Evaluation of the Effect of Ridging on the Rainwater Use Efficiency of Soybean Production in North Eastern Ghana

UNIVERSITY OF HOHENHEIM

Master Thesis

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Abstract

It is undisputed that a primary effect of climate change is the alteration of rainfall patterns. This alteration causes some areas of the world to have insufficient rainfall and others to have too much. Many other areas suffer not from change in rainfall quantity but rather suffer from sporadic rainfall, with fewer number but heavier events than are typical. Smallholder farmers of sub-Saharan Africa have been identified as particularly vulnerable to the effects of drought and sporadic rainfall, and mitigation strategies must be investigated and employed to ensure rainfed agriculture remains a feasible way to sustain agricultural production.

One potential mitigation strategy is contour ridge tillage. Soil ridging promotes the soils ability to allow water to infiltrate, have ideal permeability and water holding capacity – all necessary capabilities a soil must have in order to maintain soil moisture content to support plant growth. The ridges evacuate water in times of heavy rainfall, and the furrows maintain water in times of drought.

The objectives of the current study were to determine if soil ridging can make a significant difference on soil moisture levels, and if the ridges supported differences in select plant growth parameters, yield, and water use efficiency when compared to conventional tillage in the Chereponi District of in Northern Ghana.

Results indicated that while soil ridging did make a significant difference on soil moisture levels, it made very little difference in plant growth parameters, with no significance seen in the differences of yield and water use. Duration of rainfall into pod-filling stage, and baseline organic matter/ natural fertility gradient proved to be factors more important to soybean production than tillage type.

Further studies should focus on long term water management options, operating over a variety of years with varying rainfall levels. Water harvesting techniques to supplement soybean in growth stages for water could be an interesting climate smart agricultural solution rather than ridging.

Statutory Declaration

I, Jessica Lynn Lloyd, born on 25 October 1987, matriculation number 651077, hereby declare that the attached Master's thesis has been independently prepared, solely with the support of the listed literature references, and that no information has been presented that has not been officially acknowledged.

Supervisors: Professor Dr. Folkard Asch, PD. Dr. Ludger Herrmann

Thesis topic: Evaluation of the Effect of Ridging on the Rainwater Use Efficiency of Soybean Production in North Eastern Ghana

Semester: 6

I declare, here within, that I have transferred the final digital text document (in a PDF format) to my mentoring supervisor and that the content and wording is entirely my own work. I am aware that the digital version of my document can and/or will be checked for plagiarism with the help of an analysis software program.

Stuttgart, Germany

16 July, 2018

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Jessica Lynn Lloyd

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List of Abbreviations

1M	2.5 T/ha Manure
1P	125 kg/ha Mineral Fertiliser
1R	2.5 T/ha Residue
2M	5 T/ha Manure
2P	250 kg/ha Mineral Fertiliser
2R	5 T/ha Residue
AGB	Aboveground Biomass
ANCOVA	Analysis of covariance
Ando	Ando-Kadjura
ANOVA	Analysis of Variance
AWC	Available Water Capacity
AWG	Anoshe Women's Group
BNF	Biological Nitrogen Fixation
C	Carbon
C:N	Carbon: Nitrogen Ratio
Chere	Chere-Nakau
CSA	Climate Smart Agriculture
DAS	Days After Sowing
DW	Dry Weight
FW	Fresh Weight
GWUE	Green Water Use Efficiency
LAI	Leaf Area Index
LUCIA	Land Use Change Impact Assessment
N	Nitrogen
OM	Organic Matter
P	Phosphorous
PUE	Precipitation Use Efficiency
RCBD	Randomised Complete Block Design
SOC	Soil Organic Carbon
SOM	Soil Organic Matter
SSA	Sub-Saharan Africa
TDR	Time Domain Refractory
TSP	Triple Super Phosphate
WUE	Water Use Efficiency

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1. Introduction

1.1 Problem Statement

Rainfed agriculture is the most predominant agricultural system in the world. Globally, approximately 80% of the agricultural land is in use by rainfed production systems and accounts for 60% of world food production (Stroosnijder, 2003). In sub-Saharan Africa (SSA), 95% of the cultivated land is rainfed and approximately 260 million people live in drought-prone dry lands (Sanz et al., 2017; Svendsen, Ewing, & Msangi, 2009).

By 2050, the world's population is set to rise to 9 billion (Samir & Lutz, 2017), while total rainfall is expected to decline by 5% (Field et al., 2014). An increased population requires an increased food production. Many local water resources in developing areas are already limited and exploited, restricting their further use in order to meet production demands (Wallace, 2000). Therefore, more efficient use of rain in rainfed agriculture deserves increased scientific attention.

As climate change continues to influence rainfall patterns, it will not only reduce total rainfall, but will also cause less frequent and more intense rainfall events. The dependence on rainfall means that rainfed agricultural systems are highly susceptible to climatic variability, which can severely affect food production. In semi-arid West Africa, rainfed agriculture is subject to this unreliable rainfall and recurrent droughts, causing subsequent production failures (Partey, Zougmoré, Ouédraogo, & Campbell, 2018).

High evapotranspiration, low available water-holding capacity, poor structural stability, low infiltration rates and high compaction rates of soils in West Africa compound the problems associated with rainfall variation due to climate change (Lal, 1999). The continual fluctuation of rainfall's effect on soil moisture is something that must be stabilised in order to optimise efficiency of possible crop production system. Currently, levels of water use efficiency in cereals demonstrate the scope for improvement (Wallace, 2000). Adaptation and mitigation measures must be studied and implemented in order to assure crops have maximum water use efficiency.

One opportunity for improving food and livelihood security in at-risk areas is the adaptation of climate-smart agriculture (CSA). CSA may effectively achieve the development goals of vulnerable populations, such as the population found in the Chereponi District of Northern Ghana, who are highly dependent on agricultural production for means of food security (Ghana Ministry of Food and Agriculture, 2015). The success of CSA is dependent on effective management of the combinations of and trade-offs between the mitigation, adaptation and implementation of the CSA strategy chosen (Partey, Zougmoré, Ouédraogo, & Campbell, 2018). Soil ridging is a CSA used widely throughout the world, with particular success in arid and semi-arid areas of West Africa (ibid). Soil ridging has proven successful in increasing crop yields, maximising water use efficiency and reducing erosion in trials (ibid). Soil ridging promotes the soils permeability and water holding capacity. These capabilities are necessary for a soil to maintain proper moisture content and for a crop to have maximum water use efficiency (Doumbia et al., 2009; Shaxson, Barber, & Food and Agriculture Organization of the United Nations., 2003).

1.2 Research Objectives, Questions and Hypotheses

This study was a part of an interdisciplinary research project with cooperation between the University of Hohenheim, Stiftung Sabab Lou and the Anoshe Women's Group (AWG). It took place in 2016 during the rainy season from June until November. The cooperation was on its fourth year of partnership, focusing on the development of options for soybean [*Glycine Max (L.)*] production and sustainable agriculture in the Chereponi District, located in Ghana's Northern Region. The study focused on three communities within the Chereponi District: Nansoni, Ando-Kadjura (Ando) and Chere-Nakaku (Chere).

Previous collaborative research with the AWG analysed basic management practices such as planting density, weeding and mineral fertilisation and their effect on soybean yield, though no study on water management practices affecting the soybean has been completed. Drought and disrupted rainfall patterns are proving to be an increasing problem in the Chereponi District, and typically rank high on the list of problems by SSA farmers (Beshah, 2003). Thus, a study to determine if the women of the AWG could improve the water use efficiency of their soybean by basic management practices was justified to fill this knowledge gap.

A soil ridging trial was set up with the primary objective to determine if soil ridging is able to improve the water use efficiency of soybean, with the following supportive research questions:

1. Can soil ridging make a significant difference on soil moisture levels in the Chereponi District as compared to conventional tillage?
2. Can soil ridges significantly enhance soybean growth and development when compared to conventional tillage?
3. Is the yield of crops grown on ridges significantly higher than those grown with conventional tillage?
4. Is the water use efficiency of soybean grown on ridges significantly higher than that of soybean grown on conventionally tilled plots?
5. Is the difference in yield worth the labour of ridge formation – is soil ridging economical?

Based on these research questions the hypotheses for the study are as follows:

1. Soil ridging will make a difference on soil moisture levels in the Chereponi District as compared to conventional tillage. Tops of ridges will evacuate water, thus being dry compared to the conventional tillage, whereas the furrows will hold water, being moist compared to conventional tillage.
2. Significantly superior crops in height, number of side-shoots, leaf area, biomass and nodulation will be found on the ridged cultivation.
3. Yield of soybean grown on ridges will be significantly higher than that of soybean grown on conventionally tilled plots.
4. The water use efficiency of soybean grown on ridges will be significantly higher than that of soybean grown on conventional tillage.
5. When compared to the labour of flattening after ploughing, ridges made from the plough lines will be an economically viable alternative.

The lack of organic matter (OM) management strategies and prevalence of crop residue burning in the region justified a sister trial, analysed by Ivan Landers (Landers, 2017), regarding OM test plots in combination with mineral fertilisation. However, within the study of water management and it's effect, it is also interesting to analyse if the organic matter inputs helped maintain soil moisture or if the ridges caused an increase of the functionality of the mineral fertiliser.

1.3 Study Outline

The current study is outlined as follows: chapter two outlines relevant literature, including a definition of water use efficiency and information on the function of soil ridging and formation options. Chapter three provides a detailed site description and rainfall data for the 2016 cropping season, as well as materials used and methodologies employed during the study. Chapter four presents results from the study. Chapter five discusses the significance of the results found, in context of implications through use of literature. Chapter six provides a conclusion to the study, highlighting key points and implications, as well as offering suggestions for future research.

2 Literature Review

2.1 Rainfed Agriculture in Northern Ghana

Northern Ghana is dependent on agriculture to sustain livelihoods and is struggling to cope with decreasing yields and crop failures as a result of climate change and land degradation (Laube, Schraven, & Awo, 2012).

Northern Ghana contributes 40% of the total agricultural land in Ghana and is considered to be the breadbasket of the country (Ghana Statistical Service, 2014). Rainfed agriculture forms the backbone of the Ghanaian economy, as in Ghana irrigated land only accounts for 0.2% of cultivated agricultural land [MoFA (Ministry of food and agriculture), 2013; Nyuor et al., 2016)]. Seasonal climate is therefore a main determinate of agricultural production. In Northern Ghana, the trend of climatic variables, such as rainfall is described as irregular, with serious economic impacts on agriculture (Nyuor et al., 2016). The unpredictability of rainfalls patterns disrupts farmer's decision-making processes. The inability of farmers to predict planting time can affect yield and income, or the changing patterns may force farmers to change their crop choice (ibid). Negative impacts caused by rainfall effects have two possible sources: 1) farming seasons are marred by mid-season drought, or 2) excessive rains cause heavy flooding (ibid).

2.2 Soil Moisture

The definition of soil moisture deviates throughout literature with no single shared meaning amongst disciplines (Seneviratne et al., 2010). For example, climatologists may define soil moisture as the water-holding capacity of an entire land area, whereas eco-hydrologists are inclined to focus more on the amount of water present only in the root zone of a vegetated soil profile (ibid). A widely accepted general definition of soil moisture is "the water present in the uppermost part of a field soil and is a state variable controlling a wide array of ecological, hydrogeological, geotechnical and meteorological processes" (Romano, 2014, p. 6). For the purpose of this paper, the definition of soil moisture will abide by the definition for plant available soil moisture, where the moisture is held between field capacity and a site-specific refill point, and the plant can easily extract the water to facilitate unrestricted growth. In this range of soil moisture, plants are neither waterlogged nor water-stressed (Seneviratne et al., 2010).

Soil moisture is influenced by four main factors: 1) the precipitation pattern, 2) the texture of the soil, 3) the slope of the land and 4) the vegetation/land cover (Mohanty & Skaggs, 2001). The precipitation pattern is the most influential factor on soil moisture, followed by the texture of the soil, which determines the soils water-holding capacity. Thus, the texture of the soil dictates how long precipitation events have a direct influence on the soil profile. The slope of the land further affects this influence by governing the infiltration and run off capabilities of the soil and the vegetation/land cover governs the soil's evaporation/percolation potential (ibid).

2.3 Water Use Efficiency

Water use efficiency (WUE) represents a given level of biomass or grain yield per unit of water used by the crop (Hatfield, Sauer, & Prueger, 2001), and can be used as a direct measurement of the evapotranspiration capabilities of a crop. Past assessments of WUE in rainfed cropping systems measured quite low rates, ranging from 15-30%, with instances as low as 5% (Rockström & Falkenmark, 2000). However, the definition of WUE is not entirely befitting to this study, as WUE doubles as a term for the direct evapotranspiration capabilities of the plant (Hatfield, Sauer & Prueger, 2001). Precipitation use efficiency (PUE) is defined as the biomass or grain yield divided by the growth season's precipitation, and is expressed as kg/ha/mm, ranging from 4 (low) to 10 (improved) (Stroosnijder, 2003). PUE is a term that is often used interchangeably with WUE, as in rainfed agricultural systems there is no other source of water. Therefore, soil management practices that increase soil water storage have a positive impact on both WUE and PUE. If all the precipitation during the growth season is used for evapotranspiration and the soil moisture is equal at the start and end of the growth season, then PUE and WUE would be equal (Hatfield, Sauer & Prueger, 2001). However, a difference between PUE and WUE up to 50% has been measured (Jones & Popham, 1997). Thus, using PUE as a surrogate term for WUE is often inaccurate. By alteration of soil management practices and tillage, it is possible to increase PUE by 25-40% (Hatfield, Sauer & Prueger, 2001)

There is another, more specific, term also associated with PUE and that is green water use efficiency (GWUE). PUE is used in more general ecosystem terms, as it relates to the total amount of produced biomass per area (Stroosnijder & Hoogmoed, 2004), including weeds and other unwanted species. For a given species and location there is a positive correlation between the amount of produced biomass and the amount of transpired water. GWUE is defined as the portion of rainwater that infiltrates into the soil root zone and is used, for biomass production through the process of transpiration (Ringersma, Batjes, & Dent, 2003). The goal of GWUE improvement is to minimise non-productive water flows (including run off, soil evaporation and percolation beyond the root zone) while maximising plant transpiration. Given that the current study was unable to directly measure evapotranspiration, and the yield of weeds and unwanted species was not recorded, GWUE is the most appropriate definition of water use efficiency and is used throughout the study.

