 Soil property change from pre and posttest soil samples of treatments with manure applications only (n=15, paired t test)

Property	p	t
Clay	0.68	0.41
Silt	0.58	0.57
Sand	0.36	-0.94
Total org matter	<0.01	5.42
Total carbon	<0.01	5.41
Total nitrogen	<0.01	9.41
C/N	<0.01	-5.81
Phosphorus (ppm)	0.26	1.19
Potassium (ppm)	<0.01	10.88
Calcium meq/100g	0.13	-1.61
Magnesium meq/100g	0.41	0.85
Potassium meq/100g	0.30	1.09
Sodium meq/100g	0.20	-1.35
Sum of bases	0.34	-0.98
Cation exchange capacity	0.26	1.17
Base saturation	<0.01	-5.63

Chapter 7: Conclusion

Zai holes, as water harvesting methods, have proven to be an effective means of increasing crop productivity. In Goundi manure had the greatest effect on crop yield. The use of organic fertilizers such as manure and compost increase nutrient levels. Continued organic matter additions offers the potential for long-run increase in cation exchange capacity. The increase of yield in manure treatments indicate that soil nutrients were more important in this study. These data show (Table 6. 3, page 60) the exchangeable bases do not change from the beginning of the growing season to the time of harvest. In nutrient poor soils with low organic matter one season of organic fertilizer application may be not enough; multiple years may be required.

Organic fertilizer can be used to improve soil fertility, but in Burkina Faso manure and compost are not the easiest resources to come by. Most famers who make compost use it on higher value crops such as cotton or garden vegetables. Extension agents and NGOs attempting to develop rural communities must help create an understanding of the importance of applying and using organic fertilizer on food crops. The use of green manure has been shown to have positive effects on crop yields while still being in the reach of subsistence farmers in Sub-Saharan Africa (Satterlee et al, 2009). Green manure is the use of fresh leaves as organic fertilizer. Leaves are tilled into the soil and as they decompose they release usable nutrients to nearby plants. Adding the leaves of a nitrogen fixing tree to the soil could be used as a method of soil restoration in areas where compost and other organic fertilizers are at a premium. Another possible solution would be the use of a leguminous cover crop during the dry season to prevent erosion and soil degradation (Thurston, 1997).

In areas where rainfall is not as significant of a constraint, manure could be recommended with equal or greater emphasis than the use of water harvesting. Water harvesting can still be useful in other areas. In the northern part of Burkina Faso where rainfall is less frequent zai holes can still be an important aspect of the farming system. These methods should be used in conjunction with each other. Rock lines have been shown to increase yield in multiple studies (Fox et al, 2005; Reij et al, 2005). The difficulty with rock lines is that the construction is normally beyond the farmers' scope of labor, in both studies rock lines were implemented with help from foreign aid.

Proper extension work and trainings can eventually lead to a sustainable understanding of soil fertility. It is difficult for rural farmers to develop their farming practices through community development if there is just one person in a village using improved farming techniques. These new ideas can lead to development as ideas flow through farmer to farmer extension techniques (Tanakaa et al. 2013).

Foreign interaction has the possibility to help rural farmers. Although foreign aid normally cannot easily access rural communities and will not be the catalyst for development, it must come from within. The annual use of manure and other organic fertilizers with an understanding of best farming practices can eventually lead to an agricultural system that not in a chronic state of food insecurity. In recent years reforestation efforts that haven been implemented in years past have begun to take effect, the Sahel and the Sudian regions have been experiencing an increase of soil fertility and plant regeneration (West et al, 2014). Soil restoration methods that yield quick results, such as organic fertilizer additions will be adopted by farmers faster (Satterlee et al, 2009). Agricultural development is an extremely difficult undertaking; hard work, self-confidence, willingness to work together are vitally important (Bunch, 1985). Subsistence farmers are willing to change if it can be shown to them that these methods will work to help their families.

