2020

# THE EFFECT OF SPACING OF VETIVER GRASS (CHRYSOPOGON ZIZANIOIDES) HEDGEROWS ON HILLSLOPE EROSION IN EASTERN REGION, GHANA

Evan R. Lanese
*Michigan Technological University*, erlanese@mtu.edu

# THE EFFECT OF SPACING OF VETIVER GRASS (CHRYSOPOGON ZIZANIOIDES) HEDGEROWS ON HILLSLOPE EROSION IN EASTERN REGION, GHANA

By

Evan R. Lanese

A REPORT

Submitted in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

In Geology

MICHIGAN TECHNOLOGICAL UNIVERSITY

2020

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

Department of Geological and Mining Engineering and Sciences

Report Co-Advisor: *Dr. Blair Orr*

Report Co-Advisor: *Dr. John Gierke*

Committee Member: *Dr. David Watkins*

Department Chair: *Dr. Aleksey Smirnov*

# Acknowledgements

First, I would like to thank Michigan Technological University for its constant support on campus and overseas. My co-advisors Dr. John Gierke and Dr. Blair Orr were supportive to me throughout my entire time spent on this project. I would also like to thank Dr. David Watkins for serving on my committee.

Next, I would like to thank the Peace Corps for giving me the opportunity to learn, educate, and perform my research abroad. I am grateful for the Peace Corps Ghana Staff for their education and assistance they provided to me during my service. I would like to thank the CSIR Soil Research Center in Accra for carrying out the soil analysis. A big thank you to Dr. Dale Rachmeler and the Vetiver Network International for introducing vetiver grass to Maxwell in Ghana who later provided it to me.

I would like to thank Janet Obu for providing me with land for the field study and the village for their support. Most importantly I would like to show my gratitude to George Agyekum Neslon for being there for me every day during my service to guide me through the Ghanaian language and culture as well as help me setup the field site and record rainfall data while I was traveling. Me de wase pa pa pa.

## Abstract

Soil erosion in Ghana negatively effects many small holder farmers due to heavy rainfall, continuous land use, and a changing climate. Inexpensive, local, and sustainable practices that can be used to reduce soil movement thus building productive soils would benefit farmers in Ghana. Vetiver grass (*Chrysopogon zizanioides*) has been used to this effect worldwide. Its local availability and positive reputation leaves desire to learn about its applicability in Ghana. A field study was conducted on plots of sloping farmland (10ft by 60ft) with three treatments: (1) control with no vetiver grass, (2) two vetiver grass hedgerows, (3) four vetiver grass hedgerows. Erosion pins were placed in a grid and measured periodically during the approximate 6-month study period along with daily rainfall measurements. ANOVA analysis showed small trends that the vetiver hedgerows were helping to curb erosion, although no statically significant results existed between the treatments. This hints that the grass will be effective after a greater establishment period but did not have a significant effect during the first months of its growth.

# 1 Introduction

A field study was carried out looking at the impacts of vetiver grass hedgerows of various spacings on hillslope erosion. This field study used erosion pin data for three treatments of vetiver grass hedgerows to measure erosion and deposition along a sloping hillside over an approximate 6-month span. Rainfall data was also collected over this span. The rainfall data was compared to the erosion data and discussed. Other analysis used statistical program JMP to run paired t-tests and ANOVA tests to evaluate variation and patterns in different pin groups.

## 1.2 Cultural Context

The study was conducted in Gboloo Kofi, Akuapim North District, Eastern Region, Ghana, West Africa (Figure 1). Gboloo Kofi is a small farming village with a population of about 400. Because of family culture and dynamics, it is hard to get an accurate population as number of people in a household fluctuates throughout the year. There are three main neighborhoods in the village: New Life, Jaka, and Gboloo Kofi proper. There are about 30 households along with a school (kindergarten to junior high school) and a local clinic.

The climate of Ghana is tropical and the agroecological zone is categorized as deciduous tropical forest (Abbam et al., 2018). Most of the forest has been cut down to open land for farming. There are two major seasons: the rainy season which occurs from April to October and the dry season locally know as harmattan, which occurs from November to March. The rainy season is further broken into the major rainy season (April to mid-August) and the minor rainy season (mid-August to October). The mean annual rainfall for Gboloo Kofi is between 1,000 -1,400 mm annually (Logah et al., 2013). These rainfall patterns are known locally by farmers who plan their planting and growing seasons accordingly.

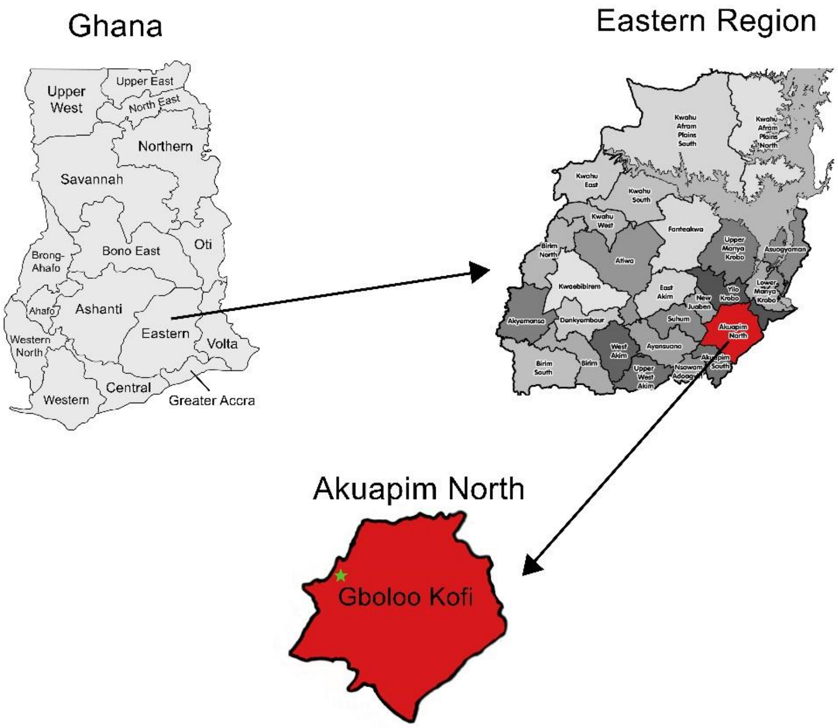


Figure 1: Map zooming from the country of Ghana, to Eastern Region, to where the study site was located, Gboloo Kofi. (Graphic created in Photoshop CS5, original maps were obtained from Wikimedia Commons and manipulated. Links to the copywrite licenses and full attribution appear in Appendix B).

The two main pillars of rural Ghanaian culture are family and religion. Family members travel and work outside the village and return to their family's homes often unexpectedly. The head of the family owns the family farm which they operate and younger adult members of the family can own portions of land. Land is passed on from deceased family members staying within the family line and can be rented or sold. One day a week called "taboo day," no one is allowed to go to farm, plant seeds/seedlings, weed with a cutlass, or any other major work. This day of rest centers the family around the home creating social interactions which occurs during food processing and leisure time.

The dynamic of family role differs depending on age and gender. There is a great respect for elders, especially when they are a family member. From childhood children have an obligation to help their parents and other family members at their farms, fetch water, process farm food products and sweep the yard. It is not uncommon for them to wake up at three or four o'clock in the morning to complete these tasks before school. The girls and women do the cooking and prepare the food for the entire family. Everyone no matter gender is involved with farm work.

In Gboloo Kofi community, some women are food vendors alongside their farm work. They provide prepared food or "chop" which is always available for sale in the mornings and afternoons by the roadside. There are usually between three and seven vendors available on any given day besides Sundays when people attend church. Men in the community are mostly farmers and motorcycle taxi drivers, locally know as okuda or motos. Once youth in the village reach into their twenties there is a strong instance of migration out of the village to seek job opportunities or education in more urban areas.

The churches in Gboloo Kofi are all some branch of the Christian Church, existing as five different denominations and church structures: Presbyterian, New Life, Assemblies of God, African Faith, and Pentecost. It is common for most people to dress up and go to church every Sunday. One family in the village still practices the traditional religion. Islam is practiced in the area but is less common in the south of Ghana and not found in Gboloo Kofi.

The resources available in the village are limited but most things one needs for everyday life can be purchased at one of three local shops. These shops are usually stocked with basic food items, school supplies, soap, and small hardware items such as nylon rope and super glue. Every Tuesday and Friday there is a larger market located about a 20 min drive east from the village in Adawso. Additional resources not available in Adawso can generally be found in Koforidua, the regional capital, about a one-hour journey from Gboloo Kofi. Accra the capital of Ghana is about two and a half hours south. The most common form of transportation in the village is by motorcycle. One can also take automobile taxis and small mini bus taxis (called *trotros*), but they are less frequent.

Figure 3: A resident of Gboloo Kofi at her house preparing cocoyam leaves for a stew. (Photograph taken by author)

Figure 2: A scene during the ceremony to welcome a new cheif to Gboloo Kofi. (Photograph taken by author)

Accessibility of cellphone network is not widespread in the village and depends on the particular day and the time of day. One can receive and make calls reliably near the roadside in the middle of town. 3G service can be accessed in one specific area, next to the water pump on the village side of the road, but occurrence of a strong signal is sporadic. In other areas of the village network is even less reliable. Consistent electricity access was introduced in the village in November 2016. Power shutoffs occur when substantial rain falls at the power station, located on the west side of Koforidua, leading to shortages that range from hours to days.

The farmers in Gboloo Kofi primarily cultivate maize (corn), cassava, plantain, sugarcane, and oil palm but also grow tomatoes, hot peppers, *okro* (okra), groundnuts (peanuts), garden eggs (small eggplants), bananas, coconut, mango, oranges, and turkey berry. For farmers the most available and cost-effective tool is the cutlass (farming machete) and is used for weeding (cutting back vegetation/clearing the land), digging holes, planting seeds, and collecting firewood. There is only one man in the village who is wealthy enough to afford plowing with a tractor and he only used this method once in the three years during the author's Peace Corps service.

Figure 4: A view of some of the homes and a food stand in Gboloo Kofi looking south across the main road. (Photograph taken by author)

Figure 5: A meal of fufu and light soup shared with a Gboloo Kofi resident and the author. (Photograph taken by the author)

## 1.3 Motivation

Soil conservation is an important topic to consider across Africa. The naive soils are infertile which can be attributed to high erosivity, low organic content, and over working of the soil (Oshunsanya, 2013). In Sub-Saharan Africa the population continues to rise with projected numbers of around 2 billion inhabitants by 2050, while historical records show that food production per capita in Africa are at much lower than the rest of the world. Low yields create economic burden for small holder farmers who represent 80% of all sub-Saharan African farms and cultivate up to 90% of the food in this region (Wiggins & Keats, 2013).

As the global climate warms at increasing rates from the release of greenhouse gases into the atmosphere, extreme weather patterns are becoming more regular. Farmers in sub-Saharan Africa are reliant on precipitation for their livelihoods. Current warming trends will likely create more unpredictable or irregular events leading to years of low rainfall and thus low yields. This would increase hardship for farmers who are noticing increased temperatures and decreased rainfall over the years, which can place a greater burden on those already struggling (Fosu-Mensah et al., 2012).