2.4 Tillage, Ridge Function and Formation

Tillage

Most soils in West Africa have poor physical and chemical characteristics and are vulnerable to crust formation, which leads to considerable runoff and increased difficulties for seedling emergence (Mason, Maman, & Palé, 2015a). Although soil tillage does promote soil and nutrient losses (Stroosnijder & Hoogmoed, 2004), it is an essential agricultural operation for crop production. When erratic rainfall patterns are combined with the physical and chemical limitations of West African soils, plant growth is further negatively impacted (Nicou, Charreau, Chopart, Faso, & Coast, 1993).

Often in West Africa, the main constraint to crop production is not the total annual rainfall, but the limited proportion of rainfall that is able to infiltrate into the root zone, due to run off, soil crusting, etc. (Sivakumar & Wallace, 1991). In terms of soil water balance, almost any modification of the soil surface will lead to changes in soil water evaporation, run off and infiltration. (Hatfield, Sauer &

Prueger, 2001). The modification will thus have a direct effect on how efficiently crops are able to use their water supply. Increasing the water infiltration and storage within the soil profile is necessary to increase the plant available soil water. Tillage breaks apart the soil crust, leading to a roughened soil surface generating increased infiltration and water storage. (ibid). Tillage also generates plant growth and yield, by increasing soil porosity, enabling greater root density, depth of rooting, water storage and plant water use, thus reducing evaporation. (Mason et al., 2015b; Nicou, Charreau & Coast, 1993).

Contour ridge tillage is a tillage method used to create soil ridges in an attempt to trap water to prevent run off and promote plant water use. Ridges are optimised when formed perpendicular to the slope. When ridges are formed parallel with the slope, the runoff speed increases as water channels between the ridges, thus increasing soil erosion and decreasing infiltration (Doraiswamy et al., 2007; Doumbia et al., 2009; Shaxson et al., 2003). Ridges have also been found to increase cereal grain yields from 30-50% in Mali, Senegal and the Gambia (Doumbia et al., 2009). The yield increase of ridging is often due to interaction with mineral fertiliser (Doraiswamy et al., 2007) but this is not always the case (Subbarao, Renard, Payne, & Bationo, 2000).

Soil Ridging Styles

Soil ridges can be formed in different styles, dependent on soil characteristics and attributes of the desired crop. The three common styles of ridging in West Africa are Zaï ridging, tied ridging and contour ridging (Biazin, Sterk, Temesgen, Abdulkedir, & Stroosnijder, 2012).

Zaï ridging is a traditional system that is effective in very sandy soils, where small pits 20-30 cm in diameter and 10-20 cm deep are dug. The bottom is lined with organic matter into which seeds are planted (Mason, et al., 2015b). The system combines the benefits of tillage and micro-catchments, and has shown results of yields tripling and water use efficiency doubling (Barry, Olaleye, & Fatondji, 2008). However, creation and maintenance of Zaï ridges also has a very large initial labour investment, of 40-60 days per hectare, and recurrent costs for pit maintenance and organic matter management (Mason, Maman & Palé et al., 2015a).

Tied ridging is a common ridging method, where earthen ridges approximately 10-20 cm high are created perpendicular to the slope of a field, with a furrow created beside each ridge (Mason, Maman & Palé et al., 2015a). The term "tied" is used because there are additional cross ties at regular intervals across the ridge troughs, which greatly reduce the flow of water down the trough (ibid). Tied ridging has been shown to collect and store surface water and in cases had led to more stable yield increases than mineral fertiliser application (Ohm et al., 1985), as well as increase the length of growth season (Stroosnijder, 2003). Tied ridging is most effective on flat land (slope less than 2%) with heavier clay soils; the low water holding capacity of sandy soils enhances ridge deterioration (Mason et al., 2015b; Shaxson et al., 2003).

Contour ridges are earthen ridges created perpendicular to the field's slope, typically 10-20 cm high with a furrow that channels runoff from excess rainfall. They have been widely used to control soil erosion in wet areas and maintain soil moisture in dry areas (Gupta, Radke, Swan, & Moncrief, 1990; Hatfield, Allmaras, Rehm, & Lowery, 1998; Lal, 1999). Contour ridges are most effective on land with less than 5% slope (Biazin, Sterk, Temesgen, Abdulkedir, & Stroosnijder, 2012), and help curtail water loss by reducing runoff and increasing infiltration rates (Traoré et al., 2009). Contour ridges are most typically planted with annual crops on the elevated portion of the ridge, allowing the furrow to accommodate excess rainfall as it infiltrates through the raised planting bed (Mason, et al., 2015b). The ridges can be created with either hand tools or animal ploughs (Doraiswamy et al., 2007), and ridge/furrow ratios vary considerably, dependant on the crop, rainfall, soil type and field slope (Partey, Zougmoré, Ouédraogo, & Campbell, 2018; Shaxson et al., 2003).

In 1984 Kilewe and Ulsaker undertook a study in semi-arid Eastern Kenya to evaluate the differences between conventional contour furrows, wide furrows and mini-benches on runoff and water storage capacity. In the contour ridges both the furrow and raised bed and were 75 cm in width. The wide furrows had

1 m wide furrows and 0.5 m beds, with two rows of maize planted per bed. The mini-benches consisted of narrow, level conservation bench terraces with five 0.75 m maize rows, and flat beds (with no furrows) with 0.75 m between maize rows. In all treatments the beds were approximately 0.2 m high. Soil moisture was measured weekly throughout the growth season of the maize at 30, 60 and 100 cm depths in the middle of each plot using a neutron probe. All of the furrow types retained runoff and resulted in a significantly higher water-storage capacity than flat tillage. At planting date, there were 79.9, 126.2, 124 and 107.0 mm of available water stored in first 100 cm of soil on the flat, conventional furrows, wide furrows and mini-bench treatments respectively. The conventional furrows, wide furrows and mini-bench treatments had successfully retained the runoff within the furrows and allowed infiltration to continue long after the rainfall had ceased. Thus, the whole rainfall was available to wet the soil down through the profile and build up an adequate soil moisture reserve. There was also a notable build up of reserve moisture in the soil profile. During the short rainy season at the site, the 100 cm soil profile on the conventional furrows, wide furrows and mini-bench was at field capacity for 24%, 28% and 16% of the total growth period respectively. The moisture stored in 100 cm profile of the flat treatment failed to reach field capacity throughout both the short and long rain seasons. Yields and water use efficiency of the maize planted on the furrows were increased compared to the flat tillage. Wide furrow tillage produced significantly greater yields than the other treatments. Since a greater yield was produced with an equal amount of rainfall, the wide furrow tillage was able to enhance moisture retention and therefore GWUE.

2.5 Soil Nutrient Status

The soils found in West Africa are often chronically poor in nutrients, especially nitrogen (N) and phosphorous (P) (Bationo, Lompo, & Koala, 1998). Consequently, nutrients availability of soil may emerge simultaneously with soil moisture as the primary limiting factors in a crop production system (Stroosnijder, 1996).

While ridge tillage practices reduce erosion, increase GWUE and can improve soil quality, in permeable soils too much water can infiltrate into the soil and cause nutrient leaching. Thus, improved water usage of a crop production system cannot be achieved without proper nutrient management. (Stroosnijder, 2003).

Most water harvesting practices have very little effect on the soil's water holding capacity or nutrient status (Zougmoré, 2003). While in 1962 Viets was able to find a linkage between nutrient status and water use efficiency, increases in the water use efficiency were found to be simply due to an increase in yield as a result of proper soil nutrient status. There is therefore very little point in maximizing the use of rainwater unless nutrient deficiency is corrected simultaneously (Zougmoré, 2003). An interesting approach to improve water infiltration and plant water use efficiency is to combine nutrient management practices, such as application of mineral fertiliser, and runoff measures, such as contour ridging (Bationo, Lompo, & Koala, 1998) .

2.6 Organic Matter Effect

Organic matter management is an imperative aspect of soil management. Organic matter supports agricultural sustainability through its effects on soil and water conservation and maintenance of soil organic carbon (SOC) at an advantageous level (Lal, 1991). Once incorporated into the soil, the organic matter acts as a source and sink for plant nutrients (Bationo, Lompo, & Koala, 1998). As a source and sink, organic matter contributes to the maintenance of soil organic matter (SOM) functions in low-input agricultural systems, including: increased water holding capacity, retention and storage of nutrients and increased buffering capacity in low activity clay soils (ibid).

Soil water evaporation has a considerable influence on a crop's GWUE, and represents a large portion of water loss from the soil-plant system (Stroosnijder, 2009). Mulching organic matter into soil is generally considered an efficient method to reduce soil evaporation that is widely used in agricultural practice. In 1996 Greb found that by reducing the soil temperature, impeding vapour diffusion/absorbing water vapour into the mulch tissue and reducing wind speed, residues and mulches incorporated into the soil were able to reduce soil water evaporation. Similarly, in 1996, Sauer, Hatfield & Prueger found that the presence of residue on that surface reduced soil water evaporation by 34 – 50%.

In 1999, Mando and Stroosnijder studied the biological and physical role of organic mulch where it improved the water balance of a crusted soil over a span of three consecutive years. The effect of the mulch was linked to the activity of the soil micro-fauna. In semi-arid regions, the biological activity was the key element in the efficiency of mulching to rehabilitate the crusted soil. An effective option to improve the soil-water balance by improved soil structure is the stimulation of soil fauna, especially subsurface termites. Termite activity generates increased infiltration, porosity and water holding capacity of the soil, as their movements through the topsoil facilitate easy entry for rainwater (Stroosnijder, 2003).

2.7 Soybean Agronomic Information

In Ghana soybean is a relatively new crop, cultivated mainly by smallholder farmers residing in the northern part of the country (Akramov & Malek, 2012). Soybean production is quickly gaining popularity as local knowledge of its production processes increases (Ghana Ministry of Food and Agriculture, 2015). Some benefits of soybean are that it has a dense, fibrous root system, it sheds its leaves (thus providing OM and nutrients to the soil), it has a thick and dense ground cover which conserves soil and moisture and provides biological nitrogen fixation (BNF) to the soil (Singh 2010; Brink & Belay 2006).

Soybean is a rugged crop, and grows well in a wide range of cropping systems and agroecosystems, however it is sensitive to excess water, and suffers in waterlogged and shallow soils (Singh, 2010; Brink & Belay, 2006, Norman, 1978). Yield of soybean is often a direct result of crop management system (Singh, 2010). Crop management options are: variety, tillage, time of sowing, depth of sowing, plant density, weed control, pest control, mineral fertiliser application, organic matter management, crop rotation, mixed cropping and water management (Endres & Kandel, 2004; Ram, Singh, Saini, Kler, & Timsina, 2013; Dugie et al., 2009). Previous reports through the University of Hohenheim in collaboration with Sabab Lou (Addo, Haddad, Harun, & Stoyanov, 2014; U. O. Archibong, Ansah Baffour, Bateki Adjogo, & Wahl, 2015; Dally, Hruschka, Owusu Akuoko, & Simmons, 2016) assessed management practices of plant density, weed control and mineral fertiliser application on a local variety of soybean found in the Chereponi District of Northern Ghana.

Average world soybean yields are 2.24 tonnes per hectare (MoFA (Ministry of Food and Agriculture), 2013). The average yield of soybean in Ghana is 1.65 tonnes per hectare, with the West African potential lying somewhere around 3 tonnes per hectare (ibid). To achieve high yields of soybean proper agricultural techniques are essential (Ram, Singh, Saini, Kler, & Timsina, 2013). Due to the less favourable ecological conditions for soybean growth found in Northern Ghana, crop management plays a crucial role (Callo-Concha, Gaiser, & Ewert, 2012).

Soybean usually thrives as a rain-fed crop, making use of limited moisture, as it is able to recover from water deficits during the vegetative growth stage better than many other crops (Singh, 2010). However, in recent years yield decreased by 8% in Northern Ghana, conceivably due to erratic rainfall (MoFA (Ministry of Food and Agriculture), 2013). There are two critical periods when soybean requires ample water: between sowing and emergence and during seed filling (Brink & Belay, 2006; Norman, 1978).

In the 2005 and 2006 cropping seasons in Northern Ghana, Lawson, Mensah and Yeboah, undertook an experiment to test the effects of land preparation on crop establishment and grain yield of soybean. The land preparation methods tested were flat field (ploughed and harrowed before planting), mounding (planted on mounds 60 cm in diameter and 30 cm in height) and ridging (earthen ridges raised 10 cm above the ground). Soybean grown on ridges was better established and produced more nodules than the flat field or mounding. The mounding proved to be the superior land preparation method, and had the greatest side shoot and root biomass, as well as mean number of pods per plant, while the ridging still consistently outperformed the flat field trial. However, no results in the trial were found significant at $P < 0.05$. The exact mechanism of why the ridges outperformed the flat fields remains unclear.

3 Methods and Materials

3.1 Site Description

The Chereponi District lies within the Guinea Savannah agroecological zone, according to the Köppen and Geiger climate index. It has a unimodal rainfall pattern, with a rainy season stretching from May to October (Ghana Ministry of Food and Agriculture, 2015). Annual rainfall is roughly 1000mm (ibid), however, climate change is causing both the duration of the rainy season and the intensity of the rainfall events to be increasingly unpredictable from year to year. Average daily temperature ranges seasonally from 21-41°C, and the average annual temperature is 27.7°C (ibid).

The majority of the Chereponi District soils are characterised as Plinthic Lixisols (Issaka, Senayah, Adjei, & Oppong, 2004). Lixisols are strongly weathered soils with low levels of available nutrients, and low nutrient reserves. Other important soil types present in the region are Dystric Planosols, Lithic Planosols and Lithic Leptosols, found mainly around the areas where water is present (ibid). The topography of the Chereponi District is underlain by Voltaian rocks and is mainly gently sloping, with some hills (Ghana Statistical Service, 2014). The soils have a light texture surface horizon, where sandy loams are common (ibid). Alluvial valleys suitable for rice production do exist in some areas of the district (ibid). Soil erosion is a considerable issue due to poor agronomic practices.

In 2014 Ukeme Okon Archibong completed a master's thesis (Archibong, 2015) in the Chereponi District in collaboration with the University of Hohenheim and Stiftung Sabab Lou to determine the contribution of subsoil properties to the suitability of soils for soybean production. His analysis provides baseline soil information, of which this study is based. Table 1 highlights key findings relevant to soil moisture capabilities of the soils in respective villages, further parameters being available in the appendix A of this report.