Literature Cited

Abdoulaye T, Sanders JH. 2005. Stages and Determinates of Fertilizer use in Semiarid African Agriculture: The Niger Experience. Agricultural Economics 32:167-179

Al Jazeera. 2014. Burkina Faso names transitional president. On line: http://www.aljazeera.com/news/africa/2014/11/burkina-faso-names-transitional-president-201411174225824l648.html. Site visited 1/28/2015

Bationo A, Buerkert A. 2001. Soil organic carbon management for sustainable land use in Sudano-Sahelian West Africa. Nutrient Cycling in Agroecosystems 61:131–142

Bayala J, Sileshi GW, Coe R, Kalinganire A, Tchoundjeu Z, Sinclair F, Garrity D. 2012. Cereal yield response to conservation agriculture practices in drylands of West Africa: A quantitative synthesis. Journal of Arid Environments 78:13-25

Bennett WF, Tucker BB, Maunder AB. 1990. Modern Grain Sorghum Production. Iowa State Press. Ames, Iowa.

Bouyoucos GJ. 1962. Hydrometer Method Improved for Making Particle Size Analysis of Soils. Agron. J. 54:464-465.

Brady NC, Weil R. 2002. Elements of the Nature and Properties of Soils (Second edition). Pearson, Prentice Hall. Upper Saddle River, NJ.

Bray RH, Kurtz LT. 1945. Determination of Total, Organic, and Available forms of phosphorus in soils. Soil Science, 59:39-45.

Bunch, R. 1982. Two Ears of Corn. World Neighbors. Oklahoma City, Oklahoma.

CIA (Central Intelligence Agency), U.S. 2013. The World Factbook 2013-14. Washington, DC, Burkina Faso. On line: https://www.cia.gov/library/publications/the-world-factbook/geos/uv.html. Site visited: 2/10/1015

Earnshaw, KM. 2011. The Effects of Soil Moisture, Field-scale Toposequential Position, and Slope on Yields in Irrigated Upland Rice Fields in Flores, Comayagua, Honduras. Unpublished Master's Thesis, Michigan Technological University, Houghton, MI.

Essama, S. 2005. Burkina Faso: the Zaï technique and enhanced agricultural productivity. IK Notes 80. World Bank.

Esse PC, Buerkert A, Hiernaux P, Assa A. 2001. Decomposition of and Nutrient Release from Ruminant Manure on Acid Sandy Soils in the Sahelian Zone of Niger, West Africa. Agriculture, Ecosystems and Environment 83:55–63

FAO. 1977. Savanna Afforestation in Africa. Rome, Italy.

Fox P, Rockstrijm J. 1999. Water-Harvesting for Supplementary Irrigation of Cereal Crops to Overcome Intra-Seasonal Dry-Spells in the Sahel. Phys. Chem. Earth 25(3):289-296

Fox P, Rockstrom J, Barron J. 2005. Risk analysis and economic viability of water harvesting for supplemental irrigation in semi-arid Burkina Faso and Kenya. Agricultural Systems 83:231–250

Grey LC. 2005. What Kind of Intensification? Agricultural Practice, Soil Fertility and Socioeconomic Differentiation in Rural Burkina Faso. The Geographical Journal, 171(1):70-82

Kjeldahl JZ. 1883. A new method for the determination of nitrogen in organic bodies. Analytical Chemistry 22:366.

Lilja N, Bellon M. 2008. Some Common Questions about Participatory Research: A Review of the Literature. Development in Practice. 18: (4/5)479-488

Madison F, Kelling K, Massie L, Good LW. Undated. Guidelines for Applying Manure to Cropland and Pasture in Wisconsin. University of Wisconsin.

Malgeryd J. 1994. Manure Characterization. Int. Agrophysics. 8:93-101

McClintock NC, Diop AM. 2005. Soil Fertility Management and Compost Use in Senegal's Peanut Basin. International Journal of Agricultural Sustainability

Nyamangara J, Mudhara M, Gilleri KE. 2004. Effectiveness of Cattle Manure and Nitrogen Fertilizer Application on the Agronomic and Economic Performance of Maize. South African Journal of Plant and Soil 22(1):59-63

Peace Corps. 2014. Burkina Faso. United States Government. Online: http://burkinafaso.peacecorps.gov/. Site accessed 1/30/2015.