Geographic pressures are also putting burden on the village farmers. With more rural to urban migration, which was evident at the study site, farm production in the rural areas is reduced (Adaku, 2013). With a growing population and farmland used at capacity, the food production system is stressed. Rural women are especially vulnerable as they work more than men and are time-poor which leads directly to a lower farm production (Arora & Rada, 2017). Useful practices that increase production can help bring struggling farmers a better standard of living. (Falconnier et al., 2018)

Building topsoil is important to protect farmland by retaining moisture and fertility in the changing climate of sub-Saharan African. As the majority of the Ghanaian population are farmers that rely on natural rainfall to grow their crops (Abbam et al., 2018), introducing new soil conservation practices that increase food yields is one way to support these small holder farmers. Education on this topic could be implemented through the use of workshops by agriculture outreach officers, NGOs, or training programs led by local farmers who were taught soil conservation techniques from previous programs (Falconnier et al., 2018).

The original motivation behind this study is to evaluate the use of vetiver grass in the context of use by small holder farmers in southern Ghana. This topic was explored by evaluating erosion between vetiver grass hedgerows at different spacing intervals with a high resolution of erosion pins. This allowed a better representation of the processes going on between the grass as well as a more widespread distribution of pins between hedgerows for different spacings. The goal is to gain better insights into the best spacing between the hedgerows depending on the slope as well as exploring more about how the grass works in conditions and soils in Ghana where the impact of vetiver grass on erosion has not been widely studied.

It is also important to discuss the additional work, expense, space and burden that installing a practice like this instills on a farmer that may already be struggling. A farming system with vetiver produces more food in a smaller amount of land but initial setup requires additional work. Although vetiver hedgerows take up some farmable land, in the long term they create conditions that require less weeding, fertilizer, and create a condensed area of harvest between hedgerows. Previous studies show vetiver hedgerow practices on farms have improved maize yields up to 49.1% over five seasons, as well as cassava yields by 34.4% to 6.5 %, depending on row spacing, over three seasons when compared to control plots (Olaolu Babalola et al., 2005; Oshunsanya, 2013).

This practice is effective in that it can be implemented incrementally over many years with installation to small areas of the farms over time, placing less of a burden on the landholder compared to some practices that have to implemented across the entire farm at one time to be effective. Increasing farm production is important because this leads directly to income for women farmers who make up most of the food production workforce in Ghana (Baden et al., 1994). Money from increased yields goes into pockets of women who make up a large proportion of small holder farmers in Ghana. Women have been shown to invest this into their children which improves future generations (Gladwin et al., 2001). As found by Ritzema et al. practices like these are most effective when applied to farmers that are at least semi-food adequate to very food adequate as farmers that are poor food adequate do not benefit from implementing interventions to increase crops yields; this should be considered during real world implementation (Ritzema et al., 2017).

This topic also looks closer at the micro-variations of ground height change between the hedgerows rather than previous studies that have just observed total erosion using sediment capture or erosion pins just behind the grass or less frequently spaced to observe soil held by the hedgerows (Are et al., 2018; Olaolu Babalola et al., 2003; Dass et al., 2011; Donjadee & Tingsanchali, 2016; Lin et al., 2009; Oshunsanya et al., 2014). This closer pin arrangement could help create models to find the best hedgerow spacing for farms given the appropriate local conditions and thus provide the largest harvest for the farmer. These results could be also used in applications pertaining to vetiver spacing in prevention of flooding hazards, reduction of sedimentation in rivers, and stabilization of hills near roads, as spacing effects are important in terms of work required for installation and cost effectiveness.

## 1.4 Scope of Study

The goal of this study was to further investigate the relationship that vetiver hedgerows planted on the contours have on countering hillslope erosion with different spacings between the hedgerows in the setting of Ghana, West Africa. This was done by looking at the objectives below:

- Compare the rainfall data to the erosion pin data based on the corresponding collection period

- Compare pin groups from certain areas of the hillslope and in different treatments using JMP’s statistical modeling to look for relevant trends supporting that vetiver hedgerows are effective in this setting

Other areas of discussion:

- Evaluate how daily heavy rainfall events compared to daily light rainfall events may have impacted erosive events
- Use USLE as a conceptual tool to discuss how the erosion can be used to discuss the P-factor

# 2 Background

## 2.1 Geography

Ghana is located in the central south of West Africa, a few degrees north of the equator. Its southern border is coastline with the Gulf of Guinea, and it's east, north, and west boundaries border countries Togo, Burkina Faso, and the Ivory Coast, respectively. A defining feature of the country is Lake Volta, the largest man-made lake in the world, created by the erection of the Akosombo Dam in 1966.

Ghana experiences a tropical climate, with hot and dry conditions in the north, warm and comparatively dry conditions along the southeast coast, and hot and humid conditions in the southwest (Central Intelligence Agency, 2020). The country is broken into six ecological zones consisting of coastal savanna, evergreen forest, and deciduous forest in the south, forest-savanna transition in the middle, with guinea savanna and sudan savanna in the north of the country (USAID, 2018). The country has two main seasons, rainy season and dry season (locally called *harmattan*). In the south the rainy season lasts from March to mid-November and is made up of a major (April through June) and minor season (September through November) while in the north the climate is dryer and only experiences one rainy season reaching its peak around September.

The site where the research was done is on the west side of the Akuapim North district in the Eastern Region in the village of Gboloo Kofi (Figure 1). The largest towns in proximity to it are Adawso, and Mangoase. The people of Gboloo Kofi are primarily composed of farmers who grow a variety of crops including maize, plantain, cassava, cacao, yam, sugarcane, rice, palm nuts, groundnuts, vegetables, and fruits. Many farmers also have livestock including chickens, goats, sheep, rabbits, grasscutters, guinea fowl, and pigs. These products are either sold locally or brought to Adawso or Mangoase market.

## 2.2 Site Description

The study was done on a small plot of land (about one third of an acre), on a sloping hillside, located on farmland just south of the village of Gboloo Kofi in Eastern Region in southern Ghana. The GPS coordinates of the study site are 5°55'54.2"N, 0°16'28.6"W (5.931730, -0.274597)

A composite soil sample was taken across the study site on April 30th, 2018 (Table 1, Appendix A). The topsoil comprises of the first three inches of soil. Below this, the subsoil is composed of a red-orange-brown colored clay soil.

Table 1: A lab analysis of the composite soil sample from the field site

| | |
|---|---|
| Percent Sand | 60.13 |
| Percent Silt | 15.71 |
| Percent Clay | 24.16 |
| Texture | Sandy Clay Loam |
| pH ($H_2O$) | 6.08 |
| Electric Conductivity (dS/m) | 111.07 |
| Percent Nitrogen | 0.13 |
| Available P (mg/kg) | 157.64 |
| Available K (mg/kg) | 243.79 |
| Percent Organic Carbon | 1.15 |
| Percent Organic Matter | 1.99 |

The soil sample is a majority of sand at over sixty percent and lesser amounts of silt and clay. With more larger particles this soil will be harder to erode than a more silt or clay heavy soil as more energy is needed to transport the sand grains. Viewing the soil in terms of its fertility, there is a low amount of nitrogen and organic matter which limits growth and soil microbes. In nutrient poor ecosystems mycorrhizal fungi and N-fixing bacteria, which exist in greater amounts with a higher organic matter, can contribute up to 90% of P and N to plants (Van Der Heijden et al., 2008). Moderate levels of phosphorus and potassium are also present in the soil.

## 2.3 Geology

The geology of Ghana is at its base part of the West African Craton (WAC). The geology of the Eastern Region of Ghana is made up of late Proterozoic-Paleozoic Voltaian Group forming a sedimentary layer over the Eastern part of the WAC, the Togo formation which is included in the Precambrian Orogenic Belt, the Cape Coast granite complex which is an intrusive basin-type Granitoid that was formed during the Eburnean orogeny, and the Proterozoic Birmian Supergroup which is part of the WAC (Dampare et al., 2006). The geology of the study area is part of the Cape Coast Granitoid complex. Most of this complex is comprised of a granitic to quartz dioritic gneiss, foliated biotite quartz diorite gneiss to hornblende-quartz-diorite gneiss (Ganyaglo et al., 2010).

## 2.4 Vetiver Grass

Originally native to India, China, Philippines, and Indonesia, Vetiver grass (Vetiveria zizanioides L. recently reclassified as Chrysopogon zizanioides) has been promoted over the past 30 years and is now used in over 120 countries worldwide (Mickovski & van Beek, 2009; Truong & Loch, 2004). This plant is a dense perennial tussock grass that grows in dense clumps with stiff erect stems. Vetiver grass is known for its hardiness as it can withstand a wide range conditions including temperatures (-10 C to 48 C), soil moisture, pH (3.3 to 10.5), salinity, and heavy metal contamination (Dalton et al., 1996). This variety of vetiver grass is a sterile Indian genotype and it cannot propagate itself with seeds, which eliminates its risk as an invasive species (Truong & Loch, 2004). Propagation generally starts from divisions of propagated clumps.

Vetiver is a versatile plant that is traditionally used in production of aromatic oil (produced from the roots), animal feed, and roof thatching (Dalton et al., 1996). More recent research has been discovered the grass to have many uses in areas including river basin and watershed protection, roadside stabilization, soil contaminant remediation (i.e. heavy metal uptake), use a mulch for crops, and grass ash as a cement replacement (O. Babalola et al., 2007; Bracken & Truong, 2000; Chen et al., 2004; Dass et al., 2011; Nimityongskul et al., 1991). Most notably and effectively the grass has been used as an inexpensive method against erosion and is used in agricultural systems along sloping regions where topsoil loss leads to sub-optimal crop growth (Olaolu Babalola et al., 2005; Oshunsanya, 2013).

Through the tropics there have been studies on vetiver grass and its uses on agricultural land and soil loss. Its usefulness has been shown in a number of regions such as Vietnam, India, and China although its studies in Africa have been limited (Du & Truong, 2003; Howeler et al., 2003; Sagare & Meshram, 1993; Xia et al., 1996). Vetiver grass has been present in Ghana for many years, as it was introduced by Dale Rachmeler, the present Director of the Vetiver Network International, to a Ghanaian named Maxwell who is now a local resource and seller of Vetiver grass. The presence of previous studies of vetiver grass in Ghana are unknown. Other studies done on the grass in West Africa were done in Nigeria and showed significant increased yield in maize and cassava with vetiver strips as compared to control plots (Oshunsanya, 2013).

## 2.5 USLE:

The Universal Soil Loss Equation (USLE) has been used worldwide to estimate soil loss caused by sheet and rill erosion. It was created to predict the average soil erosion rates for certain types of crops that are planted using certain management practices while also knowing the soil type, rainfall pattern, and topography of the site being studied (H. Wischmeier et al., 1978). As it developed, the equation was modified so that it could be applied to a greater scope of locations and other circumstances throughout the world, with different factors being calculated in a variety of ways based on the data available, geographic location, and conditions on the site being studied (Benavidez et al., 2018). Today USLE is one of the most widespread methods to quantify soil erosion.

The USLE equation is as follows:

$$A = R * K * L * S * C * P$$

where, A is the mean annual soil loss (tons * acre$^{-1}$ * year$^{-1}$), R is the rainfall erosivity factor (hundreds of foot-tons * inches * acre$^{-1}$ * hour$^{-1}$ * year$^{-1}$), K is the soil erodibility factor (ton * acre * hour * hundreds of acre foot-ton$^{-1}$ * inch$^{-1}$), L is the slope length factor (unitless), S is the slope steepness factor (unitless), C is the cover and management fact (unitless), P is the support practice factor (unitless). It is most often calculated in English units first and then converted to metric units where A is represented in units of metric tons * hectare$^{-1}$ * years$^{-1}$ (Foster et al., 1981). While this equation will not be used to calculate average yearly soil loss for this experiment it is included to set up later discussion about its use, as it is widely used in sheet and rill soil erosion modeling.