Table 1: Key properties of topsoils found in the Chereponi Distrct (O. Archibong, 2015)

	Nansoni	Ando	Chere
Horizon Depth (cm)	19	17	21
Sand (%)	60	55	53
Silt (%)	30	33	37
Clay (%)	10	12	10
Available Water Capacity (%)	2.07	2.99	4.01
Carbon $_{org}$ (%)	0.87	0.7	0.5
C:N	13.84	10.7	9.15

A summary of other relevant previous soil experimentation can be found in appendix A.

During the 2016 season, Meret Zeller completed a master's thesis (Zeller, 2017) on a participatory monitoring system for rainfall distribution throughout the Chereponi District, also in collaboration with the University of Hohenheim and Stifung Sabab Lou. Figure 1 illustrates the rainfall measurements of a participating AWG member located centrally amongst the trial fields. Figure 2 provides an overview of the cumulative 2016 rainfall compared to data from the last ten years.

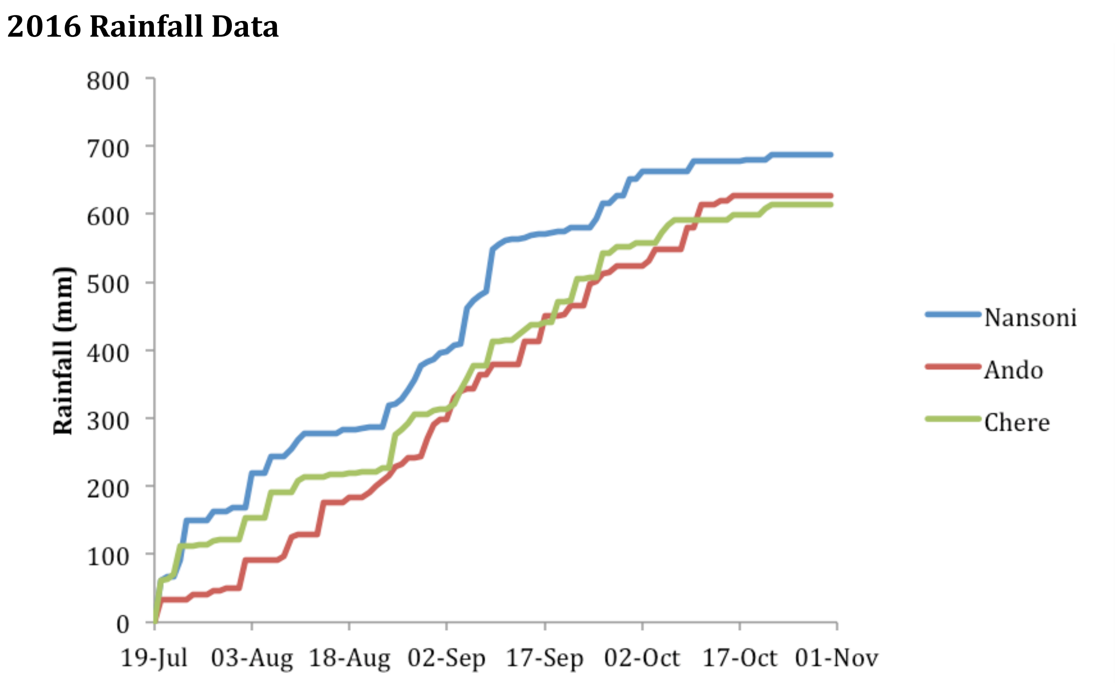

Figure 1: Cumulative rainfall measured in respective villages throughout the 2016 growth season

Since data collection did not start at the beginning of the rainy season, only the last two thirds of the season is shown, thus the total per village is not comparable to local meteorological data. However, the rainfall season in figure 1 does encompass the growth season of the soybean in its entirety. During July and August, there was no considerable distinction between the three communities. In September as the rains began to ease, Ando maintained a higher rainfall rate, thus narrowly passing Chere in total rainfall. It is important to note that this higher rainfall occurred during the pod filling stage of the soybeans, and could consequently have a direct impact on yield.

During the 2016 growth season Nansoni had a total rainfall of 687.55 l/m^2 with an average rainfall per day of 6.40 l/m^2, a median value of 0.64 l/m^2 and a modal value of 0.00 l/m^2. Ando had a total rainfall of 626.43 l/m^2 with an average rainfall per day of 6.02 l/m^2, a median value of 0.00 l/m^2 and a modal value of 0.00 l/m^2. Chere had a total rainfall of 613.70 l/m^2 with an average rainfall per day of 5.84 l/m^2, with a median value of 0.00 l/m^2 and a modal value of 0.00 l/m^2.

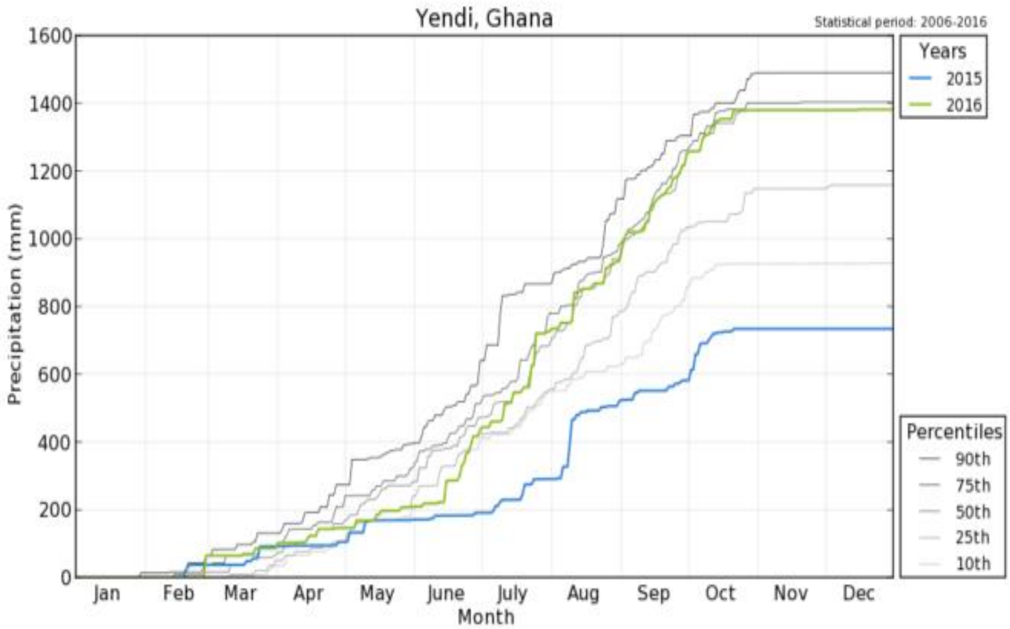

Figure 2: Cumulative rainfall data from 2016 and percentiles (2006-2016) at measurement station Yendi,Ghana (Ghana Meterological Agency (GMET) 2017).

The total amount of rainfall in 2016 fell within approximately the 75 percentile from the last 10 years. While the rainfall amount was higher than normal, it was not an outlier year, thus the rainfall dynamics of soil moisture can be considered normal.

3.2 Experimental Design

The experiment ran throughout the 2016 rainy season, from mid June – mid November. Fields were treated with both contour ridge tillage and with conventional tillage practices for comparison. On both the contour and conventional tillage, mineral fertiliser was added with organic residue and manure were added in two quantities, in order to evaluate the effect of organic matter and mineral fertilisation on the yield performance of the soybean, as analysed by Ivan Landers(Landers, 2017).

3.2.1 Plot Selection and Layout

To reduce site-specific effects, the experiments were laid out in a Randomised Complete Block Design (RCBD) with 14 replications – each community acting as a blocking factor. Communities included in the trial were Nansoni, Ando and Chere.

15 plots were originally selected in an effort to maintain 5 replicates per community. An attempt was made to use the same fields as previous research teams for the sake of continuity and comparability of results. One field in Chere was unplanted due to flooding and subsequent water logging, and another field in Ando was un-harvested due to browsing animals. Table 2 provides of list of fields by field code, experiment type, location and slope. (Please note ARF4 the field that was completely destroyed by roaming livestock.)

Table 2:Location and trial type of all research fields planted during the 2016 growth season

Village	Field Code	Experimental Design	Latitude	Longitude	Slope (%)	Row Grade (%)
Ando	ARF1	TSP Trial	10.150151	0.292291	4.9	1.5
Ando	ARF2	OM Trial	10.156998	0.292550	3.5	0.9
Ando	ARF3	OM Trial	10.157057	0.291060	1.6	1.5
Ando	ARF4	OM Trial	10.166372	0.296978	2.5	1.4
Ando	ARF5	OM Trial	10.171726	0.297263	1.8	1.0
Nansoni	NRF1	OM Trial	10.189914	0.200046	2.2	1.1
Nansoni	NRF2	OM Trial	10.188938	0.203562	2.2	1.0
Nansoni	NRF3	OM Trial	10.190041	0.203302	2.2	1.0
Nansoni	NRF4	OM Trial	10.189055	0.197487	2.2	2.1
Nansoni	NRF5	TSP Trial	10.211825	0.206993	2.1	1.7
Chere	CRF1	OM Trial	10.266598	0.246322	2.1	1.1
Chere	CRF2	OM Trial	10.260477	0.248097	2.7	2.1
Chere	CRF3	OM Trial	10.246078	0.259994	2.1	1.2
Chere	CRF4	TSP Trial	10.248006	0.247698	1.9	0.7

All plots were arranged in identical fashion. Subplots were planted perpendicular to the natural slope of the land, with ridges always on the lower side of the slope in order to avoid water pooling in the conventionally prepared plots. Each subplot was 2.5 m x 2.5 m, with 50 cm separating subplots to avoid treatment contamination. The soybean seed had a germination rate of 88% and was planted at 4 cm depth with 2 seeds per pocket. Pockets were 5 cm apart and rows were 40 cm apart, as previously recommended (Wahl, 2015).

Field Layout

Organic matter and mineral fertilisation treatments were applied to subplots at random. The following field plans show each field and the treatments applied to its subplots.

Table 3: Key to treatment and application rates

Colour	Code	Treatment	Application Rate
		Control	No TSP or OM
	1	TSP	125 kg P per ha
	2	TSP	250 kg P per ha
	1M	Manure	2.5 T DM per ha
	2M	Manure	5 T DM per ha
	1R	Residue	2.5 T DM per ha
	2R	Residue	5 T DM per ha

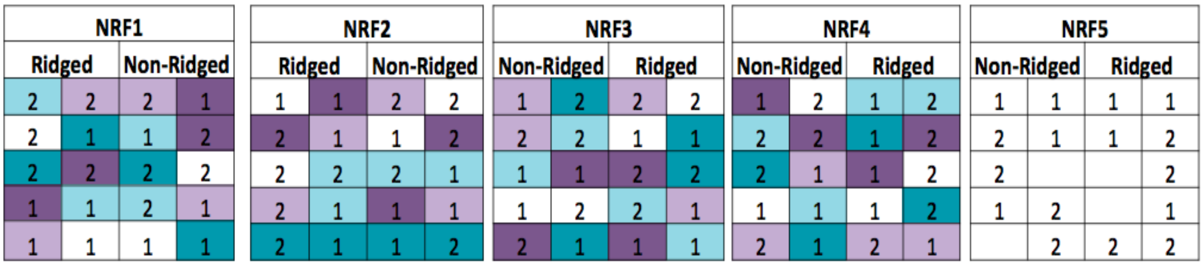

Image 1: Experimental layout for fields in Nansoni

Image 2: Experimental layout for fields in Ando

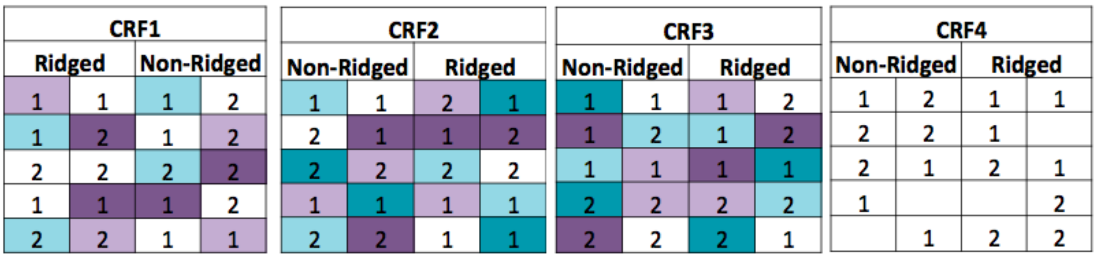

Image 3: Experimental layout for fields in Chere

3.2.2 Experimental Treatments

Soil Ridging

Following tillage and prior to the arrival of the research team all fields were levelled using hand-hoes, in order to prepare a more uniform seedbed and fill in large troughs created by uneven and incorrect ploughing method. Ploughing method proved too poor and inconsistent to be used as a guide for ridge formation; additionally, tractor operators often ploughed along the slope rather than across it in order to maximise speed. Due to the early arrival of the rainy season, most fields in the area were already planted, including some that were pre-designated for research purposes. Thus, certain fields were already planted at time of plot establishment, although without crop emergence. These fields were ARF2, ARF4, NRF2, NRF3, NRF4 and NRF5. Various crops had been sown in each field and fields were re-levelled and residues removed before re-planting. Ridges were constructed with the help of hand-hoes. Furrows were dug approximately 10 cm deep, with excess soil placed onto the ridges to create raised beds. Ridges were 60 cm wide and accommodated two rows of soy per ridge, planted with 20 cm to between seed and ridge edge, and 40 cm inter-row spacing. The furrows were 40 cm wide, thus, three ridges were accommodated per subplot. Image 4 and 5 display the ridge construction process on land already flattened by hand hoe after tillage (Author's own photographs, July 2016).


Image 4: Ridge construction process


Image 5: Ridge construction process

Organic Matter

Two different locally available OM sources were used, manure and crop residue, at two different application rates. Manure used was a composite of cow manure and a "mixture" consisting of sheep, goat and donkey faeces. Samples were taken of the different manure types, weighed, sun-dried for three days and re-weighed in order to calculate fresh weight (FW) requirements to obtain the desired dry weight (DW) application rates. Manure was incorporated into the soil in strips directly before planting. "Light" (1M) manure treatment contained 1.68 kg cow + 0.56 kg mixture for a total of 1.56 kg DM per 6.25 m^2 or 2.5 T per hectare. The "heavy"(2M) manure treatment contained 3.36 kg cow + 1.12 kg mixture, totalling 3.125 kg DM per 6.25m^2 or 5 T per hectare.