Piper J, Kulakow P. 1993. Seed yield and biomass allocation in Sorghum bicolor and F_1 and backcross generations of S. bicolor x S. halepense hybrids. Can. J. Bot. 72: 468-474.

Pleysier JL, Juo.1980. A Single-Extraction Method Using Silver-Thiourea for Measuring Exchangeable Cations and Effective CEC in Soils with Variable Charges. Soil Science.129 (4):205-211.

Recensement Général de la Population et de l'Habitation (RGPH). 2006. Resultats Prelminaires, du Recensement General de la Population et de l'Habitation De. Goverment du Burkina Faso

Reij C. 1989. The Agro-forestry Project in Burkina Faso: An analysis of Popular Participation in Soil and Water conservation. Working Group for Resource Development in African Free University, Amsterdam

Reij C, Mulder P, Begeman L. Undated. World Bank Technical Paper Number 91. World Bank Washington D.C.

Reij C, Tappan G, Belemvire A. 2005. Changing Land Management Practices and Vegetation on the Central Plateau of Burkina Faso (1968–2002). Journal of Arid Environments 63:642–659

Roose E, Kabore V, Guenat C. 1999. Zaï Practice: A West African Traditional Rehabilitation System for Semiarid Degraded Lands, A Case Study in Burkina Faso. Arid Soil Research and Rehabilitation. 13:343-355

Sarig S, Blum A, Okon Y. 1987. Improvement of the water status and yield of field-grown grain sorghum (Sorghum bicolor) by inoculation with Azospirillum brasilense. J. agric. Sci. 110:271-277

SAS Institute Inc. 2012. Version 9.4, Cary, NC: SAS Institute Inc.

Satterlee BM, Yemefack M, Orr BD. 2009. Maize yield and soil property responses to Entada abyssinica (Steud. ex A. Rich.) cuttings in the Adamawa Lowlands, Cameroon. Journal of Food, Agriculture & Environment Vol.7 (1): 192-296

Sawadogo, H. 2011. Using Soil and Water Conservation Techniques to Rehabilitate Degraded Lands in Northwestern Burkina Faso. International Journal of Agricultural Sustainability 9 (1):120–128

Sawadogo H, Bock L, Lacroix D, Zombré NP. 2008. Restauration des Potentialités de Sols Dégradés à l'Aide du Zaï et du compost dans le Yatenga (Burkina Faso). Biotechnol. Agron. Soc. Environ. 12 (3):279-290

Spiers, M. 1991. Agrarian Change and the Revolution in Burkina Faso. African Affairs. 90 (358)89-110. Oxford University press.

Tanakaa A, Saitob K, Azomab K, Kobayashia K. 2013. Factors Affecting Variation in Farm Yields of Irrigated Lowland Rice in Southern-Central Benin. Europ. J. Agronomy 44:46–53

Thirion F, Chabot F, Andeler D. Undated. Physical Characterization of Animal Manure. Cemeagref Domaine des Palaquins.

Thurston DH. 1997. Slash/Mulch Systems, Sustainable Methods for Tropical Agriculture. Westview Press. London, UK.

Timberlake J, Chidumayo E, Sawadogo L. 2010. Distribution and Characteristics of African Dry Forests and Woodlands. Dry Forests and Woodlands of Africa.

Walkley, A, Black IA. 1934. An examination of the Degtjareff Method for Determining Organic Carbon in Soils: Effect of Variations in Digestion Conditions and of Inorganic Soil Constituents. Soil Sci. 63:251-263.

West CT, Some A, Nebie EK. 2014. Famines are a Thing of the Past: Food Security Trends in Northern Burkina Faso. Human Organization 73(4)

Zougmoré R, Zida Z, Kamboua NF. 2003. Role of Nutrient Amendments in the Success of Half-Moon Soil and Water Conservation Practice in Semiarid Burkina Faso. Soil & Tillage Research 71: 143–149