Of the factors that make up USLE all contribute to quantify soil erosion for a specific group of data. Each of these factors represents different conditions that influence soil erosion. In this study the USLE is used as a tool to evaluate the factors that drive soil erosion. The goal is to hold factors R, K, L, S, and C as constant while manipulating the P factor through the treatments. The R and K factors are held constant as the total area where the plots exist is small enough that rainfall and soil variability across all plots are treated as not differing significantly. The L and S factors are held constant in that the slope of the plots does not differ significantly across all plots and the length of the plots is consistent across all plots. The last variable, the C factor, is held constant by applying weed management treatments at the same time and equally across all plots. The P factor was the only factor that changed and is influenced here by the presence and spacing of vetiver grass hedgerows. This allows the P- factor to be viewed proportionally to the amount of erosion for each treatment.

# 3 Methods

To better grasp the relationship between vetiver hedgerows and their effect on hillslope erosion as well as further investigate their use in the West African climate, a field experiment with 15 plots and three treatments was prepared on an area of Ghanaian farmland. Local methods and tools were used in land preparation, planting, weed control, fertilization, berm construction, and land maintenance as the experiment was done in conjunction with the authors Peace Corps Volunteer service and no tractor access was available at the study site. Using these local farming methods is relevant to local farmers in that they would be able to duplicate the results, making the study useful locally in its rural setting. (Earnshaw & Orr, 2013; Satterlee et al., 2009).

Rainfall data was collected daily from the 25th of August 2018 to the 17th of December 2019 for this study. Erosion pin measurements were taken five times between the 23rd of May 2019 to the 17th of December 2019. The statistical software JMP was used to analyze the erosion pin data to look for trends in the data comparing pin groups.

## 3.1 Field Experiment

The first step in setting up the experiment was to find an area of land that was large enough to hold fifteen plots, each measuring 10 ft by 60 ft, with a four-foot buffer between plots. These plots were modeled around the USLE unit plot but manipulated to fit the area of land I was limited to work with (W. H. Wischmeier & Smith, 1958). The site had a consistent slope across all plots (within +/-5 deg) and was free from major obstructions, like trees, stumps, paths or rocks that may impact the outcome of the erosion data. The major limitation experienced when selecting a plot was all of the land that fit the above criteria was used for farming which went to supporting the livelihood of the residents of the village.

My personal relationship with a particular family in the village adjacent to where I was conducting the study allowed me to use a portion of their farmland for the study. The family was also a resource for performing this experiment using local practices. The land was rented from the family to substitute for the income that would normally be gained by the family using the land to farm and sell crops. Having this access brings an advantage as using actual farmland as this study represents the exact conditions in which this application of this experiment might be implemented, therefore bringing more legitimacy to the study. The area chosen had some obstructions such as logs that were removed during the setup of the experiment to make a clear space for the setup of the plots.

The design of the plot was determined to be 10ft wide (along the contour of the hillslope) and 60 feet long down the slope of the hillside. Not all plots were positioned the exact same direction because the slope direction varied slightly for each plot and thus was oriented according to the maximum slope at the location of each individual plot. The corners of each plot were marked with ¼ in rebar and held in place with concrete, positioned one foot away from the width of the corner of the plot on each side so that the markers were easy to locate but did not affect the soil erosion or vetiver grass growth on the plots; these made it easy to measure where the erosion pins were to be placed as these were a well-established and immovable reference point for each plot.

Three treatments were applied to the study area. With fifteen total plots each treatment was randomly chosen and applied to five of the plots (Figure 6). Treatments are as follows:

- Treatment one (T1) is the control, no hedgerows were planted on these plots

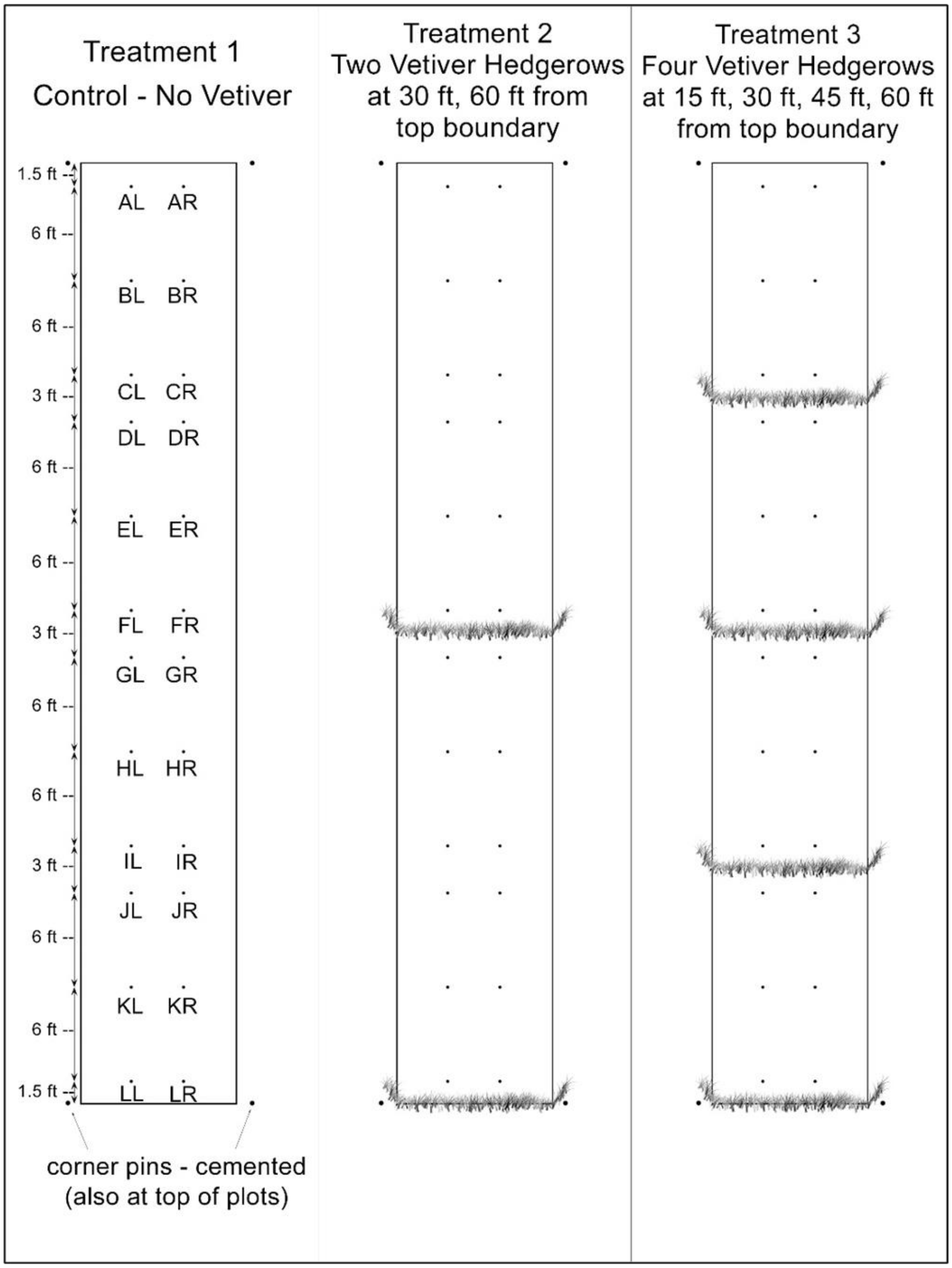


Figure 6: Setup of plots with the three treatments to scale with spacings, pin letter designations and location of vetiver hedgerows. Labeling shown for treatment one is consistent across all treatments. (created by author using Photoshop CS5)

- Treatment two (T2) includes two Vetiver hedgerows that were planted along the contour, one at the bottom of the plot at the border of the plot at lowest elevation and one 30 ft downslope from the top border [@ 30ft and 60ft, where zero is the border of the plot at the highest elevation (top of the slope)]

- Treatment three (T3) includes four Vetiver hedgerows, planted along the contour, one at the bottom of the plot at the border of the plot at lowest elevation and three at 15 ft upslope from the previous hedgerows [@ 15ft, 30ft, 45ft, and 60ft where zero is the border of the plot at the highest elevation (top of the slope)]

Each treatment was chosen randomly for each plot so there would be 5 replicates for each treatment. First, a random dice roller application was programmed so that it randomly generated a whole number between one and fifteen (Pereira, 2018). A number generated between one and five designated a selection for T1, a number between six and ten designated a selection for T2, and a number between 11 and 15 designated a selection for T3. The treatment designation for each plot was started by generating a random number and assigning the corresponding designation to the first plot. This process was repeated all the way up to plot 15. Every time a number, and thus a treatment designation, was assigned to a plot the number was marked off on a list of numbers from one to fifteen. If a number that had already been generated was repeated, an additional number could be generated until a number that was not repeated could assign the treatments that were remaining. This process above was repeated five times, creating five separate lists of random designations for all 15 plots. A random number between one and five was generated to choose which of the five lists would be used apply the treatments to the field plots.

The next step was to clear the land. This was done so that the land could be easily surveyed and measured to evenly place pins. Local methods were implemented and a farming machete was used to cut the weeds all the way to the ground surface. After this the plant material was removed offsite, piled upslope or downslope at least 15 feet away from the boundaries of the plots. Also, some small trees were cut and removed from the research area.

After the land was clear the plots were measured and marked using premeasured ropes. The ropes were created so that each end was finished with a knot and then tied with a loop at the end. The distance from knot to knot was 10 ft or 60 ft apart so that the loops could be staked in place and the appropriate distance could be measured from knot to knot. A pair of both 60ft ropes and 10ft ropes were used.

First the top 10 ft rope was staked in along the contour using an A-frame level to line up the rope with the contour. Some areas had changes in slope direction along the hillside so ten measurements were taken to find the average slope direction along the entire plot. Next the knot on one end of a 60ft rope was aligned with the knot on the 10 ft rope and staked into place so the knots were touching. This was repeated with the opposite side. The other ends of the 60ft ropes were taken downhill until they were taut and a second 10 ft rope was used to measure the bottom width of the plot. The knots were aligned the same way as the top of the plots. Care was taken to make sure that the plot corners were aligned at right angles making a rectangular plot. Temporary wooden markers were placed at the plot corners and the ropes were removed. The process was repeated for all existing plots. A premeasured 4 ft rod was placed between plots to allow appropriate space for a buffer zone between plots.

Long term rebar markers (#6 imperial bar size) were cemented one foot away from each corner out from the width of all the plot. Holes were dug using an ɔsoɔ, a local single bladed hoe, best compared to half of a modern post hole digger. Holes were dug about four inches in diameter and about one foot deep. The rebar posts were cut to lengths of 3 feet thus protruding 2 feet from the ground. Concrete was mixed and added after the post was placed to fill the hole about halfway and then was back filled with the soil that was initially removed.

After about one week the concrete was deemed sufficiently set and the temporary wooden markers were removed. This method was sufficient to hold these markers in place for the full time the experiment was carried out.