Sesame (*Sesamum indicum*) stalk was the only crop residue locally available in June at the end of the dry season. Stalks were picked, dried and chopped into small pieces, then transported to each field site. "Light" (1R) residue treatment was 1.56 kg DM per 6.25 m^2 or 2.5 T per hectare. "Heavy" (2R) residue treatment was 3.126 kg DM per 6.25 m^2 or 5 T per hectare. Dry matter weights were estimated by sun drying the organic matter, and then adjusting by a factor of 5% to compensate for the moisture potentially remaining without oven drying at 105°C. Due to time constraints, the residue was scattered between rows and lightly incorporated into the soil by hoeing after emergence to avoid damaging seedlings.

Phosphorous Fertiliser Trials

One field per community served as a phosphorous only trial, providing a baseline for fertiliser response without additional organic matter inputs.

Locally available triple super phosphate (TSP) fertiliser, from the Yara company was the source of mineral fertiliser. The fertiliser was 46% P_2O_5, the equivalent of 20% phosphorus. Fertiliser was applied by micro-dosing each pocket, performed simultaneously with the weeding at approximately 28 DAS. "Light" (1P) fertiliser was applied at a rate of 1.25 g per pocket or 125 kg per hectare and “heavy” (2P) fertiliser was applied at 2.5 g per pocket or 250 kg per hectare. Micro-dosing was completed with participating AWG members, by using constructed paper cylinders, as seen in image 6 and 7 (Author’s own photographs, August 2016). Accuracy of the cylinders was tested for before field fertilisation, using a Sartorius Entris Lab Scale and 20 replications of filling the cylinder and weighing the amount it was able to contain. Cylinders that deviated by more than 10% of desired weight were not included in the field materials. Once calibrated, the cones were reinforced using tape, and proved reliably rigid in the field.

Image 6: Cone constructed to accommodate "light" and "heavy" fertiliser application

Image 7: Micro-dosing triple super phosphate fertiliser at the base of soy plants

3.3 Methodology

Soybean Variety

Soybeans used in the field trials were a locally available variety called *Jenguma*, sourced from the AWG stock. The variety is noted for its ability to resist pod shattering before and during harvest. *Jenguma* has a cycle to maturity of 110-120 days.

Germination

Due to time constraints, the soybeans were not effectively sorted or cleaned before planting. A simple germination test was conducted prior to sowing to determine the germination rate of 88%. Five groups of 10 seeds were placed on moistened serviettes in petri dishes and left in dark storage for 72 hours. Germinated seeds were counted and the average of the five groups was used as a germination rate.

Planting

The soybean was planted using the dibbing method, with pegs and string to provide a planting guide. Pockets contained two soybean seeds planted at 4 cm depth and were spaced five centimetres apart. Rows had a spacing of 40 cm, as per recommendations of previous research (Wahl, 2015). The research team carried out planting in collaboration with the participating women and their families. At times, this included small children and toddlers, which may have had a negative influence on planting and emergence rates.

Mineral Fertilisation

Fertiliser application occurred in the first week of August, between 21-28 days after sowing (DAS). It was deemed best to apply fertiliser by side dressing, post-emergence, with each pocket receiving its micro-dosed application. Phosphorous fixation is a serious problem in heavily-weathered acidic soils where the longer the phosphorous is in contact with the soil, the greater the risk of fixation (Holford, 1976). Therefore, providing fertiliser closer to the time when it is required by the plant would increase fertiliser use efficiency.

Weeding

All plots were weeded simultaneously with fertilisation, in the first week of August 2016, with hoes and by hand. Canopy closure occurred between 35-42 DAS and was effective against further weed proliferation; thus no further weed management was required. This compared favourably to farmers' fields, where low planting densities meant full canopy closure was only achieved later in the season, and thus weeding was required on multiple occasions.

Bare Soil Evaporation

Two samples were taken from a representative field of each community, one sample from a ridged plot and one sample from a conventionally prepared plot. Samples were taken by hammering a cylinder into the ground and carefully removing it and wrapping it in cellophane plastic tape to ensure soil contents were not lost during transport. Cylinders were approximately 15 cm in height and approximately 70 cm in circumference. Samples were stored in a dry, shaded, indoor space until all samples were collected.

To begin analysis, each sample was weighed as initial weight and each soil sample had its' soil moisture read. All moisture readings were taken in triplicate and then averaged. Water was then added until the soil was at field capacity and the volume of water retained was recorded. Three soil moisture measurements were taken at regular intervals. Final weight was then recorded when the samples soil moisture was less than its initial soil moisture measurement. All soil samples were exposed to direct sunlight and no precipitation during the evaporation experimentation.

Bulk Density and Infiltration

Each soil was weighed before and after water was added, to ensure that water had totally evaporated when the soil was back to dry condition. The original weight was used, minus the volume of the cylinder for the bulk density calculation. The volume of each sample was calculated independently to allow for cylinder variation within the bulk density calculation

It was not possible to measure infiltration data in the field. Instead, water conductivity was modelled using the Land Use Change Impact Assessment tool (LUCIA). As a comparison to the basic bare soil evaporation rate measured, soil water conductivity is a more useful parameter to assess the water balance in the soil, as infiltration is based on both the soil's current saturation content at a particular time, and it's physical properties.

Soil Moisture

Soil moisture was measured with a HH2 SM300 Soil Moisture and Temperature Sensor, manufactured by Delta-T Devices Ltd. Calibration of the instrument to local soil was performed once prior to the season. Calibration was checked frequently throughout the experiment by dipping the prongs halfway into water, as per the instruments manual's recommendation (Delta-D Devices, 2007)

Soil moisture measurements were taken as frequently as possible throughout the duration of the growth season. Each ridged plot had six measurements taken: three measurements taken on ridges and three taken in the furrows. Each conventional plot had three measurements taken at random. In the event of rainfall during moisture data collection, measurements taken before the rain were discarded so the entire community was evaluated with the same rainfall events.

Rainfall data was measured in each village in the morning before the soil moisture measurements were taken by the AWG member most central to the fields within the community (Zeller, 2016).

Emergence

Between one and two weeks after sowing, all plants in one row were counted in order to estimate emergence rates. During harvest, one meter squared was defined with string in each subplot, and before removing the plants for harvest, total pockets as well as total plants were counted. In order to ensure that emergence and final density numbers were comparable, the total pockets at harvest were multiplied by 0.84 in order to account for the third row included in the meter square area harvested from. Areas in the subplots were avoided if they had large gaps due to animal or insect damage.

Plant Height

Plant height was measured at approximately 21 and 49 days after sowing. First measurements were taken prior to weeding and fertiliser application, and the second were taken approximately three weeks after fertiliser application. Ten plants were randomly chosen from each plot and each plant was then measured from the ground to the tip of the meristem, while avoiding addition of height from the youngest leaf. A simple ruler and tape measure were used as measurement tools.

Side Shoots

Side shoots were counted on 10 randomly selected plants per plot at approximately 28 DAS (or seven days after weeding and fertiliser application). The youngest shoot was included in the count when it was clearly differentiated from the meristem.

Leaf Area

Leaf area was calculated destructively at approximately 40 DAS. One plant per subplot (280 in total) was stripped of its leaves, which were then placed on millimetre paper along with a subplot label, and photographed with a digital camera. Leaf areas were calculated later by tracing the leaves with *Image J* software, version 10.2.

Biomass and Nodulation

Biomass and nodulation were analysed in conjunction at approximately 70 DAS. One representative plant per plot was chosen, and then carefully dug out to remove roots from the soil whilst losing as few nodules as possible.

The portion of the plant above the ground as well as the roots were then placed in an open manila folder and allowed to dry for as long as possible (approximately 21 days) due to absence of an oven.

Nodules were carefully removed from the roots and counted in field to ensure the most accurate results possible. Image 8 demonstrates the root and nodules removal from the soil, before nodules were stripped to be counted (Author's own photo, August 2016).

Image 8:Nodules on soy root before being removed and counted

Yield and Aboveground Biomass

An area of one meter squared, which always included three rows, was marked and harvested in each subplot. Pods were removed from all plants in the area. Aboveground biomass (AGB) was set aside and weighed on site. Pods were bagged, labelled and transported to Chereponi for threshing, winnowing and weighing. Pod shell weights were kept separate from grain, and weighed and added to each plot's AGB total weight.

Three representative plants were harvested from each subplot. The number of pods per plant was recorded in the field, and plants were subsequently harvested and enclosed in labelled folders for transport back to Chereponi. In Chereponi, seeds were separated from pods and placed into vials. These were transported back to the University of Hohenheim in order to determine seed DW and moisture content at harvest. The vials were labelled and pre-coded, with individual tare weights having been previously recoded. At the University of Hohenheim, seeds were weighed to determine fresh weight, then dried in an oven at 105°C for 48 hours. Dividing seed dry weight by fresh weight provides an estimation of moisture content in the field at harvest. From this data, average moisture content of seeds at harvest was computed for each field, and recorded yields were adjusted accordingly on a field-by-field basis. Yield per subplot was further adjusted by multiplying by a factor of 0.84 in order to accurately estimate yield on a per hectare basis.

4 Results

4.1 Soil Water Evaluation

A simplified bare soil evaporation analysis was conducted in order to determine the length of time rainfall events had on the topsoil moisture. Soil moisture was measured by the soil moisture meter, and also gravimetrically at the beginning and end of the experiment to determine that all the moisture had evaporated. Due to mobility restrictions, it was not possible to measure the soil gravimetrically more often. The results of the soil moisture measurements are displayed in figures 3 – 5, and the gravimetric analysis, as well as the amount of water added to the soil for the experiment, bulk density and soil conductivity calculations are included in table 4.

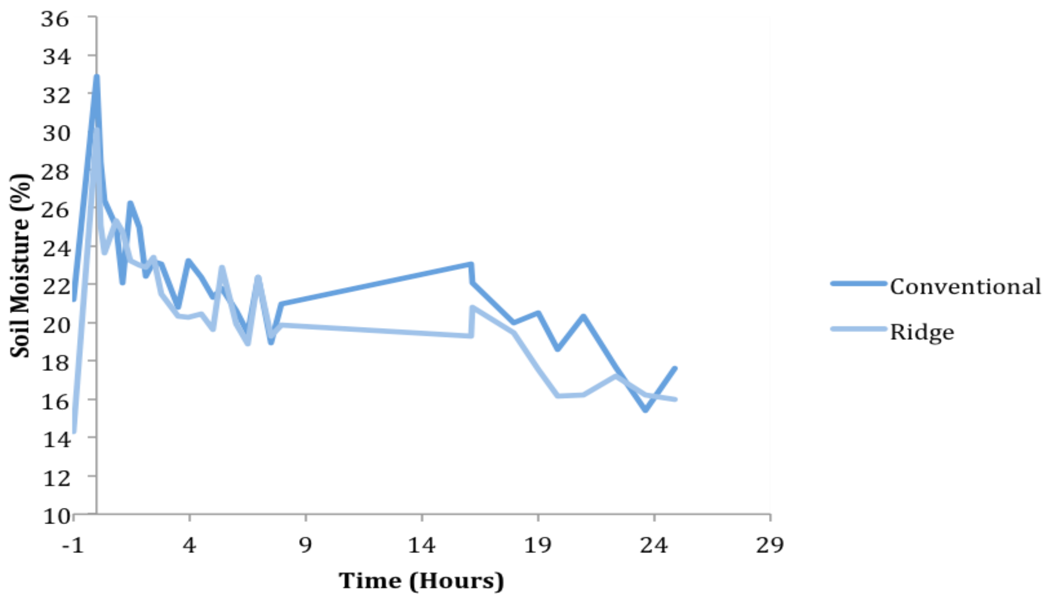

Figure 3: Nansoni bare soil evaporation, where each point has n=3. -1 represents the soil moisture value before water was added to each sample.

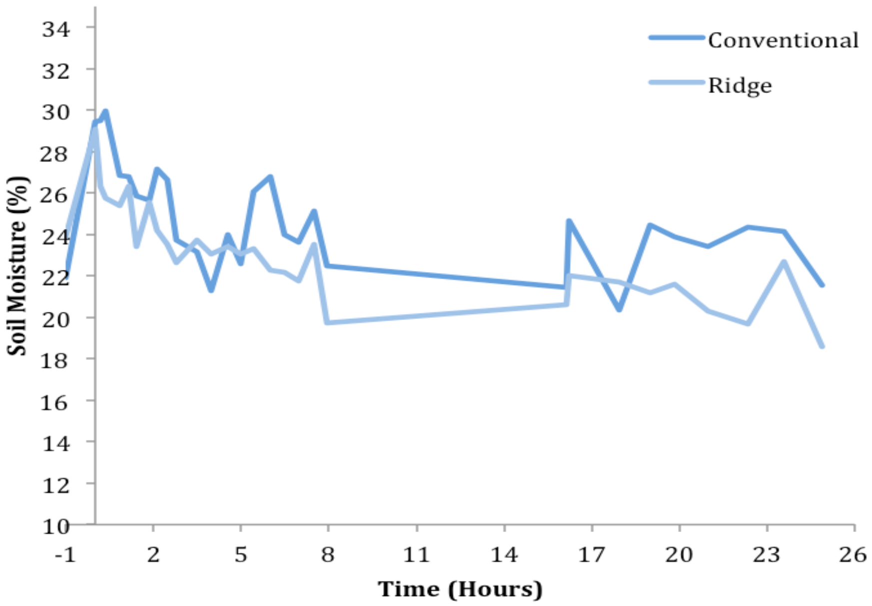

Figure 4: Ando bare soil evaporation, where each point has n=3. -1 represents the soil moisture value before water was added to each sample.