Berms and swales were constructed at the top of each plot so that rainfall landing upslope of the plots did not run down on to affect the study area. The berms were mounded above the top border of each plot with the ends of the berms running far enough away from the plot corners to lead into the swale of an adjacent plot. The berms were extended at least four feet out, perpendicular to the length, of any side of a plot that had no adjacent plots. The swales were created just upslope of the berm as a result of the trench created by the soil removed to form the berm (Figure 7). After the berms were mounded, they were walked on, compacting the soil to create an effective barrier.

Figure 7: Newly constructed earthen berms installed by author with a farming hoe at the top border of each plot. (Photograph taken by the author)

An inclinometer was constructed from a one meter long flat length of lumber with a bubble level centered and fixed to the top surface of the board. This tool was used in conjunction with a tape measure to find the slope of the hill at any point. The measurement of the slope was accomplished by finding an area large enough for one side of the board to rest flat on the hillside with the bubble level facing upwards, the bubble viewable from the side. The other end was pointed directly down the slope and adjusted up and down until the bubble read level. Then the measurement from the ground directly below the other end of the board to the bottom of the board was taken. The end of the board not in contact with the ground was adjusted left and right to find the maximum measurement possible and was recorded in centimeters to the nearest half centimeter. As the slope is calculated by rise over run, the board represents the run and the measurement as the rise. As the board is 100 cm, the measurement made using the tape measure in centimeters also represents the slope in this location. For each plot ten slope measurements were taken in a 2-column grid, evenly spaced throughout the plot.

The erosion pins were installed in a grid which was designed to measure the erosion and deposition along the plot focusing on the areas above, below, and between where the grass hedgerows were planted. Rods of 29.5 ft rebar (#3 imperial bar size) were precut into 360 pins of 55 cm in length each. To install the pins a wooden peg (15.0 cm), a wooden mallet, a washer (3.6 cm outside diameter, 1.3 cm inside diameter, 2mm thick), and guide ropes were used. The guide ropes for this step were identical to the guide ropes used to measure the plots above except that the 10 ft ropes were marked every one third (3.33 ft) the length between knots with a permanent marker. The 60 ft ropes were marked in accordance with the planned pin spacing (Figure 6). The 10-foot guide ropes were placed on the ends of the plots and the 60 ft guide ropes were placed over these, aligning them so the marked points along the 60 ft rope were directly over where the pins were to be placed. At each location the pins were installed vertically, the washer was put around the pin which contacted the ground and the wooden peg was used to measure the proper height as the wooden mallet hammered the pin into the soil (figures 8 and 9). Near the end of the hammering when the pin was protruding about 20 cm from the soil care was taken to make sure the pin was protruding exactly 15.0 cm from the top surface of the washer as a baseline for future measurements. This washer was then removed and reused for the installation of the additional pins.

The vetiver grass was delivered in large clumps with many tillers (50+ per clump, Figure 10). First the roots were trimmed back to allow for new growth. Dead material was removed and the tillers were split from the clump so that each tiller was an individual plant with its own roots. They were then placed in a water and mud slurry enough to cover the roots and keep them moist to ensure survival and promote growth before planting (Figure 11). Planting was done after a significant rainfall to ensure that the soil was initially moist and would survive planting. Planting was conducted according to the randomly selected treatments. Guide ropes were used to measure where the grass hedgerows would be planted along the plots.

All grass was planted in the same day using the following process: a trench was dug, along the width of the plots about 10cm deep to support the grass until the roots had the ability to take hold and support the plant. Additional tillers were planted extending the hedgerow into the buffer zone 45 degrees upslope for one foot on either side of each hedgerow. The vetiver tillers were then placed into the trench and the trench was then backfilled. The first two weeks the vetiver grass tillers were watered so they were able to survive the transplanting process.

Figure 8: An erosion pin installed using a 15 cm wooden peg (shown with black rings around it), a washer, guide rope, and wooden mallet (not shown). (Photograph taken by author)

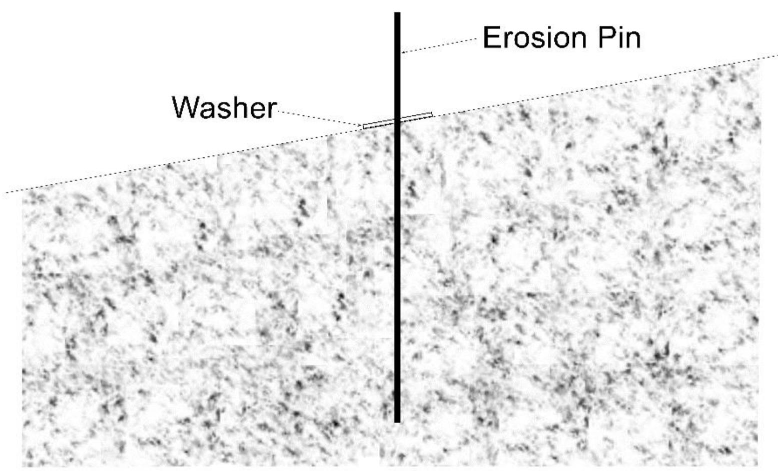


Figure 9: Cross section of the ground perpendicular to the slope with an erosion pin and washer. (Created by author using Photoshop CS5)

Figure 10: The vetiver grass just after delivery; preparation of the grass is still needed before planting. (Photograph taken by author)

Figure 11: Preparation of the vetiver grass by tiller separation, root trimming and coating the roots in a mud slurry before planting. (Photograph taken by author)

A watering can was used to water the base of the grass but the watering was skipped on days that it rained. Three weeks later the grass that was planted was reevaluated to make sure that it was growing properly and any tiller with no new growth was removed and replanted to make sure that the entire hedgerow had no holes in it.

Fertilization was done approximately one month after the tillers were planted to boost the initial growth and further increase their establishment (Figure 12). A farming machete was used to open the soil creating a small trench about 2 inches deep and 6 inches upslope from the hedgerow. Along this trench 200 ml of an NPK fertilizer was sprinkled evenly. Then the soil was added back, covering the fertilizer holding it in place so that the nutrients would be held in place rather than being washed away by the next rain.

The weeds were managed throughout this experiment using traditional methods. Two were implemented, the first method is using a weeding machete to cut back weeds, the second is using a backpack sprayer to spray a glyphosate solution over the weeds. Care was taken not to spray glyphosate on the vetiver grass hedgerows as they are susceptible to this weedicide (Bazoobandi & Ariyan, 2012). Before pin height data collection days weeds were required to be cut down creating access the erosion pins for measurement especially during periods of regular precipitation. Dates and notes on the specific management are recorded in Table 2.

Pin measurements were taken over time intervals to monitor the erosion and deposition. One day was chosen for pin height collection so that all measurements would be conducted during the shortest amount of time possible as well as between rainfall events so that no soil erosion from rainfall needed to be considered within the data groups (Table 3). First the duff layer around the pin was carefully removed to expose the soil surface. A washer was then inserted around the pin and laid flat on the ground. Next a metal ruler was used to

Table 2: A chronological list of the dates and treatment practices used on weeds during the study period

| **Management Practice** | **Date** | **Collection Period** | **Notes** |
|---|---|---|---|
| Weeded with Cutlass | 4/16/2019 | Pre P1 | Weeded to bare ground to prepare plots |
| Weeded with Cutlass | 5/10/2019 | Pre P1 | Weeded to bare ground to place erosion pins |
| Sprayed Glyphosate | 6/27/2019 | P1 | A problem with the spray application or mixture caused a not fully effective treatment |
| Sprayed Glyphosate | 7/24/2019 | P2 | The treatment was fully effective |
| See Notes | 8/18/2019 | P2 | Weeds recorded dead from glyphosate spray |
| Weeded with Cutlass | 10/27/2019 | P4 | Weeded to knee height to expose pins |
| Weeded with Cutlass | 12/27/2019 | P5 | Weeded to knee height to expose pins |

Table 3: Important time periods during the study that correlate with times between erosion pin height collection periods

| Time Period | Collection Date Ranges | Days in Collection Period |
|---|---|---|
| P1 | 5/23/2019 – 7/3/2019 | 41 |
| P2 | 7/3/2019 – 8/19/2019 | 47 |
| P3 | 8/19/2019 – 9/25/2019 | 37 |
| P4 | 9/25/2019 – 11/5/2019 | 41 |
| P5 | 11/5/2019 – 12/11/2019 | 36 |

Figure 13: NPK fertilizer was added to the ground upslope from the vetiver grass after it had time to establish itself. (Photograph taken by author)

Figure 12: Looking east across the plots near the end of the study on December 17th, 2019. (Photograph taken by author)

measure the distance from the top face of the washer to the height of the pin. All measurements were always taken on the east side of the pins to maintain consistency among future measurements. The washer was then removed and this process was repeated with all of the other pins.

Daily rainfall data was collected approximately 400 meters from the site of the experiment from August 25th, 2018 to December 16th, 2019. The instrument used was a Stratus Precision Rain Gauge. Measurements were taken around 7:00 am each morning. A local boy was trained to use the rain gauge and record the data on days that I was traveling, which maintained consistent daily data.

## 3.2 Data Analysis

### 3.2.1 Data Organization

The field recorded pin erosion data was organized into a spreadsheet. The pin height data ranges were calculated from the data of the pin heights of each data collection date and the proceeding data collection date, except for the first range which was calculated from data from the first collection period and the initial pin height. Each set of range data was labeled P1 through P5, signifying the time period between the two collection dates. Values of over five times the mean of all data points were excluded from analysis as assumed to be disturbance from human interaction. The ranges for each pin per period were calculated such that negative range values represent erosion while positive values represent deposition at the pin locations. This range data is what was used for the other analyses.

### 3.2.2 Rainfall and Total Soil Loss

The rainfall and pins heights were compared by visually using bar graphs. First the rainfall was divided into collection periods and the sums for each collection period were totaled. As rainfall is known to reach a threshold where it vproduces significant erosive events (Morgan, 2005),a value was chosen to represent a separation between the smaller and larger events. A daily rainfall value of greater or equal to 0.8 cm per day was separated from the daily events that were less than 0.8 cm. These were plotted together on a bar graph. The total average pin height change for each treatment per collection period was also plotted for comparison to the same periods.

It can be useful to also look at the absolute value of the erosion pin data to represent overall erosive impact from the rainfall (Kearney et al., 2018). The absolute values of this data are also represented in bar graphs to compare against the total rainfall per collection period.

### 3.2.3 Tests: ANOVA and Paired-t

Two types of statistical tests were run to look for correlations comparing different pin groups. The first test used was a paired-t test (Hsu & Lachenbruch, 2005). The other test used was a one way analysis of variance (ANOVA) (Steel & Torrie, 1960). The significance level used for these tests was 0.05. If there was significant variation between the groups being compared, a Tukey-Kramer HSD test would be run to further look at the specific groups that differed among all compared (Steel & Torrie, 1960). For any pin pair, for example pin pair B, refers to BL (left) and BR (right). These tests were run individually (a data point for BL and BR) and not as a mean (a single value representing an average of BL and BR) even though they are grouped under the same category in the results.

#### 3.2.3.1 Paired-t Tests:

This test compares two population means where there are two samples in which observations from one sample can be compared with observations from the other sample. Since there is a symmetry to the pin placement with a left and right pin for each distance from the end of the plot, the pin height range data for any one right pin is paired with its left counterpart. The test was also done to compare two pins pairs that are just up and down slope from each other (E and F) while paring the pin locations from each replication in each time period, for example EL and FL from the same replicate plot during time period T1.