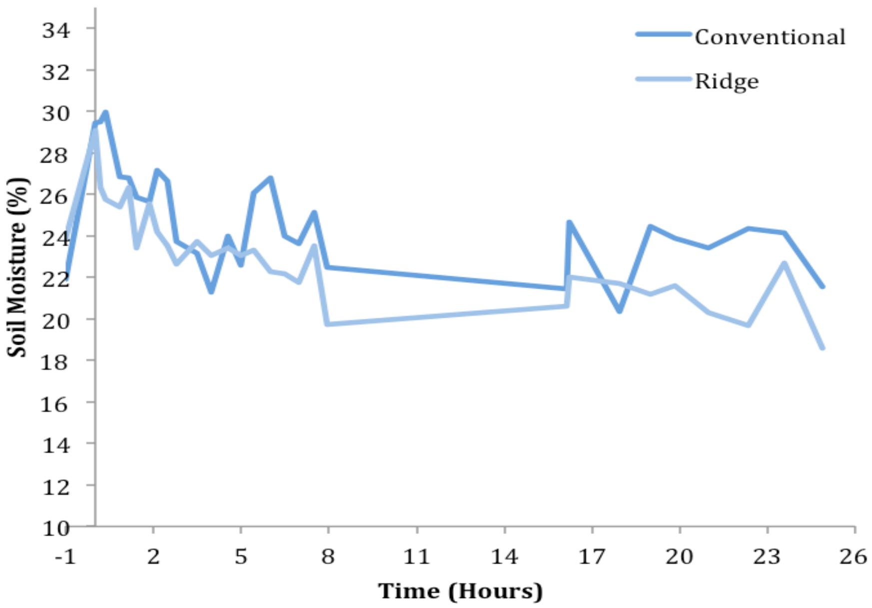

Figure 5: Chere bare soil evaporation, where each point has n=3. -1 represents the soil moisture value before water was added to each sample.

Table 4: Initial and final weights for bare soil evaporation, including bulk density and field capacity measurements.

Treatment	Initial Weight (kg)	Final Weight (kg)	Field Capacity (mL)	Bulk Density (g/cm³)	Saturated Conductivity (mm/day)
Nansoni Ridge	7.2	6.8	290	1.3	1977
Nansoni Conventional	8.4	7.8	280	1.6	1081
Ando Ridge	8.4	8.0	320	1.4	1235
Ando Conventional	9.6	9.1	250	1.5	586
Chere Ridge	10.5	10.1	230	1.5	439
Chere Conventional	10.5	10.2	340	1.5	439

The bulk density of the ridged plots was consistently lower than that of the conventionally prepared plots. Each soil's final weight was less than that of it's original, indicating gravimetrically that all the moisture had evaporated, since none was found beneath the samples, having filtered all the way through.

4.2 Soil Moisture Dynamics

In order to determine the effect of ridges on soil moisture, measurements were taken as many times as possible throughout the season. Each community had moisture measurements taken 9 times; a summary of those measurements can be seen in appendix B.

The relationship to the previous relevant rainfall events is the parameter of interest when determining soil ridging's effect when compared to conventional tillage. If there was a significant impact, furrows would retain more moisture than conventional tillage in times of drought, and ridges would have less moisture than conventional tillage in times of high rainfall.

Significant Effects of Soil Ridging

The primary objective of this study is to determine whether soil ridging can make a significant impact on soil moisture. In order to evaluate the effects, an analysis of covariance (ANCOVA) analysis was ran in SAS, with the previous 24-hour's rainfall acting as the covariant. Tables 5 – 7 show the results of the analysis.

Table 5: Season cumulative type III tests of fixed effects for Nansoni soil moisture rainfall dynamic.

Effect	Significance
DAS	<.0001
Slope	0.0791
Phosphorous	0.3691
OM	0.1567
Position	<.0001
Slope*DAS	0.1624
Phosphorous*DAS	0.2146
OM*DAS	0.2132
Position*DAS	<.0001
Slope*Phosphorous	0.0978
Slope*OM	0.1033
Phosphorous*OM	0.8626
Phosphorous*Position	0.4458
OM*Position	0.9459
Slope*Phosphorous*DAS	0.2891
Slope *OM*DAS	0.6180
Phosphorous*OM*DAS	0.9984
Phosphorous*Position*DAS	0.0916
OM*Position*DAS	0.8285
Slope *Phosphorous*OM	0.2768
Phosphorous*OM*Position	0.9537
Slope *Phosphorous*OM*DAS	0.5342
Phosphorous*OM*Position*DAS	0.7700

DAS, and (measurement) position had significant effects on soil moisture content, when calculating effect over all rainfall / soil moisture measurement events. Similarly, measurement position and DAS had a significant interaction. Organic matter and phosphorous did not approach a significant effect level at $P < 0.05$, nor did they contribute to any significant interactions.

Table 6: Season cumulative type III tests of fixed effects for Ando soil moisture rainfall dynamic.

Effect	Significance
DAS	<.0001
Slope	<.0001
Phosphorous	0.8601
OM	0.0042
Position	<.0001
Slope*DAS	<.0001
Phosphorous*DAS	0.6037
OM*DAS	0.0086
Position*DAS	0.0002
Slope*Phosphorous	0.3294
Slope*OM	0.9405
Phosphorous*OM	0.1587
Phosphorous*Position	0.3232
OM*Position	0.7148
Slope*Phosphorous*DAS	0.4560
Slope *OM*DAS	0.2700
Phosphorous*OM*DAS	0.7143
Phosphorous*Position*DAS	0.2232
OM*Position*DAS	0.0930
Slope *Phosphorous*OM	0.0709
Phosphorous*OM*Position	0.8105
Slope*Phosphorous*OM*DAS	0.3316
Phosphorous*OM*Position*DAS	0.1502

DAS, slope, OM and (measurement) position all had significant effects on soil moisture content, when calculating effect over all rainfall / soil moisture measurement. Similarly, slope and DAS had a significant interaction, as did organic matter and DAS and soil preparation and DAS. Phosphorous did not approach a significant effect level at $P < 0.05$, nor did it contribute to any significant interactions.

Table 7: Season cumulative type III test of fixed effects for Chere soil moisture rainfall dynamic.

Effect	Significance
DAS	0.0025
Slope	<.0001
Phosphorous	0.5284
OM	0.7059
Position	<.0001
Slope*DAS	<.0001
Phosphorous*DAS	0.4718
OM*DAS	0.9427

Position*DAS	<.0001
Slope*Phosphorous	0.0931
Slope*OM	0.3249
Phosphorous*OM	0.0328
Phosphorous*Position	0.8452
OM*Position	0.3607
Slope*Phosphorous*DAS	0.6182
Slope*OM*DAS	0.9989
Phosphorous*OM*DAS	0.8998
Phosphorous*Position*DAS	0.3942
OM*Position*DAS	0.9989
Slope*Phosphorous*OM	0.9646
Phosphorous*OM*Position	0.5008
Slope*Phosphorous*OM*DAS	0.9593
Phosphorous*OM*Position*DAS	0.9991

DAS, slope and (measurement) position all had significant effects on soil moisture content at $P < 0.05$, when calculating effect over all rainfall / soil moisture measurement events. Similarly, slope and DAS had a significant interaction, as did measurement position and DAS and phosphorous and organic matter. Soil preparation, OM and DAS had a significant three-way interaction.

4.3 Comparison of Events

The purpose of the soil ridges was to alleviate times of water stress - both in excess and insufficient water. Therefore, in each village two measurement dates were compared to each other and to a day of "average" rainfall to assess the ridges' efficiency. The two measurement dates chosen were to represent a "dry" rainfall event (no recent rainfall) and a "wet" rainfall event, which had a large amount of rainfall the day before soil moisture measurement. Figures 6 – 8 demonstrate this comparison. A direct comparison of the selected dry, wet and average rainfall events to each other using an ANCOVA in SAS proved that in all communities the significant effects remain as when the ANCOVA was run using all events, in tables 5 - 7.

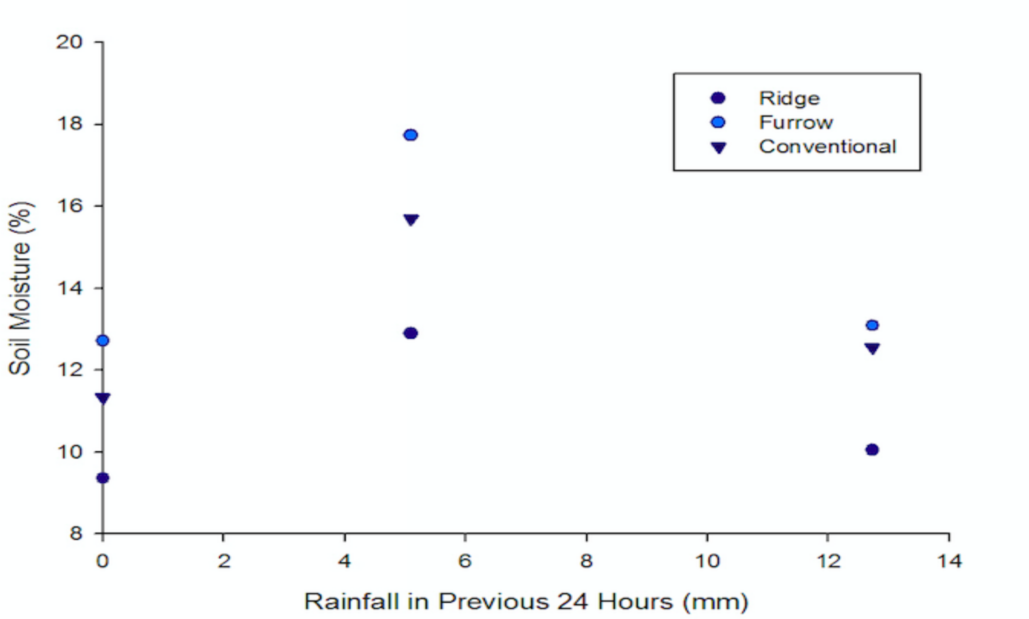

Figure 6: Three selected values from the Nansoni soil moisture data set, representative of no recent rainfall events, an average rainfall event and a large rainfall event (n=150).

The "dry" rainfall event occurred at 34 DAS, the average rainfall event occurred at 58 DAS and the "wet" rainfall event occurred at 29 DAS. It is important to note that canopy closure occurred at approximately 35 DAS; a closed or almost closed canopy affects the water's infiltration into the soil in all measurements.

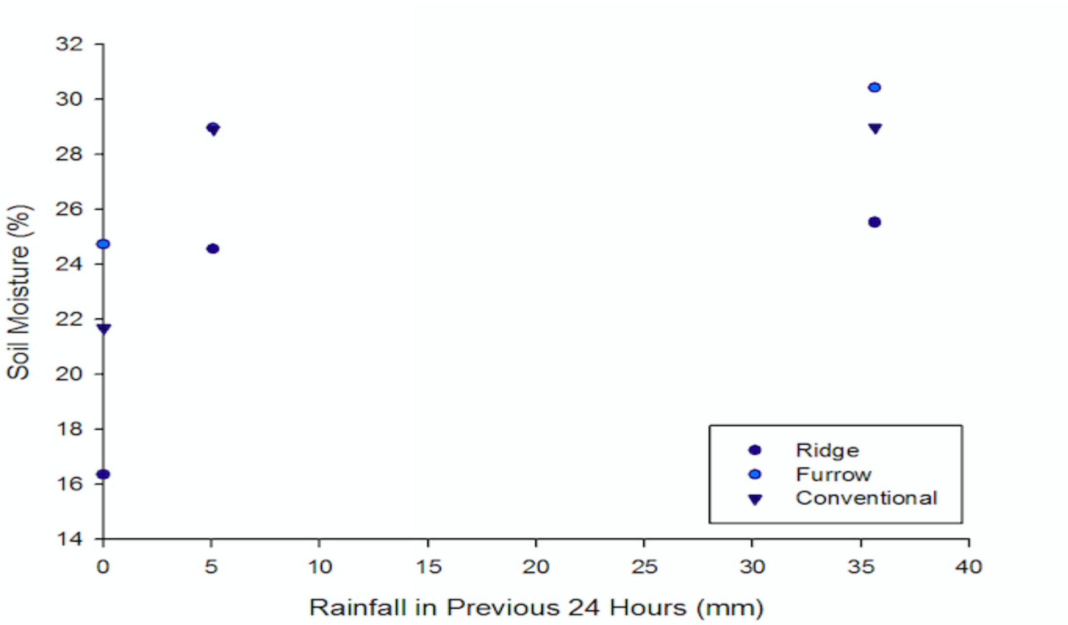

Figure 7: Three selected values from the Ando soil moisture data set, representative of no recent rainfall events, an average rainfall event and a large rainfall event (n=150).

The "dry" rainfall event occurred at 19 DAS, the average rainfall event occurred at 40 DAS and the "wet" rainfall event occurred at 47 DAS. It is important to note that canopy closure occurred at approximately 35 DAS; a closed or almost closed canopy affects the water's infiltration into the soil in wet and average instances, but not the dry – there were no soil moisture measurements taken after a day of no or very low rainfall after the canopy closed in Ando.

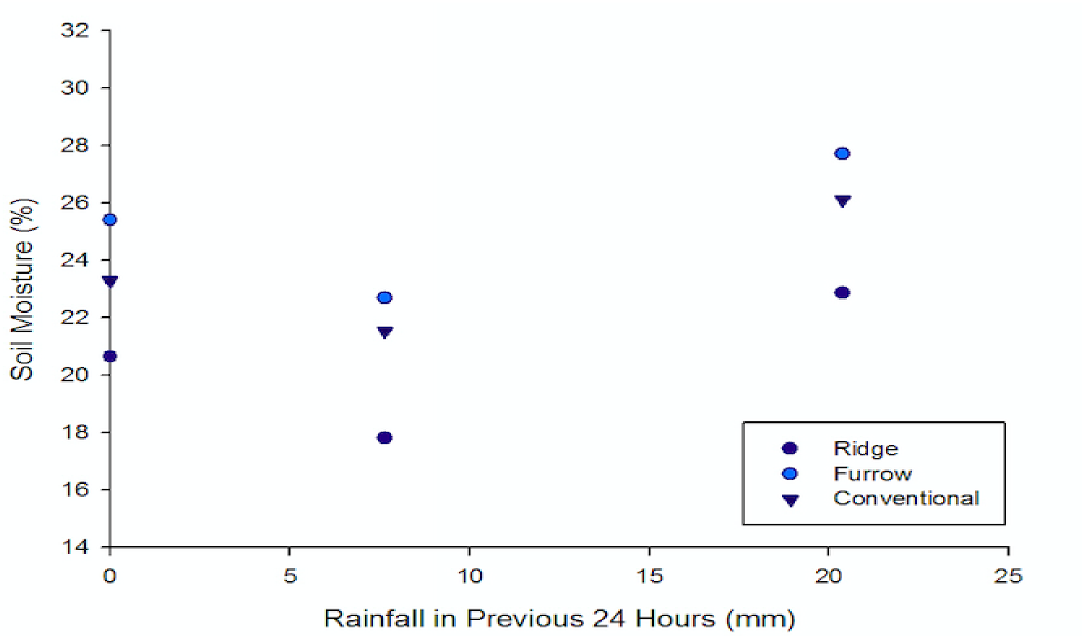

Figure 8: Three selected values from the Chere soil moisture data set, representative of no recent rainfall events, an average rainfall event and a large rainfall event (n=150).