I – Middle of Plot Pins, All Treatments: The first paired t-test evaluated the pins around the halfway point lengthwise for each plot and time period per treatment. These were tested to see if the hedgerow spacings had any effect on reducing the overland flow enough to reduce erosion between the rows. The pin groups included for this trial were G and F for all treatments. For T2 and T3 a hedgerow existed between the pins with a tighter spacing for T3 while in the control no hedgerow was present.

II – Pins at Top ¼ of Plots, All Treatments: The second paired t-test looks at the pins highest on the slope just under the berm for all treatments. As the berms were meant to block all rainfall and sediment from above the plot this trial tests the pins just under to test for consistency of erosion within this uppermost area of the plots. The pin pairs compared are A, B, and C. The only pins in close proximity to a hedgerow are pins C in T3. Separate tests were run for pin pairs A, B, and C. Data from all periods was given a label T1, T2, or T3 depending on its corresponding treatment. This same analysis was also done with the pin pairs L which are the bottom most pins of each plot in all treatments.

III- Two Pins Upslope from Any Given Hedgerow, Treatment 3: The next t-test analysis done looks only at pins from treatment three. The pins farthest from any hedgerow exist exactly between the hedgerows leaving them potentially the most susceptible to erosion from overland flow. These were compared to the corresponding pins just below them, which are directly above the hedgerow barrier, to see if the vetiver reduced erosion just upslope from the hedgerow within this treatment. The pin pairs that are compared in each trial include B & C, E & F, H & I, and K & L, with first letter in each pair being the pins in between the hedgerows (B, E, H, K) and the second being the pins just upslope from the hedgerows (C, F, I, L).

IV- Top ½ Plus Pin Downslope from Middle Hedgerow, Treatment 2: This analysis focuses on treatment two, specifically the area from the top of the plot, just below the berm, down to just below the first vetiver hedgerow; this is the longest bare distance before a hedgerow for any trial. Thus this was used to test if there is a correlation between the predicted increase in overland flow velocity as the water accumulates momentum when it travels down slope unrestricted by a hedgerow versus the predicted decrease in flow velocity by the hedgerow restricting the overland flow, resulting in predicted less erosion or deposition around the vetiver hedgerow. The pin pairs F and G in treatment two were compared with the pin pairs just upslope from them. Thus, pin pairs A-E, F and A-E, G were run.

V- Pins Just Below Any Hedgerow, Treatments 2 & 3: This analysis evaluates pins that are just below the grass hedgerows. This was done to evaluate if the area just below a hedgerow experiences similar erosive or depositional influences across treatments with varying hedgerow spacings. There is one hedgerow and thus one occurrence of this in treatment two and three hedgerows and three occurrences in treatment three. These are all evaluated together in one trial. Treatment one was excluded from this trial as there are no hedgerows in the control group. The pin pair included in this trial are G from T2 and D, H, and L from T3.

VI- Pins Above and Below Any Given Hedgerow, Treatments 2 & 3: The goal of this trial is to compare the pins just upslope and downslope of any single hedgerow. This is done to compare predicted patterns of sediment accumulation just upslope from the hedgerows with the contrasted area just below that would experience greater erosion if the hedgerow traps upslope from the hedgerow. The pin pairs evaluated in this trial are C & D at the upper most hedgerow, F & G at the middle of the plot hedgerow, and I & J at the hedgerow second from the bottom. The last hedgerow was excluded because there are no pins below lower boundary of the plot.

#### 3.2.3.2 ANOVAs:

First, all the erosion pin range data was analyzed to check for a normal distribution according to a Gaussian Curve. The ANOVA tests were used to run the same collections of data used for the paired-t tests above, I – VI.

# 4 Results

This section will evaluate the data in terms of how effective the grass hedgerows were at capturing sediment over varying spacings over the given time period. First rainfall will be looked at generally to see how this compares to the total erosion per time period for each treatment. After this the following prediction will be tested: there will be soil accumulation uphill from the hedgerows as they form a permeable barrier allowing water to pass while trapping sediment which will become more effective with a decrease in spacing between hedgerows. Certain areas of treatments will also be compared to each other over a number of trials, by selecting certain pin groups, to evaluate hedgerow effectiveness.

## 4.1 Rainfall and total average erosion

As the total rainfall varies with the season it is important to view how total rainfall effects the erosion during the different periods between pin height measurements. Figure 14 shows most of the total rainfall amount per day fell under a heavy rainfall (greater or equal to 0.8 cm/day). It was observed that generally days where total rain was light (less than 0.8 cm/day) rainfall was more spread out over a longer time period while days with larger rain events experienced rainfall events in which rain fell in a more abrupt span. These shorter and larger volume rainfalls are the most important to look at in terms of erosion as this is when most of the sediment is transported.

When comparing the total rainfall to the average total erosion among all pins per treatment it is hard to obtain any conclusive results. It must be noted that the average total erosion in only based on the area where the pins were present not giving an accurate representation of the erosion over the entire plot. Also, should deposition and erosion be present in equal proportions among these points they would effectively cancel each other out. Still this gives some indication of what was experienced over the various treatments and time periods.

The combined erosion and deposition are addressed by using absolute values of the erosion pin data to get an idea of overall soil movement (Figure 16). When viewing the erosion this way it is still difficult to find any relevant trends between rainfall and its direct impact on erosion over this time period. Greater erosion is predicted during larger periods of heavy rainfall especially among T1 as it is unprotected by vetiver hedgerows. The lack of correlation between the rainfall at total erosion can be explained by other factors discussed below.

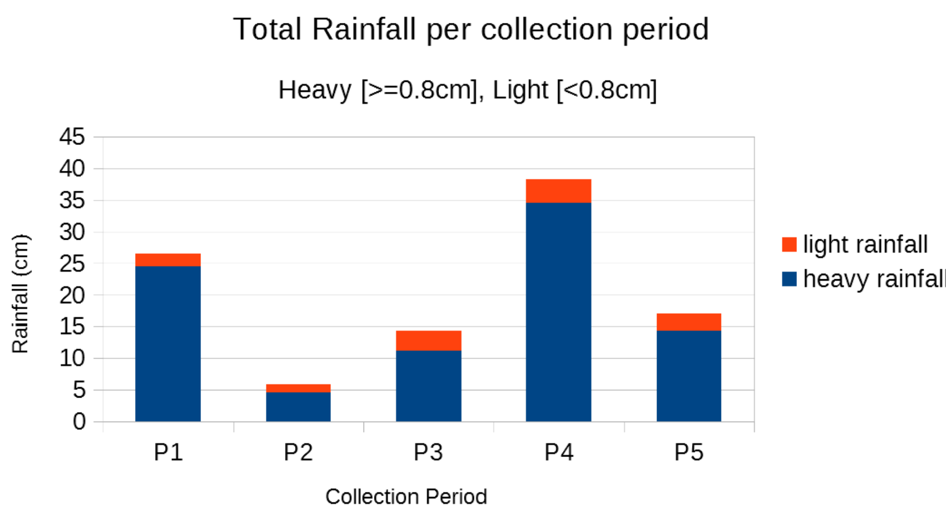


Figure 14: A measure of rainfall over the collection period (P1-P5) with light (less than to 0.8 cm per day) and heavy (greater or equal to 0.8 cm per day) for each collection period.

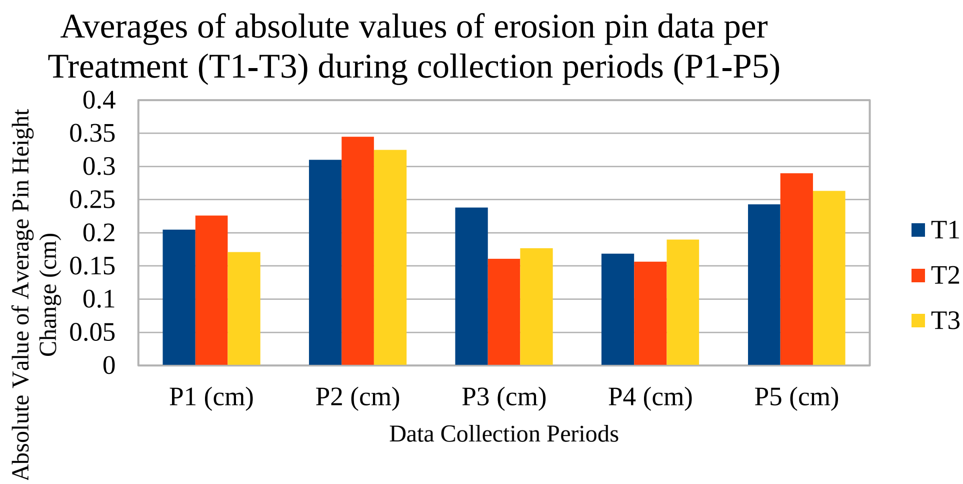


Figure 15: Average erosion represented by absolute values of average change in pin height (cm) for each treatment over all time periods.

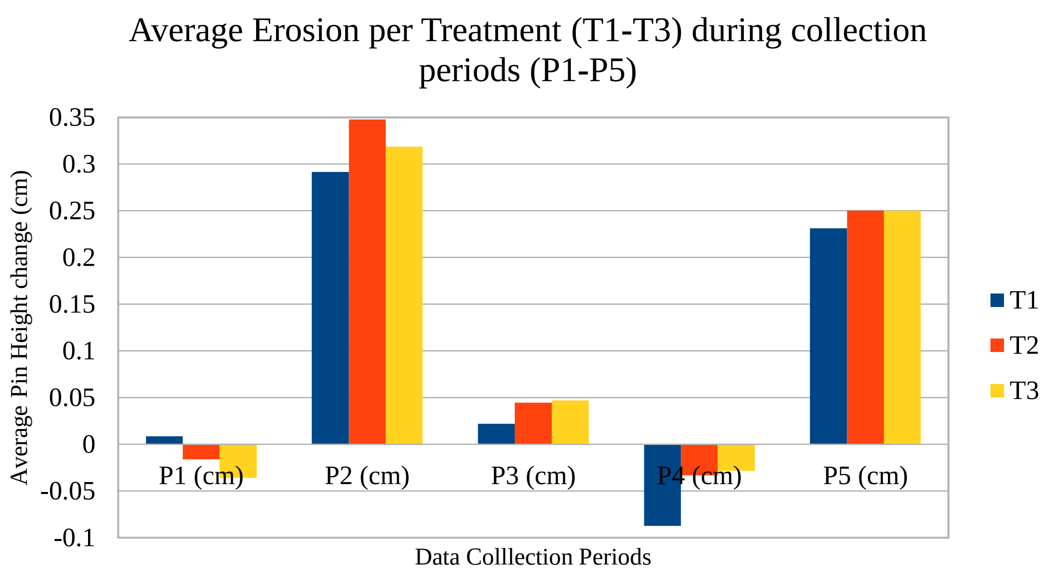


Figure 16: Average erosion represented by average pin height change in cm for each treatment over all time periods.