The "dry" rainfall event occurred at 34 DAS, the average rainfall event occurred at 30 DAS and the "wet" rainfall event occurred at 58 DAS. It is important to note that canopy closure occurred at approximately 35 DAS; a closed or almost closed canopy affects the water's infiltration into the soil in all measurements.

4.4 Plant Growth Parameters

Plant growth parameters were used in this study to determine if the ridges were able to provide a growth benefit that may not be present in yield results. Growth parameters also act as a safe guard in the event that yield is not possible to collect due to unforeseen circumstances (no yield possible to record, dismal yield due to poorly timed rains, etc.). Growth parameters included are: plant height before mineral fertilisation, leaf area/leaf area index (LAI), side shoot count, height after mineral fertilisation and biomass and nodulation. Parameters were chosen for analysis for ease of which they could be assessed in a remote location.

Plant Height Before Mineral Fertilisation

While the tallest plants were found in the conventional plots of Ando, there were no significant differences between soil preparation method, or community when measuring height at 20 DAS (prior to mineral fertilisation), when conducting Type III F-tests in SAS. However, organic matter did have a significant effect (P=0.0005) across all plots. No other effects, nor interactions, approached significance at P < 0.05.

Table 8: Mean plant height (before fertilisation) at 20 DAS by soil preparation method of three communities in the Chereponi District.

Treatment	Plant Height (cm) (± SEM)
Nansoni Ridged	$9.96^{a} \pm 0.53$
Nansoni Conventional	$9.87^{a} \pm 0.54$
Ando Ridged	$10.80^{a} \pm 0.60$
Ando Conventional	$11.11^{a} \pm 0.69$
Chere Ridged	$10.95^{a} \pm 0.60$
Chere Conventional	$10.89^{a} \pm 0.60$

a-b Means across columns with different superscripts differ (P < 0.05)
Conventional=Soil prepared by flattening plough lines; Ridge=Soil prepared by ridging method
n=400 for Chere, n=500 for Nansoni and Ando

Side Shoot Count

There were no significant differences in side shoots between soil preparation methods when conducting Type III F tests in SAS, despite there being differences between communities. Organic matter did have a significant effect, where P=0.0037. No other effects, nor interactions, approached significance at P < 0.05.

Table 9: Mean values of side shoots by soil preparation method in three communities in the Chereponi District measured at 33 DAS.

Treatment	Number of Side shoots per Plant (± SEM)
Nansoni Ridge	$6^{a/b} \pm 0.34$
Nansoni Conventional	$6^{a/b} \pm 0.34$
Ando Ridge	$5^{b} \pm 0.38$
Ando Conventional	$6^{a/b} \pm 0.38$
Chere Ridge	$6^{a/b} \pm 0.38$
Chere Conventional	$6^{a} \pm 0.38$

a-b Means across columns with different superscripts differ (P < 0.05)
Conventional=Soil prepared by flattening plough lines; Ridge=Soil prepared by ridging method
n=400 for Chere, n=500 for Nansoni and Ando

Leaf Area and Leaf Area Index

With respect to leaf area, there were no significant differences between soil preparation methods across communities when conducting Type III F tests in SAS, despite the ridged plots out performing the conventional plots in two out of three communities. Organic matter did have a significant effect (P=0.0007), as well as significant interactions with mineral fertilization (P=0.0391) and community (P=0.0423).

Regarding LAI, there was a significant difference between soil preparation methods, where P=0.0043, while community did not have an effect (P=0.4543) when conducting Type III F tests in SAS. Mineral fertilisation did have a significant effect (P=0.0263), as well as organic matter (P=0.0095). Position and mineral fertilisation had a significant interaction, where P=<.0001, as well as position and organic matter, where P=0.0340. Community had a significant interaction with position, where P=0.0089, and with phosphorous, where P=0.0003. Community, position and organic matter had a significant three-way interaction, where P=0.0143, as well as community, position and organic matter having a significant interaction, where P=0.0003. Community position and organic matter also had a significant interaction, where P=0.0190. Position phosphorous and organic matter had a significant interaction at P=0.0277, and community, position, phosphorus and organic matter had a significant interaction where P=0.0494.

Table 10: Mean values of leaf area and leaf area index by soil preparation method of three communities in the Chereponi District measured 33 DAS.

Treatment	Leaf Area (cm^2/plant) (± SEM)	LAI (± SEM)
Nansoni Ridge	369.62^a ± 64.56	1.79^B ± 0.40
Nansoni Conventional	325.57^a ± 64.56	2.03^B ± 0.40
Ando Ridge	489.88^a ± 72.72	4.16^A ± 0.69
Ando Conventional	507.89^a ±72.89	1.35^B ± 0.69
Chere Ridge	467.88^a ± 72.89	$2.94^{A/B}$ ± 0.54
Chere Conventional	435.52^a ± 73.09	2.13^B ± 0.53

a-b, A-B Means across columns with different superscripts differ (P<0.05)
Conventional=Soil prepared by flattening plough lines; Ridge=Soil prepared by ridging method
n=40 for Chere, n=50 for Nansoni and Ando

Height Measurements After Mineral Fertilisation

In table 11, in Nansoni there was a significant difference between soil preparation methods when measuring plant height approximately 28 days after fertilisation (50 DAS). However the p value for soil preparation was not significant, at P=0.071. Organic matter did have a significant effect, and there was a significant mineral fertiliser*organic matter interaction and soil preparation*organic matter interaction.

Table 11: Mean plant height 50 DAS by soil preparation methods of three communities in the Chereponi District.

Treatment	Plant Height (cm) (± SEM)
Nansoni Ridged	47.76[a] ± 3.66
Nansoni Conventional	42.62[b] ± 3.66
Ando Ridged	44.84[a/b] ± 4.11
Ando Conventional	45.58[a/b] ± 4.12
Chere Ridged	50.28[a/b] ± 4.12
Chere Conventional	47.21[a/b] ± 4.13

a-b Means across columns with different superscripts differ (P<0.05)
Conventional=Soil prepared by flattening plough lines; Ridge=Soil prepared by ridging method
n=400 for Chere, n=500 for Nansoni and Ando

To demonstrate the effect of the soil preparation*organic matter interaction, table 18 represents plant height fractionated by community, organic matter treatment and soil preparation type. Despite Ando having the highest average height across all treatments, the control plots in Nansoni had the largest heights by treatment. While this could be a treatment effect, it could be a field effect as well, as the Nansoni control field was set quite far away from any housing, and thus could be deemed as “non-responsive” to fertiliser effects.

Table 12: Plant height (cm) measured at approximately 50 DAS (after mineral fertilisation) according to organic matter treatment and soil preparation method.

Treatment	Control	Light Manure	Heavy Manure	Light Residue	Heavy Residue
Nansoni Ridge	62.4	45.06	46.88	43.96	45.93
Nansoni Conventional	54.75	41.93	44.18	38.75	34.75
Ando Ridge	33.55	51.74	53.59	52.44	47.00
Ando Conventional	28.1	54.78	59.96	52.16	50.13
Chere Ridge	35.05	56.85	51.67	52.13	49.8
Chere Conventional	25.8	55.03	57.62	45.78	45.95

N=4 for control in all communities, n= 16 for all organic matter types in Chere and n=20 for all organic matter types in Nansoni and Ando.

Biomass and Nodulation

Regarding plant biomass, there were no significant differences between soil preparation methods when conducting Type III F tests in SAS, despite there being differences in communities. Therefore, community had a significant effect (P=0.017) and the soil preparation method had a significant interaction with the mineral fertilization (P=0.0223).

In respect to nodulation, there were no significant differences between soil preparation methods when conducting Type III F tests in SAS. While there were differences between communities, the direct comparison of flat plots versus ridged is the same between communities. There were no significant effects of fertilisation nor were there any significant interactions.

Table 13: Mean biomass and nodulation by soil preparation method of three communities in the Chereponi District measured 71 DAS.

Treatment	Biomass Dry Weight (g/plant) (± SEM)	Number of Nodules per Plant (± SEM)
Nansoni Ridged	13.56^{b} ± 1.68	51.12^{A} ± 3.91
Nansoni Conventional	12.31^{b} ± 1.68	$2.01^{A/B}$ ± 3.91
Ando Ridged	12.81^{b} ± 1.92	26.92^{B} ± 4.49
Ando Conventional	$15.46^{a/b}$ ± 1.93	37.40^{B} ± 4.53
Chere Ridged	20.09^{a} ± 1.93	$45.10^{A/B}$ ± 4.53
Chere Conventional	20.82^{a} ± 1.94	$39.79^{A/B}$ ± 4.57

a-b, A-B Means across columns with different superscripts differ (P<0.05)
Conventional=Soil prepared by flattening plough lines; Ridge=Soil prepared by ridging method
n=40 for Chere, n=50 for Nansoni and Ando

To demonstrate the effect of the soil preparation*mineral fertilisation, table 20 presents the dry weight (g) per plant, fractionated by community, mineral fertilisation level and soil preparation type. In both Ando and Chere, plants had more biomass in fertilised fields, only in Nansoni were the non-fertilised plants larger than the fertilised plants. Again, this could be attributed to the individual field effect of the Nansoni control field being non-responsive to fertiliser treatments.

Table 14: Biomass (g/plant) per plant at 71 DAS according to mineral fertilisation and soil preparation.

Treatment	Control	P1	P2
Nansoni Ridge	16.96	17.13	15.65
Nansoni Conventional	18.12	14.65	12.39
Ando Ridge	7.55	14.27	17.95
Ando Conventional	4.31	13.82	13.33
Chere Ridge	7.61	14.81	21.93
Chere Conventional	9.82	19.43	17.30

N=4 for control in all communities, n= 40 for Phosphorus 1 & 2 in Chere and n=50 for Phosphorous 1 & 2 in Nansoni and Ando.

4.5 Yield Parameters and Yield

Harvested Above Ground Biomass

Regarding biomass per plant at harvest, there were no significant differences between soil preparation methods when conducting Type III F tests in SAS. While there were differences between communities in conventionally compared plots, the direct comparison of flat plots versus ridged was the same between communities. Organic matter did have a significant effect (P=0.0091), as well as a significant interaction with soil preparation method (0.0031) as well as community*mineral fertilisation having a significant interaction (0.0117).

Regarding pods per plant, there were no significant differences between soil preparation methods when conducting type III F tests in SAS. Community did have a significant effect (P=0.0389) as well as a significant community*organic matter interaction (P=0.0174).

Table 15: Means of AGB harvested by soil preparation of three communities in the Chereponi District.

Treatment	Total Weight (g/plant) (± SEM)	Number of Pods (± SEM)
Nansoni Ridged	$0.72^{a/b}$ ± 0.04	$48.34^{A/B}$± 2.53
Nansoni Conventional	0.68^{b} ± 0.04	45.17^{B} ± 2.53
Ando Ridged	$0.79^{a/b}$ ± 0.03	54.76^{A} ±2.87
Ando Conventional	0.81^{a} ± 0.04	$49.76^{A/B}$ ± 2.89
Chere Ridged	$0.70^{a/b}$ ± 0.04	42.13^{B} ± 2.89
Chere Conventional	$0.69^{a/b}$ ± 0.04	41.50^{B} ± 2.91

a-b, A-B Means across columns with different superscripts differ (P<0.05)
Conventional=Soil prepared by flattening plough lines; Ridge=Soil prepared by ridging method
n=120 for Chere, n=150 for Nansoni and Ando

Harvest Index

In Chere there was a significant difference in Harvest Index (HI) between soil preparation method when conducting Type III F tests in SAS. The interaction of community*soil was significant at P=0.0281.

Table 16: Mean harvest index by soil preparation method of three communities in the Chereponi District

Treatment	Harvest Index (± SEM)
Nansoni Ridged	0.31^{b} ± 0.02
Nansoni Conventional	0.31^{b} ± 0.02
Ando Ridged	$0.34^{a/b}$ ± 0.02
Ando Conventional	$0.33^{a/b}$ ± 0.02
Chere Ridged	0.34^{b} ± 0.02
Chere Conventional	0.38^{a} ± 0.02

a-b Means across columns with different superscripts differ (P<0.05)
Conventional=Soil prepared by flattening plough lines; Ridge=Soil prepared by ridging method
n=40 for Chere and Ando, n=50 for Nansoni

Yield

There were no significant differences in yield regarding soil preparation when conducting Type III F tests in SAS. Soil preparation*organic matter did have a significant interaction (P=0.0127) as well as the interaction between soil preparation*organic matter*mineral fertilisation (P=0.0235).

Table 17: Mean yield (g/m^2) by soil preparation method of three communities in the Chereponi District.

Treatment	g/m^2 (± SEM)
Nansoni Ridged	0.19^a ± 0.02
Nansoni Conventional	0.18^a ± 0.02
Ando Ridged	0.23^a ± 0.02
Ando Conventional	0.22^a ± 0.02
Chere Ridged	0.20^a ± 0.02
Chere Conventional	0.21^a ± 0.02

a-b Means across columns with different superscripts differ (P<0.05)
Conventional=Soil prepared by flattening plough lines; Ridge=Soil prepared by ridging method
n=40 for Chere and Ando, n=50 for Nansoni
Yield measurements were adjusted for water content.

Table 18 provides an overview of all treatment factors fractionated by both community and soil preparation type. Despite having less total rainfall in Ando than in Nansoni, Ando produced higher yields across almost all treatments, confirming that the total amount of annual rainfall was not the main limiting factor in the cropping systems of the Chereponi District.

Table 18: Yield measured in g/m^2 of soybean grown in the 2016 growth season in the Chereponi District.

Treatment	Control	P1	P2	LM	HM	LR	HR
Nansoni Ridge	0.17	0.17	0.18	0.20	0.19	0.18	0.19
Nansoni Conventional	0.14	0.17	0.17	0.19	0.17	0.17	0.20
Ando Ridge	0.17	0.19	0.21	0.23	0.25	0.23	0.24
Ando Conventional	0.12	0.17	0.18	0.23	0.23	0.23	0.24
Chere Ridge	0.14	0.21	0.23	0.17	0.19	0.22	0.19
Chere Conventional	0.12	0.18	0.17	0.25	0.21	0.21	0.22

N=4 for control in all communities, n= 16 for all OM types in Chere and n=20 for all OM types in Nansoni, n= 40 for P1 & P2 in Chere and n=50 for P1 & P2 in Nansoni and Ando.

4.6 Green Water Use Efficiency

While soil preparation method did not have a significant effect when conducting Type III F tests in SAS, position*organic matter did have a significant effect (P=0.0049) as well as significant interactions of community*position*organic matter (0.0197), community*position*mineral fertilisation (P=0.018), position*mineral fertilisation*organic matter (P=0.0065) and community*position*mineral fertilisation*organic matter (0.0443).

Table 19: Mean water use efficiency (g/m²/l rainfall) by soil preparation method of three communities in the Chereponi District.

Treatment	Grams Soybean Yield Produced per Litre of Rainfall (± SEM)
Nansoni Ridged	$0.19^{b} \pm 0.02$
Nansoni Conventional	$0.26^{b} \pm 0.02$
Ando Ridged	$0.37^{a} \pm 0.03$
Ando Conventional	$0.36^{a} \pm 0.03$
Chere Ridged	$0.30^{a/b} \pm 0.02$
Chere Conventional	$0.31^{a/b} \pm 0.02$

a-b Means across columns with different superscripts differ ($P<0.05$)
Flat =Conventional soil preparation; Ridge=Soil prepared by ridging method
n=40 for Chere and Ando, n=50 for Nansoni

Table 20 provides an overview of all treatment factors fractionated by both community and soil preparation type. The highest water usage was observed in Ando, in the plots treated with organic matter.

Table 20: Water use measured in g/m²/l rainfall of soybean grown in 2016 in the Chereponi District

Treatment	Control	P1	P2	LM	HM	LR	HR
Nansoni Ridge	0.24	0.24	0.27	0.30	0.28	0.26	0.28
Nansoni Conventional	0.20	0.24	0.24	0.27	0.25	0.25	0.29
Ando Ridge	0.28	0.31	0.33	0.36	0.40	0.37	0.39
Ando Conventional	0.19	0.27	0.28	0.37	0.37	0.37	0.39
Chere Ridge	0.23	0.34	0.37	0.28	0.31	0.35	0.31
Chere Conventional	0.19	0.29	0.28	0.41	0.34	0.34	0.36

N=4 for control in all communities, n= 16 for all OM types in Chere and n=20 for all OM types in Nansoni, n= 40 for P1 & P2 in Chere and n=50 for P1 & P2 in Nansoni and Ando.

4.7 Mean Yield Comparison

With no significant effects of soil preparation on yield, it is easy to summarise that the trial was unable to successfully demonstrate that soil ridges were able to produce a higher yield of soybean than that of soybean grown on conventionally prepared plots. There is, however, a different approach to regard the success or failure of the trial. While no treatments were significantly different from one another when running an ANOVA test on yield, a direct comparison to the control plots with individual pairwise comparisons can determine if any of the treatments actually increased the possible yield compared to no inputs at all.

In no community did the ridges produce a significant effect over conventionally prepared plots, with no other inputs when conducting a t-test in Excel. However, in Nansoni manure had a significant effect on yield in ridged plots, as well as in Chere when combined with mineral fertilisation, "heavy" manure and both residue concentrations. No plots without ridges showed a significant difference to the control plot's yield values.

Table 21: Mean yield treatment values, pairwise comparison to control values.

Nansoni		Ando		Chere	
Ridge Treatment		Ridge Treatment		Ridge Treatment	
Treatment	P Value	Treatment	P Value	Treatment	P Value
Ridges Only	0.20	Ridges Only	0.45	Ridges Only	0.36
P1	0.27	P1	0.10	P1	0.03
P2	0.13	P2	0.06	P2	0.04
LM	0.01	LM	0.07	LM	0.45
HM	0.04	HM	0.07	HM	0.01
LR	0.18	LR	0.09	LR	0.04
HR	0.20	HR	0.06	HR	0.03
Conventional		Conventional		Conventional	
Treatment	P Value	Treatment	P Value	Treatment	P Value
P1	0.29	P1	0.22	P1	0.06
P2	0.23	P2	0.22	P2	0.11
LM	0.15	LM	0.10	LM	0.08
HM	0.07	HM	0.07	HM	0.01
LR	0.05	LR	0.07	LR	0.05
HR	0.15	HR	0.06	HR	0.12

N=4 for control in all communities, n= 16 for all OM types in Chere and n=20 for all OM types in Nansoni, n= 40 for P1 & P2 in Chere and n=50 for P1 & P2 in Nansoni and Ando.

5 Discussion

5.1 Soil Water Evaluation

A complete bare soil evaporation analysis of the soils from each village was not possible to conduct. The bare soil evaporation experiment conducted in this study is not complete, as it does not analyse the soil's moisture down to a very minimal level. However, results still agree with the two-stage model of evaporation, suggested by Ritchie et al. in 1972. The initial evaporation rate while the soil is still moist is governed by the external evaporability capability that is acting on the soil (Lemon, 1956). If there is no additional rainfall and evaporation persists, as the soil surface continues to dry, the ability of the soil to transmit water to the soil surface declines below the evaporability capability of the atmosphere, thus dropping the evaporation rate, often quite abruptly (ibid). Within this experiment, a rapid initial drop in soil water content was found, followed by a more gradual decline.

The modified bare soil experiment was still able to its meet objective: to assess the longevity of rainfall's impact on measured soil moisture. Within 24 hours, each soil sample had approximately the same soil moisture as was read by the SM300 Soil Moisture Meter prior to the addition of water to the samples. Despite the ridges holding more water, in all samples after the first hour the conventional plots held more soil moisture than the ridged. After approximately 24 hours, the measured soil moisture was comparative to its original level. The gravimetric analysis showed that the water had in fact evaporated, as each sample weighed equal to or less than its initial weight. Also, no water was found underneath the samples when they were transported for weighing.

Since the rapid drop in soil moisture was to the samples initial moisture level, this indicated that when assessing rainfall's impact on the plant available soil moisture, the rainfall events that took place in the 24 hours prior to measurement had direct impact on the measurements taken that day. Saturated conductivity rates ranged from 439-1977 mm/day; it is likely that the majority of the water added was lost to evaporation rather than deep percolation.

According to Bear (1988), these calculated saturated conductivity rates are on par for a semi-pervious, well-sorted sand containing silt and some loam as was found in the Chereponi District.

In both Nansoni and Ando, the ridge samples had a lower bulk density than the samples taken from the conventionally prepared plots and was able to accommodate more water when field capacity was measured, thus indicating larger pore space between soil particles, attributed to the ridge construction. This is also demonstrated in the saturated conductivity; in Nansoni the ridge sample's conductivity was 896 mm/day higher than the conventional, and in Ando the ridge sample's conductivity was 649 mm/day higher than the conventional. In Chere the bulk density was equal for both the ridged and conventional samples, while the conventional samples held more water. Given that the soil texture between the three sites was similar, Chere did have a notably higher available water capacity (AWC) than Nansoni or Ando: 4.01% compared to 2.07% and 2.99% respectively (Archibong, 2015), which could attribute to the higher field capacity of the conventional sample compared to the ridged. It is also possible that the ridge sample had settled more in Chere, thus reducing the pore size between soil particles. The ridge sample in Chere was taken from the outskirt of the ridge plot, beside a footpath leading to the community's only water source. Well-trodden footpaths have been known to be compacted by traffic, and have significantly higher bulk density than those around them (David, Darmody, & Price, 2000) – it is possible the ridge was compacted by traffic before the sample was taken, thus increasing it's bulk density.

5.2 Soil Moisture Dynamics

Measurement Position

Throughout the 2016 growth season, measurement position had a significant effect on soil moisture in all three communities, despite their respective differences (soil composition, AWC, C:N ratio, rainfall events, etc.). This significance answers the research question "does soil ridging make a significant difference on soil moisture levels in the Chereponi District", and accepting the hypothesis that soil ridging will make a difference on soil moisture levels when compared to conventional tillage. The furrows consistently held the highest soil moisture content, and ridge tops were consistently most dry. Agreeing with the idea that ridges evacuate water, and furrows maintain moisture content received by infiltration from the ridge. In Zimbabwe in 2009, Makrira investigated the use of a ridge trough system set up in a similar fashion to the current study. However, the study incorporated use of time domain refractory (TDR) tubes to monitor the changes in the soil moisture more closely over the course of the season. With measurements made twice weekly from TDR tubes placed as near as possible to the ridges and furrows, at 10 cm soil depth, and at regular intervals of up to two meters, results obtained from this study confirmed that zones of greatest soil moisture concentrations are those around the furrows.

DAS

The effect of DAS also had a significant impact through assessment of all soil moisture measurement events in all three communities. As leaf area increased, there was thus more interference between rainwater reaching the soil surface, directly impacting the soil moisture content. Thus, in the earliest DAS, both rainfall and solar radiation would have reached the soil surface at an approximately equal rate. Since soybean is a broadleaf crop, after canopy closure (approximately 35 DAS) rainfall was subject to solar radiation before it reached the soil surface, as it first made contact with the leaves of the soybean plants (Jackson & Schmugge, 1991).

Maximum GWUE is achieved when the ratios of assimilate reserve components to yield components and of evapotranspiration to transpiration are maximised (Norman, 1978). As greater plant cover reduces soil evaporation, soybean is able to increase its WUE, increasing both soil water extraction and transpiration (ibid). Consequently, after the water reached the soil surface of the ridges, it was no longer subject to solar radiation. The larger plants absorbed the water more readily, thus causing a further decrease in soil moisture both on the ridges and in the furrows. A significant interaction within the study between measurement position and DAS, also found in all three communities, supports this idea.

Theoretically, if rainfall persists after leaf senescence occurs, the soil moisture would again increase. The leaf area index would decrease again, and less water would be evaporated off the crop's leaves. However, this study was unable to evaluate soil moisture during or after senescence.

Slope

It is well established within literature that slope is a main determinate of the appropriate soil ridging method for a specific area (Biazin, Sterk, Temesgen, Abdulkedir, & Stroosnijder, 2012; Lal, 2001; Liu, An, Wang, Wu, & Zhang, 2015). The effect of slope also had a significant impact on soil moisture in Ando and Chere, while there was no significant impact in Nansoni. The slopes measured in Nansoni were all very similar; ranging only from 2.1% to 2.2%. Therefore, a slope would not be expected to have a significant impact within this block. In 2015, Liu et al. determined that there is a convex curve relationship style for field slope relating to soil conservation and runoff. Within a contour ridge experiment performed in a soil box on a sandy loam soil from a plough layer (71.2% sand, 28.1% silt and 0.7% clay), they were able to determine that the greatest benefit of ridging occurred when the slope ranged from three to seven percent. Contour failure occurred at slopes from 8.7% to 17.6%. This failure was typically due to the ridge top being too close to the furrow on the upper side of the ridge, thus in heavy rainfall events the overflow would erode the ridge top. Since all slopes in the current experiment were less than five percent gradient, contour failure was not seen, nor was the convex curve distinguished. Liu's experiment also established a relationship between slope gradient and infiltration. As the slope increases, a higher ridge height can reduce soil erosion and increase infiltration. The higher ridges create a deeper furrow when used on the steeper slopes, thus facilitating this increased infiltration. As the slope increases and ridge height remains constant, as was the case in the current study, erosion is increased and infiltration decreased.

There was also a significant interaction between slope and DAS in both Ando and Chere. In both Ando and Chere DAS and slope were found to be strongly significant (P= <0.0001 for both parameters in Ando and P=0.0025 DAS, <0.0001 slope in Chere over the growth season), it is possible that such strong effects of both parameters combined to a significant interaction. There is, however, another plausible explanation for the significant interactions. As the season progressed, the soil ridges did degrade. While at the end of the season they were still visibly raised above the furrow, they were no longer 10 cm in height. Slope has a direct impact on ridge degradation (Lal, 2001), and soil ridge construction has a direct impact on soil moisture (Liu, An, Wang, Wu, & Zhang, 2015; Biazin, Sterk, Temesgen, Abdulkedir, & Stroosnijder, 2012). As the ridge structure degraded over the course of the growth season, a shift in the soil mositure dynamics would be expected.

Organic Matter

Organic matter content directly affects the stability of aggregates formed within the soil. The degree of aggregation affects pore volume and pore size distribution, therefore affecting infiltration capacity and soil moisture retention capabilities (Ridder & Keulen, 1990).

Soil moisture can be directly linked to soil organic matter (SOM). In 2005, Mando et al. determined on a soil found in Burkina Faso consisting of approximately 55% sand, that SOM decreased under continuous farming without additional inputs. As the SOM disappeared from the soil profile, with it there was a decrease in soil moisture.

Organic matter had a significant influence on soil moisture only in Ando. While all organic matter was added to plots using an identical method, it is unclear if the soil contained previous organic matter, which could act as a better moisture retainer than the crop residue that was mulched into the soil lightly after planting, or the manure that was only added in seeding strips, thus not contributing to a significant soil moisture effect. Across SSA, SOM stocks often dictate a strong fertility gradient in smallholder agricultural communities (Vanlauwe, et al., 2001). This gradient is often based on the proximity of the field to household dwellings, or areas were people frequently congregate (ibid). The trial fields in Ando were all quite close to the village's only road leading to Chereponi; it is entirely possible that the soils contained a higher initial SOM compared to Nansoni and Chere (where fields were located away from the road), and thus the initial SOM stocks of the soil found in Ando were potentially higher, and were therefore able to play a contributing role in soil moisture retention.