## 4.2 Paired t tests:

The first method of analysis that was used on the erosion pin range data was the paired t test. Trials that relate to the ANOVA trials are also noted in the listing below. The areas of this study that were tested are:

- Pin pair range data in positions F and G in all treatments, for all P (Trial I)
- Pin pair range data in positions A, B, and C across all treatments, for all P (Trial II)
- Pin pair range data for C, B, F, E, H, I, K, and L from T3, for all P (Trial III)
- Pin pair range data for A-G for T2, for all P (Trial IV)
- Pin pair range data for G – T2 and D, G, J – T3, for all P (Trial V)
- Pin pair range data for C, D, F, G, I, and J for T3, for all P (Trial VI)

The data based on time periods and replications:

- Pin pair range data for F paired with E, for each T separately and together, for each treatment for each time period separately

All but one of the results from the t-tests comparing left and right pins with the same letter designation do not have a significant p value meaning the null hypothesis that the left and right pins show no variance between them cannot be rejected. One result from T3 BL-BR proved significant, but some spurious correlation can be expected with a confidence interval of 0.05 and large number of tests. One cannot disprove the null hypothesis that there is no significant variation between the left and right pins which is what would be expected with a mirrored pin on the right and left side of any single plot. One can concur from these tests that that the left and right pins for any distance from the plot boundary, thus corresponding to a given letter, can be effectively treated the same for the ANOVA analyses below.

When evaluating the t-tests that compare the two pin groups between time periods for each replication, the results show that most pairs have no statistical variation to indicate F and E showed a statically significant difference. Three of these fifteen tests had a small enough p value to be statistically significant. Although these three tests showed no pattern in whether this significance was due to variations in positive or negative p values.

## 4.3 Analysis of Variance (ANOVAs):

The ANOVA results from trials I-VI presented in the methods are discussed below. The term pin pair refers to both the left and right pins of a certain distance away from the top plot boundary (corresponding to a specific letter A-L) across a specified treatment. For example, pin pair A for all treatments refers to AL and AR across all plots for all time periods. A pin group refers to more than one pin pair grouped together.

To conduct ANOVAs one must assume the data is distributed normally according to a Gaussian curve. The data was determined to be distributed well, especially for field data thus the ANOVAs were carried out according to the description provided in the methods (Figure 17). The goal for the ANOVAs was to compare areas of interest around the hedgerows by analyzing different pin locations and treatments.

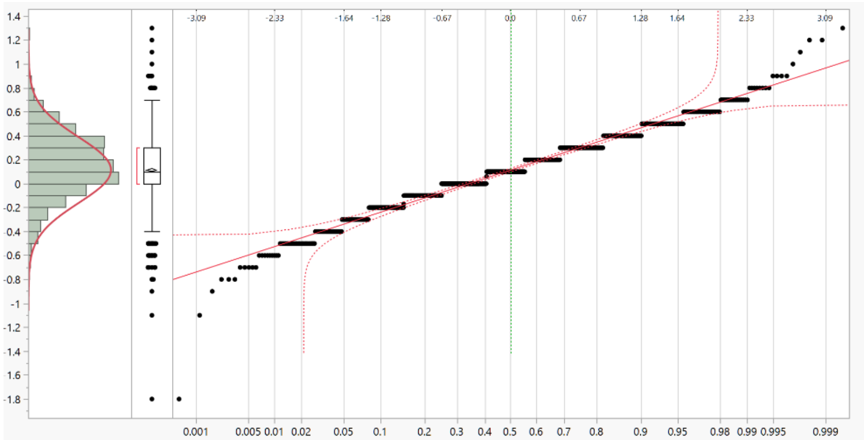


Figure 17: A distribution analysis in JMP of all the pin height range data as to test for a normal Gaussian distribution. (Created with JMP Pro 14.0.0)

I – Middle of Plot Pins – All Treatments:

The first ANOVA trial compares pin groups G and F in all treatments. This is done to test areas just above (F) and below (G) a hedgerow in T2 and T3 with the control plot to test if the hedgerow spacings had any effect on reducing the overland flow enough to reduce erosion between the rows. It is predicted that the pin groups for T1 will experience the most erosion as there are no hedgerows allowing more space for the water transporting sediment to gain momentum from the top bounds of the plot as T3 is predicted to show the least erosion with two hedgerows uphill from pin G.

Table 4: the R-squared, F-ratio, and p value statistics from the ANOVA for Trial I

| Compared Pin Pairs for All Treatments | R squared | F-ratio | p |
|---|---|---|---|
| F | 0.015 | 1.1 | 0.33 |
| G | 0.00031 | 0.022 | 0.98 |

Looking at the R squared or P values, the test does not show a statistically significant difference between the treatments F and G. The small variation can be seen with T3, pin pair F but this is only hinting at the treatment becoming effective with the closest spacing between the hedgerows that was tested (Figure 18).

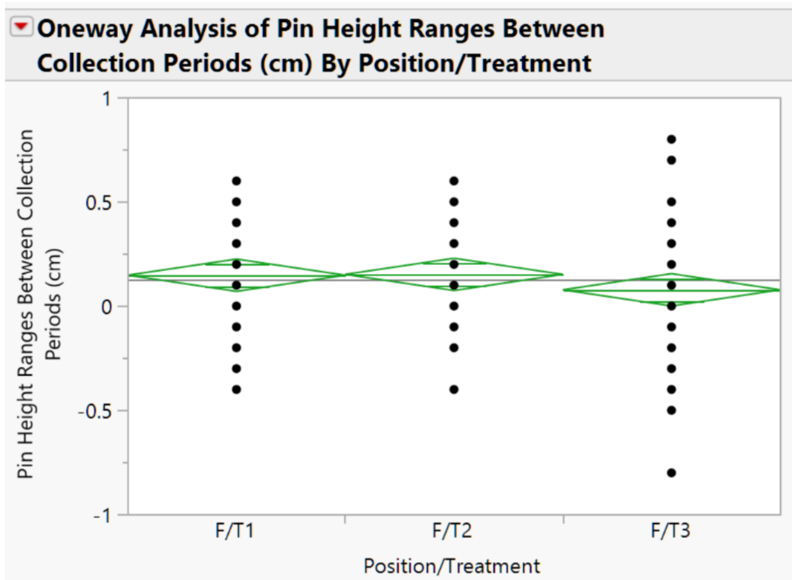


Figure 18: One way ANOVA of pin range data for pin F over all collection periods separated by treatment. (Created with JMP Pro 14.0.0)

II – Pins at Top ¼ of Plots, All Treatments:

The second trial evaluated the pin groups farthest upslope, A, B, and C. It is predicted that the berms will block all rainfall and sediment from above the top boundary of the plot, thus this trial tests the pins just under this area evaluating consistency of erosion within the uppermost area of the plots. The pin height ranges for pin groups in these positions (A, B, and C) would not be statistically different across all treatments, except for pin data from C in treatment three as there is a hedgerow just before C. Thus, placement C for treatments one and two is predicted to be statistically similar while pin C in treatment three would differ.

Table 5: the R-squared, F-ratio, and p value statistics from the ANOVA for Trial II

| Compared Pin Groups for All Treatments | R squared | F-ratio | p |
|---|---|---|---|
| A | 0.0088 | 0.65 | 0.53 |
| B | 0.0078 | 0.58 | 0.56 |
| C | 0.0067 | 0.49 | 0.61 |

The R squared value for all trials is very small supporting that the variation is not due to treatment. Small F- ratios in all trials supports the null hypothesis; this means all groups are statistically not different. This data successfully supports the hypothesis of no differences between pin groups A and B but goes against what was expected in pin group C by also showing no significant difference in T3 from T1 and T2 (Figure 19).

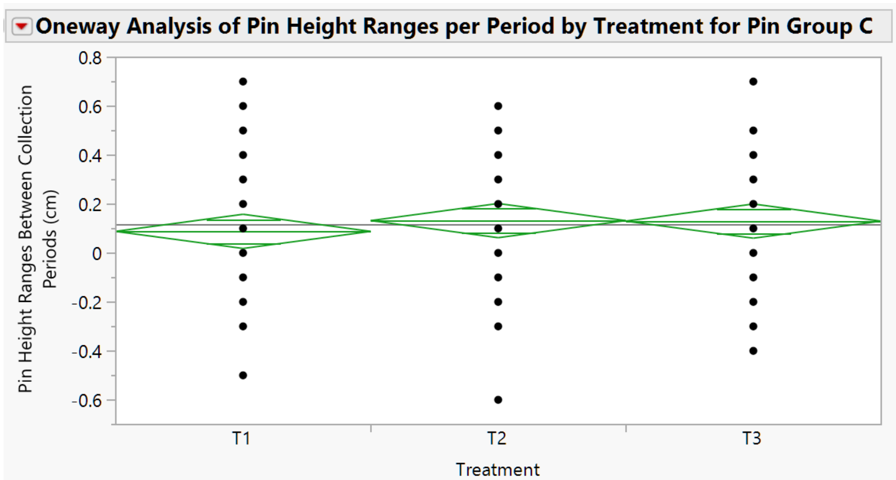


Figure 19: One way ANOVA of pin range data for pin pairs C over all collection periods and treatments. (Created with JMP Pro 14.0.0)

III – Two Pins Upslope from Any Given Hedgerow – Treatment 3:

The third trial evaluated the two pin pairs from treatment three that were just above any given hedgerow: B&C, E&F, H&I, and K&L. It is predicted that the pins between the hedgerows were the farthest from any barrier leaving them potentially more susceptible to erosion from overland flow. These were compared to the corresponding pins just below them, which are directly above the hedgerow barrier, which one would predict should experience more deposition as the hedgerows were predicted to create a sediment barrier. The results for these trials are displayed in the Table 6.

The results in R squared and F-ratio values for all these trials show that the variations in pin height between the compared pin data sets is not significant.

Table 6: the R-squared, F-ratio, and p value statistics from the ANOVA for Trial III

| Compared Pin Groups, T3 | R squared | F-ratio | p |
|---|---|---|---|
| B, C | 2.0E-5 | 0.0020 | .96 |
| E, F | 0.013 | 1.3 | .25 |
| H, I | 0.0037 | 0.35 | .56 |
| K, L | .0026 | 0.25 | .62 |

While no statistical significance can be drawn from this analysis it is important to note that the means for three of the four pairs analyzed show the pins between the grass experiencing small amounts of greater relative deposition while the pins closer to the grass experience this slightly less so (Figure 20). The hedgerow barrier is not fully grown so instead of blocking sediment transport above the hedgerow it is slowing it down thus causing more deposition to occur between the hedgerows than at the area just upslope from them.

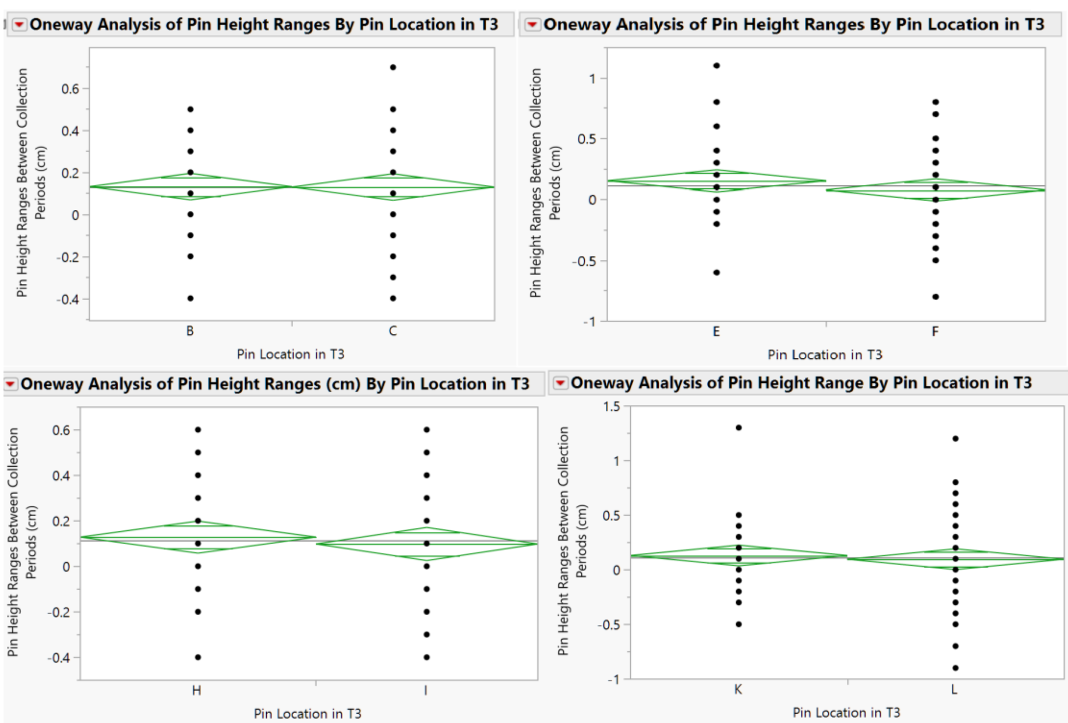


Figure 20: One way ANOVA of pin range data for two pin pairs just upslope from hedgerows over all collection periods for Treatment 3. (Created with JMP Pro 14.0.0)

IV- Top ½ Plus Pin Downslope from Middle Hedgerow – Treatment 2:

The fourth trial focuses on pins from the top half of treatment two. The longest distance before a hedgerow barrier (pins A-E) occurs in this region and treatment. An increase in overland flow velocity is predicted as the water accumulates momentum as it travels down slope unrestricted by a hedgerow. It is also predicted that a decrease in flow velocity occurs before the vetiver hedgerow as it restricts overland flow, resulting in predicted deposition or less erosion compared to the length above it. Pin G, just below the hedgerow, is also analyzed to see the relationship with the pins A-E in the case that the vetiver hedgerow is not fully formed. The results R squared and F-ratio statistics from the ANOVAs are shown in Table 7. The R squared and F-ratio indicate that there is no statistical relevance between any of the pin groups.

Table 7: the R-squared, and F-ratio statistics from the ANOVA for Trial IV

| Compared Pin Groups, T2 | R squared | F-ratio |
|---|---|---|
| A-F | 0.017 | 1.0 |
| A-E, G | 0.016 | 0.93 |

When visualizing the means from the ANOVA it can been seen that from the top of the plot to just before the hedgerow (pin groups B – E) the pin height range means decrease indicating that a pattern of increasingly less deposition is occurring (Figure 21). This could be due to the predicted increase in overland flow velocity until just before the hedgerow by accumulation and just after the hedgerow, hinting that the hedgerow is starting to retain some sediment or at least slow it down. Other areas were evaluated for similar patterns, such as the G-L pin groups in T2 as well as the full length of the T1 plot. The patterns that were found here are not replicated in either of these examples, but instead a more random pattern was present. From this I would conclude that if this trend is to be verified a longer-term study should be implemented.

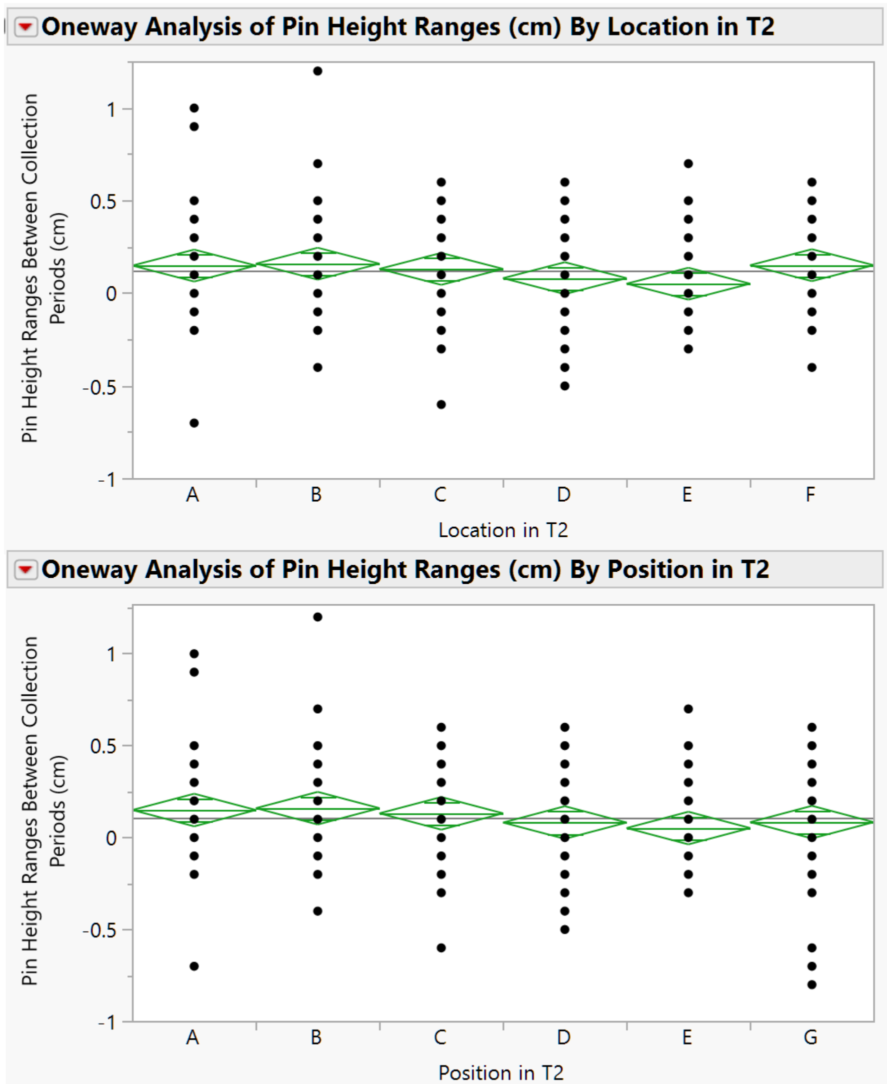


Figure 21: One way ANOVA of pin range data for all pin pairs A-E, F and A-E, G over all collection periods for Treatment 2. (Created with JMP Pro 14.0.0)

V- Pins Just Below Any Hedgerow – Treatments 2 & 3

The fifth trial compares the pins from just below the hedgerows in T2 and T3. This evaluates if the area just below the hedgerows experiences similar erosive or depositional influences across treatments with varying hedgerow spacings. It is predicted that the areas below hedgerows should experience similar erosion should the barriers be completely grown. Although with hedgerows that are not fully formed, pin groups from T2 may experience a heavier sediment load than T3 below the hedgerow because of the longer distance between hedgerows, as described in trial IV, potentially causing greater deposition. The R squared, F-ratio, and p value from the ANOVA are presented in Table 8.

Table 8: the R-squared, F-ratio, and p value statistics from the ANOVA for Trial V

| Trial/Compared Pin Groups | R squared | F-ratio | p |
|---|---|---|---|
| T2/G, T3/D, T3/G, T3/J | 0.017 | 1.0 | .91 |

From these values the null hypothesis cannot be rejected and thus this could be interpreted as the hedgerows are creating a consistent barrier creating similar conditions with areas just downslope from the grass. Although having all of the trials be represented as non-significant, it is more likely that all pins do not show enough variation to verify the prediction. A similar trial not discussed was run with pins just below any given hedgerow with the same results.

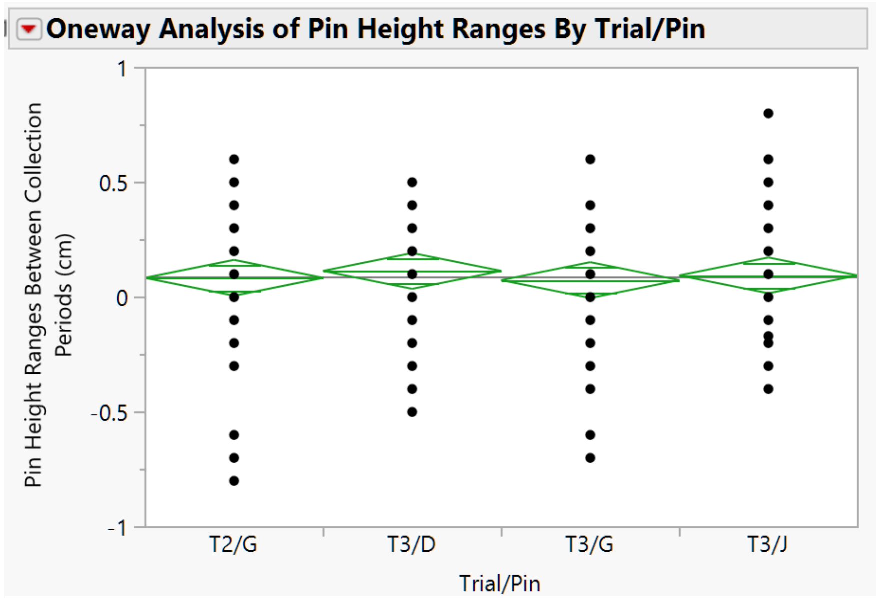


Figure 22: One way ANOVA of pin range data for all pin pair G for Treatment 2 and pin pairs D, G, and J for Treatment 3. (Created with JMP Pro 14.0.0)

VI- Pins Above and Below Any Given Hedgerow – Treatments 2 & 3

The sixth ANOVA trial compares pin groups that are just upslope and downslope of any single hedgerow to test variations on either side of any grass barrier. Had the hedgerow fully or partially developed it is predicted that a greater variation in deposition of soil above the hedgerow would occur when compared to just below the hedgerow, with a greater accumulation for T2 with the increased distance above the hedgerow. For the trials in T2 and T3 the ANOVA statistics are displayed in Table 9.

While again there are no significant values among these comparisons there are some small variations among T3/C, D and T2/F, G that show hints in the direction of accumulation before the hedgerow. The remaining analyses show close to no variation between the two.