In Ando there was also a significant interaction between organic matter and DAS. Both had strong significant effects, where organic matter P=0.0042 and DAS P=<0.0001 over the course of the growth season. It is possible the combination of both strong significant effects created a significant interaction. It is also possible that an organic matter type or concentration provided more moisture holding capabilities than the others. The decomposition of plant residues causes concurrent declines of soil moisture (Tian, Brussaard, & Kang, 1995). Mulch decomposition is affiliated with C:N ratio and lignin content. The residue used in all three communities was the sesame stalks harvested from the same field, so the role of mulch retention should be constant throughout the communities. Sesame is a grass species with a relatively low C:N ratio, and high lignin content, found in its stalks. This low C:N ratio may have resulted in slower decomposition than if whole plants or broad leaf residues had been incorporated (Palm, Gachengo, Delve, Cadish, & Giller, 2001). While the sesame may not have had an effect on soil moisture, as seen in Nansoni and Chere, if in fact Ando had a higher OM concentration in the soil before the 2016 growth season, the previous residues would be further degraded, and would cause a significant effect on soil moisture as the growth season progressed.

Only in Chere was there a significant impact of the interaction between mineral fertilisation and OM on soil moisture. If mineral fertilisation and OM stimulated growth, the roots of the soybean could have led to higher soil moisture retention (Norman, 1978). While the direct influence of the mineral fertilisation and OM interaction on yield and plant growth parameters was not examined in this thesis, it is possible in Chere that there was a positive interaction from both of these fertilisation methods, and the plants responded accordingly. Roots and shoots of soybean plants do not grow at the same ratio. While the shoots of plants may be growing at an apparently slow or retarded pace, the roots may be growing at twice the pace (Norman, 1978). While plant parameters did not show sign of a mineral fertilisation and OM interaction effect, it is possible that it did in fact exist, but was only distinguishable by root growth. If so, this would explain an impact on soil moisture - soybean roots are extensive and fibrous, and effect of their soil moisture retention has been well documented (Norman, 1978). While nodulation was assessed in the current study, it was done by quite a crude method (image 8, p. 27). The lateral root system of the soybean was not entirely accounted for, thus measured nodulation was not a good indicator of root volume or surface area in the current study.

5.3 Plant Growth Parameters

Soil Preparation

Soil preparation had a significant effect only on leaf area index when conducting Type III F tests in SAS with an ANOVA in SAS (see Appendix C for the full ANOVA results). Thus responding to the research question "do soil ridges provide an advantage to soybean while growing?" and rejecting the hypothesis that significantly superior crops in height, number of side shoots, leaf area, biomass and nodulation would be found on the ridged cultivation. Measurement position significantly impacted soil moisture levels in all three communities, but soil preparation did not significantly impact any growth parameters in the communities. This indicates that soil moisture was sufficient in the conventionally grown plots, and soil ridging was unnecessary to improve the quality of soybean grown in the Chereponi District in 2016.

Organic Matter

While organic matter had a significant impact on almost all plant parameters, only in Ando did it have a significant impact on soil moisture. The scope of the current study is to evaluate soil moisture level's impact on crop parameters and yield, not the agronomic effect of organic matter and mineral fertilisers, therefore effects of organic matter in Nansoni and Chere are beyond the scope of this research.

Across the plant parameters measured in Ando, there was a significant impact by the organic matter. Whether this is due to OM response factors or the modified soil moisture is difficult differentiate. Given that the soil moisture was altered in all communities, and only Ando was found to have an organic matter effect, it's probable to say that the organic matter in Ando was working with effects from a previous SOM threshold, as previously stated. Within the yield results, there was no effect seen by OM, alluding that the OM stock was depleted during the vegetative growth phases of the soybean.

Organic matter did have a significant interaction with mineral fertilisation and community, regarding leaf area. This indicates that not all communities responded to the organic matter and mineral fertilisation interactions equally, and that a fertility gradient across the Chereponi District could be seen.

Leaf area was measured at 33 DAS, five days after mineral fertilisation. This time period was a time of consistent rainfall in all three communities, after mild drought. In soybean, there is generally a strong relationship between N and leaf area (Norman, 1978). However the fertilisers applied did not have significant N concentrations. The mineral fertiliser was TSP, and the C:N ratio of the OM was 14:1, 12:1 and 49:1 for the composite manure, cow manure and crop residue samples respectively (Landers, 2017). Due to the low N concentrations of the fertilisers, a direct impact on leaf area was not expected as a result of their addition. However after a mild spell of drought, a jump in plant growth is quite common (Norman, 1978), and the timing of the addition of mineral fertiliser compliment this growth.

5.4 Yield Parameters and Yield

Soil preparation did not have a significant effect on either yield or yield parameters when conducting Type III F tests with an ANOVA in SAS. Thus negatively answering the research question "is the yield of soybean grown on ridges significantly higher than the yield of soybean that was grown on conventional tillage?" and rejecting the hypothesis that yield of crops grown on ridges will be significantly higher than that of soybean grown on conventionally prepared plots.

Yield Parameters

Regarding all yield parameters, there was no significant effect of soil preparation. Ando outperformed both Nansoni and Chere in terms of AGB and number of pods. The conventional plots in Chere yielded the largest harvest index, indicating the best plant to yield ratio. It is important to note this ratio is not necessarily representative of overall plant health. Smaller plants yielding smaller amounts of grain have a higher harvest index than large plants yielding a medium amount of grain. The conventional plots in Chere simply grew and reproduced at the most equal rate throughout the growth season.

Organic matter had a significant effect on AGB, as well as a significant interaction with soil preparation. Plots with organic matter typically had higher AGB than plots without organic matter, and ridge plots with organic matter typically had higher biomass than their conventional counterparts. This indicates that while the difference in soil moisture was only visible in Ando, perhaps the organic matter was creating a difference in soil moisture out of the scope of moisture measurements, as previously proposed.

Community had a significant effect on pods per plant, and also had a significant interaction with organic matter, further substantiating the theory of there being a notable difference in SOM stocks and thus a fertility gradient across the three communities studied.

Community also had a significant interaction with soil preparation when harvest index was analysed ($P=0.0281$). This indicates that the ridges had a different effect on plant growth in different locations. Since soil preparation had a significant effect on LAI, a difference in harvest index is expected. Community's interaction shows that the soybean responded differently across the communities. This could be a consequence of different rainfall patterns during the pod filling stage causing yields to increase in Ando, and not elsewhere, since the ridges did not have an impact on grain yield.

Yield

While the effect of the ridges was not statistically significant, it is worthwhile to acknowledge that over all three communities the ridges produced an average of 0.21g/m^2 (or 2.1 tones/ha) compared to the conventional tillage producing an average of 0.20g/m^2 (or 2.0 tones/ha). While the difference is minimal, the ridges did in fact outperform the conventional tillage, based on the average of the 13 trial fields. Only in Chere did the conventional tillage produce more than the ridges, by 0.01g/m^2 (0.1 tones/ha). While the difference is minuscule, Chere is the only block where bulk density did not decrease by soil ridging. Thus, the ridges entirely failed in Chere. Not only were they ineffective, but also hampered the soybean production.

Ando had the highest yields of the three communities. Ando is also the only community where OM played a significant role in the soil moisture. However, within the yield results, OM did not independently play a significant role, but there was a significant interaction between soil preparation and organic matter (P=0.0127). This signifies that the organic matter interacted differently under dry or wet conditions, since the organic matter was only spread on the ridge tops and the conventional plots, never the furrows. There was also a significant interaction between soil preparation, organic matter and mineral fertilisation (P=0.0235). This interaction indicates that the relationship between the organic matter and fertilisation was dependent to some extent on soil moisture.

It was not proven within this study that soil ridging has direct influence on the functionality of mineral fertilisers, as the two-way interaction between soil preparation and mineral fertilisation was not significant. However the significant three-way interaction with OM may allude to a relationship. Soil moisture was only measured in the first five centimeters of soil; the residues direct exposure to the sun would not represent their ability to retain moisture well. The mulch mixed lower in the plots would be the mulch with a more impactful moisture retention rate, and would be out of the realm of soil moisture measurements conducted in this study. It’s also possible that the lower bulk density of the ridges better accommodated the decomposition of the residue, as more water is able to infiltrate after rainfall events, and increased oxygen is present to aid decomposition (Beare, Hendrix and Coleman, 1994).

A similar experiment was performed by Adeboye, Schultz, Adekalu and Prasad in 2011 and 2012 (published in 2017), in Ile-Ife, Nigeria, with similar agroecological conditions to those found in the Chereponi District. Soil ridging combined with mulching by plant residues increased both soil water storage and yields in both years of the two-year trial. Soil ridges without mulch proved to increase seasonable water use, and portioned a higher proportion of evapotranspiration towards productive transpiration. When compared to treatments of only mulch, mulch + soil ridging treatments caused an increase in water productivity for grain yield and AGB, as transpiration efficiency was further increased when the soil surface was altered to conserve water when there were fluctuations in seasonal rainfall.

Transpiration and evapotranspiration were not measured within the current study, so it's not possible to tell if they increased with ridging treatment, organic matter treatment or a combination the two. The effect of OM and ridging is not seen in yield because, again, the rainfall stopped during the pod filling stage of the soybeans. Therefore, soil ridging was not able to conserve enough moisture to create an effect on yield, but soil ridging in combination with OM and with OM and mineral fertilisation, did.

5.5 Water Use Efficiency

Soil preparation did not have a significant effect on green water use efficiency when conducting Type III F tests with an ANOVA in SAS. Thus answering the research question "is the water use efficiency of soybean grown on ridges significantly higher than that of soybean grown on conventionally tilled plots?" and rejecting the hypothesis that the water use efficiency of soybean grown on ridges will be significantly higher than that of soybean grown on conventional tillage.

Ando had a significantly higher GWUE when compared to Nansoni and Chere. Unlike in Nansoni and Chere, rainfall in Ando had a sharp increase at the beginning of October (as seen in figure 1, p. 20), which encompassed the pod filling stage of development for soybean. It is repeatedly stressed throughout literature that in soybean production pod filling is a critical stage for soil moisture requirements (Roekel & Purcell, 2015; Snyder, Carlson, & Shaw, 1982; Norman, 1978; Rawson, Turner & Begg, 1978). To see significantly higher yields from the community where the rains lasted the longest was anticipated.

Soybean is a hardy plant, which can withstand periods of drought. Soybean varieties differ greatly in response to soil moisture. Mederski et al., (1973) measured the seed yield of eight cultivars grown under low and high soil moisture conditions. While all cultivars performed best while grown under high moisture conditions, the late maturing cultivars produced almost as much seed yield under low moisture conditions as they did at the high moisture conditions. This indicates that the susceptibility of soybeans to moisture stress has a stronger link to maturity, rather than variety.

As seen in figure 2 (p. 21), 2016 was a year of high rainfall in the Chereponi District. Compared to previous years, 2016 was in the 75th percentile, and as seen in figure 1 (p. 20), even in times of relative drought there was light rainfall on a regular basis. Therefore, rainfall was not the limiting factor of crop production in the 2016 season. While the ridges did in fact alter soil moisture, this alteration was not necessary in order to produce maximum yield.

5.6 The Economic Aspect and Mean Yield Comparison

Due to the early arrival of the rainy season in 2016, it was not possible to properly evaluate the economics of the soil ridging. The intent was to construct planting ridges off of pre-existing ridges from plough lines, to minimise labour. Since the rains began early, by the time the research team arrived in Chereponi the fields had been ploughed and hand levelled (and in many cases planted).

Ridging from flat land proved to be difficult. It took three men 45 minutes to ridge one study area. One study area equates to 62.5 m^2, so it would take approximately 6 hours to ridge one acre (or approximately 15 hours per hectare). Given that the ridges only produced 0.1 t/ha more than the conventional plots, a detailed analysis is not necessary to prove that ridging simply is not economical. Thus, answering the research question “is the difference in yield worth the labour of ridge formation – is soil ridging economical". The hypothesis that when compared to the labour of flattening after ploughing, ridges made from the plough lines will be economically viable was not able to be tested, as the fields were flattened before arrival of the research team.

While no treatment governed a significant difference in yield from another (see table 23, p. 48), this does not necessarily mean that the treatments did not differ significantly from the control plots. Table 27 (p. 51) provides an overview of individual pairwise comparisons between the treatments, split by ridged and conventional tillage, compared to the control plots of each community. No treatment varied significantly from the control plots when grown on conventional tillage. While the ridges themselves did not prove superior, they did cause interactive effects, and several treatments were significantly different than the control. In Nansoni both concentrations of OM by manure were significantly greater than control, and in Chere both mineral fertilisation concentrations, both residue concentrations and HM were significantly different than that of the control plots.

Interestingly enough, there were no significant differences between mineral fertilisation, nor OM type or concentrations when compared to the control in Ando. This supports the idea that the duration of the rainfall events into the pod filling stage is a more important yield enhancing effect than any of the agronomic treatments, or treatments combined. The control of that community must have been quite large to not be significantly dwarfed by the fertilised plants.

Clearly due to labour constraints at planting time and the intense method of ridge creation without a plough line to ridge from, farmers would never choose to ridge for such a small return per area. If ploughing practices in the area proved possible to ridge from, it would have to be determined whether the time spent ridging is approximately equal to that spent flattening. If this were the case, ridging even for a small amount of extra yield would prove beneficial.

6 Conclusion

Soil ridging did successfully alter soil moisture by creating ridge tops that evacuated excess rainfall and furrows that maintained more soil moisture than was found in the conventionally prepared plots. However, this effect did not prove to significantly enhance the yield or water use efficiency of the soybean. While leaf area was significantly effected, other plant parameters remained uninfluenced. Due to the extensive labour necessary to construct the ridges, and their minimal yield return, soil ridging was not found to be economical in the Chereponi District in 2016.

Duration of the rainy season relative to the maturity of the soybean proved to be more important to yield generation than the actual agronomic practices explored in the trial. Soil ridging failed to compensate for this complete lack of rain at the end of the season. The soybean was planted too late to reap the benefits from rainfall that occurred during the critical pod filling stage in two out of three trial communities.

Rainfall for the 2016 growth season was in the 75th percentile as per the last ten years. Given the relatively high amount of rainfall, and that the duration of the longest drought spell was a mere five days, it is difficult to determine if soil ridging is an effective practice of climate smart agriculture in the Chereponi District.

This raises an interesting idea of which climate smart agricultural methods are effective in the Chereponi District. Further research could determine an appropriate method that is agronomical, economical and culturally acceptable and could be employed by the AWG members to mitigate changing rainfall patterns on soybean crops. Rainfall in the area has proven unreliable, but heavy at times; perhaps different water-harvesting technologies could be more a suitable method in order to stabilise yield than soil ridging proved to be throughout the course of this project.

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