Table 9: the R-squared, and F-ratio statistics from the ANOVA for Trial VI

| Trial/Compared Pin Groups | R squared | F-ratio | p |
|---|---|---|---|
| T3/C, D | 0.017 | 0.37 | 0.55 |
| T3/F, G | 4.3E-5 | 0.0041 | 0.95 |
| T3/I, J | 3.7E-5 | 0.0035 | 0.95 |
| T2/F, G | 0.015 | 1.5 | 0.22 |

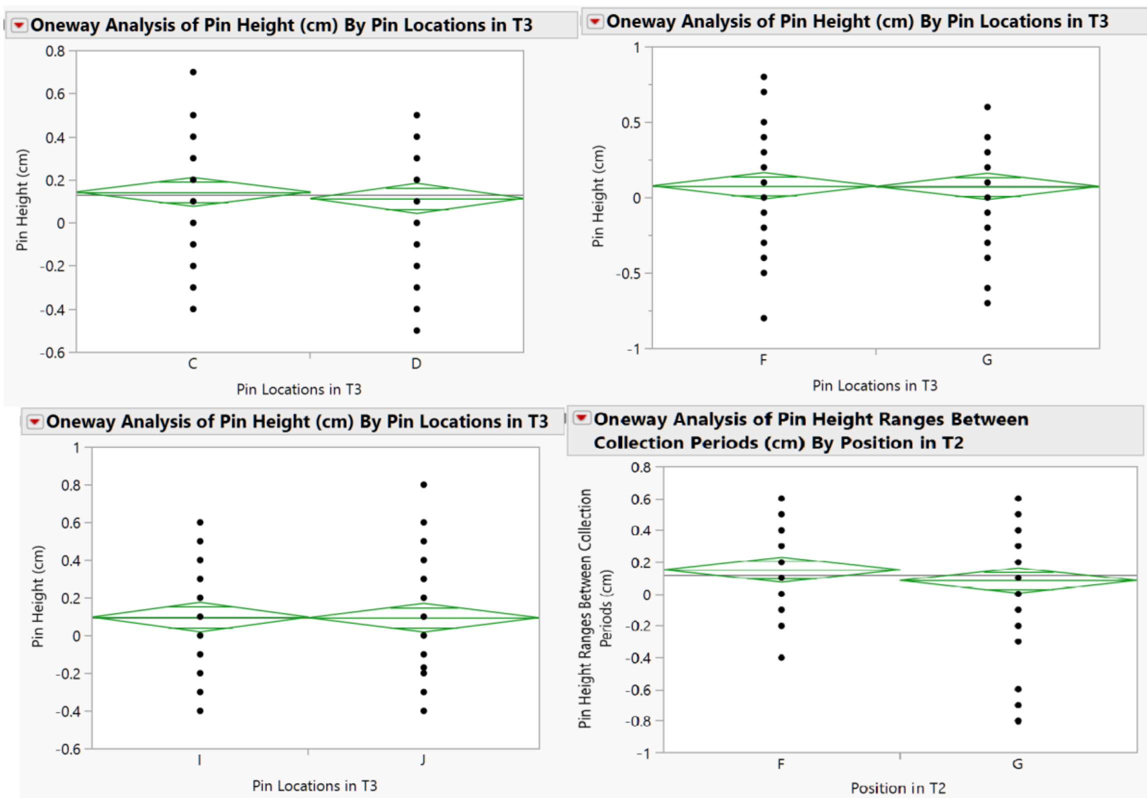


Figure 23: A one way ANOVA of pin range data for all pin pairs that exists above and below a given hedgerow in Treatments 2 and 3. (Created with JMP Pro 14.0.0)

For analysis of all ANOVA trials above there are none where the p value was less than 0.22. Also the means are all with in statistical range of error between each other. Thus, one can conclude that the null hypothesis cannot be rejected and thus it must be assumed that there is no statistical difference to draw any statistically definitive conclusions from the data present.

It is important to discuss reasons for variability as many of the pin pair data groups show a large amount of variation within the groups of measurements. Likely factors that influence this variation include small localized variances in soil conditions, variability in plant species that make up the weed cover, variation in fauna activity in and on the plots, as well as micro-variations on slope across the plots. All these factors were controlled for but ultimately these small variations existed on the field plots.

# 5 Discussion

## 5.1 C- Factor:

Since the weeds during the experiment were not controlled so that they were always cleared leaving bare soil to be eroded, then it is important to consider the cropping factor and its effect on erosion. While the cropping factors have been calculated using remote sensing techniques in tropical regions there has not been extensive research into how these calculations compare to measured data collected from the field (Almagro et al., 2019) This study works on bringing light to the C-factor pertaining to hedgerows which thus could be used to reduce uncertainty in future studies, especially in tropical climates. While no significant results came from this study similar long-term studies could help relate this study to what C-factor weeds contribute.

I think it is also important to consider bioturbation as a relevant factor when evaluating erosion over a longer period of time. The USLE system has no place where animal activity is considered as it may play an insignificant role where the equation was created in the US. In the field I noticed fauna presence with worm castings on the soil surface, as well as ant, rat and termite activity. These have been shown to play a larger role in estimating long term effects of erosion and play a significant role in soil creation in the same climate region of Ghana where this study was conducted (Awadzi et al., 2004; Breuning-Madsen et al., 2017).

## 5.2 Areas of Improvement/Future Work

From carrying out this field trial and post evaluation, some aspects of improvement were learned throughout the experiment that should be considered for future studies. The first involves the weed management, with a heavy amount of weed cover this greatly reduces the amount of erosion that took place over the experiment limiting the magnitude of range in pin measurements between treatments. Weed management locally was done with a farming machete which was difficult to use with erosion pins hidden in the grass as striking them during weeding could affect their placement in the ground and thus invalidate or skew pin measurements. I would recommend using high visibility paint to coat the pins in the future so they could be located easily while weeding with a farming machete or use glyphosate spray with caution as it can also kill the vetiver grass. Weeds grow fast in the tropics and weed management should be done with a team of two to three people for the area of land in this study on a two week cycle (Manik et al., 2003).

By the end of this study there were still areas where the hedgerows were not fully grown together. With gaps in the barrier it does not prove to be as effective of a sediment capture tool. This can be improved by pruning the grass to a height of 15-20 cm after it is fully established to allow for increased shoot growth which would create a denser formation between the plants allowing for less permeable hedgerow in a shorter amount of time. The pruned clippings should be moved offsite as not to affect the experiment by vetiver grass mulching which is a proven factor to influence erosion (Oshunsanya, 2013; Truong & Loch, 2004). Another means of improving this would be to plant three or more slips, instead of the one slip used in this experiment which would increase the rate at which the vetiver is able to produce additional stems and leaves, again creating a denser hedgerow at a faster rate (Agricultural Division (ASTAG) & The World Bank, 1991).

While the time period was limited by the author's service in the Peace Corps, the study would have best been tested over a period of two or more years. Vetiver grass has been shown to be effective months after planting, but a longer study period would have been preferred. This study evaluates the grass as it is transitioning into a complete barrier from its time of initial planting. Having an establishment period of one growing season before data collection would allow the grass to become more established as an effective barrier against erosion before data collection occurred. This could also help with weeding as the erosion pins could be placed after the hedgerow was established and pins would not need to be avoided during weed removal for this period.

A compacted earthen berm was used in this experiment to block sediment and rainfall from entering the top of the plot. Using other materials such as bricks, cement, or wood to create a barrier would give more confidence that the upper bounds of the plot would completely block all sediment from upslope entering onto the plot.

A tipping bucket rain gauge that collected data at 15 min or less intervals would be best to get a better grasp of how intensive the rainfall was throughout a moderate to heavy rainfall. This would allow us to select a more accurate threshold for the rain fall data and get a better representation of how specific rainfall events effect the movement of soil.

I also propose that there are some changes to consider regarding the installation of the erosion pins themselves. Traditionally, as used in this experiment, the erosion pins are inserted into the ground vertically. I propose that the pins be inserted perpendicular to the ground surface at the time of installation. This would allow the washer and the pin to be perpendicular with each other when measurements are taken, lessening the impact of one side the washer being raised due to the pin being measured from the side upslope of a given pin, which would give a smaller measurement, when compared to a larger measurement on the side downslope of the pin.

# 6 Conclusion

This study demonstrated that vetiver grass hedgerows hint at being an effective barrier to decrease hillslope soil erosion in small-holder Ghanaian agriculture systems. Trials I, IV, and VI results were consistent with small visual agreements with what was predicted from the hedgerows acting as a barrier to trap sediment from runoff. ANOVA Trial IV indicates that this analysis has the potential to be used in finding erosional trends in relation to the relative erosion and deposition that can occur behind a hedgerow. More trends are noticeable in trials that have pins close to the grass barriers before and after, supporting that the barriers represent a positive effect on prevention of topsoil loss by hillslope erosion. The hints provided above make it probable that over a longer establishment period for the hedgerow the predicted trends would become statically visible.

Some limitations exist in this study. Results from all trials show that variations in the data are not large enough to be statistically verified. The rainfall data and total erosion, represented by erosion pin height change viewed both with and without absolute values, lack correlation to each other. The short study period shows that the grass does not produce significant soil capture capability during its early growth. Since these trends cannot be statically verified showing that the vetiver hedgerows were not effective in trapping sediment during this time period.

Understanding the trends that exist between these hedgerows can help build models of best hedgerow spacing dependent on the environmental conditions. These models can be implemented to help farmers execute best practices for vetiver hedgerow use in increasing topsoil retention and crop production thus contributing to providing a higher standard of living.

# 7 Works Cited

Abbam, T., Johnson, F. A., Dash, J., & Padmadas, S. S. (2018). Spatiotemporal Variations in Rainfall and Temperature in Ghana Over the Twentieth Century, 1900-2014. *Earth and Space Science*, *5*(4), 120–132. https://doi.org/10.1002/2017EA000327

Adaku, A. A. (2013). The effect of rural-urban migration on agricultural production in the northern region of Ghana. *Journal of Agricultural Science and Applications*, *02*(04), 193–201. https://doi.org/10.14511/jasa.2013.020402

Agricultural Division (ASTAG), & The World Bank. (1991). *Newsletter of the Vetiver Information Network* (Issue 5). https://www.vetiver.org/TVN_NL05.pdf

Almagro, A., Thomé, T. C., Colman, C. B., Pereira, R. B., Marcato Junior, J., Rodrigues, D. B. B., & Oliveira, P. T. S. (2019). Improving cover and management factor (C-factor) estimation using remote sensing approaches for tropical regions. *International Soil and Water Conservation Research*, *7*(4), 325–334. https://doi.org/10.1016/j.iswcr.2019.08.005

Are, K. S., Oshunsanya, S. O., & Oluwatosin, G. A. (2018). Changes in soil physical health indicators of an eroded land as influenced by integrated use of narrow grass strips and mulch. *Soil and Tillage Research*, *184*(May), 269–280. https://doi.org/10.1016/j.still.2018.08.009

Arora, D., & Rada, C. (2017). A Gendered Model of the Peasant Household: Time poverty and Farm Production in Rural Mozambique. *Feminist Economics*, *23*(2), 93–119. https://doi.org/10.1080/13545701.2016.1220676

Awadzi, T. W., Cobblah, M. A., & Breuning-Madsen, H. (2004). The role of termites in soil formation in the tropical semi-deciduous forest zone, Ghana. *Geografisk Tidsskrift*, *104*(2), 27–34. https://doi.org/10.1080/00167223.2004.10649516

Babalola, O., Oshunsanya, S. O., & Are, K. (2007). Effects of vetiver grass (Vetiveria nigritana) strips, vetiver grass mulch and an organomineral fertilizer on soil, water and nutrient losses and maize (Zea mays, L) yields.

*Soil and Tillage Research*, *96*(1–2), 6–18. https://doi.org/10.1016/j.still.2007.02.008

Babalola, Olaolu, Jimba, S. C., Maduakolam, O., & Dada, O. A. (2003). *Use of the Vetiver Grass System for Soil and Water Conservation In Nigeria*. 1–9.

Babalola, Olaolu, Oshunsanya, S., & Are, K. S. (2005). *Continuous cultivation of maize under vetiver grass strip management; runoff, soil loss, nutrient losses and maize yields*.https://www.researchgate.net/publication/292730578_Continuous_cultivation_of_maize_under_vetiver_grass_strip_management_runoff_soil_loss_nutrient_losses_and_maize_yields

Baden, B. S., Green, C., Otoo-oyortey, N., & Peasgood, T. (1994). Background paper on gender issues in Ghana. *Bridge Development - Gender*, *Report No*(19), 1–77.

Bazoobandi, M., & Ariyan, H. (2012). Efficiency of graminicides and glyphosate in control of Vetiver grass (Vetiveria zizanioides (L.) Nash). *Weed Research Journal*, *4*, 61–72. https://www.researchgate.net/publication/306235804_Efficiency_of_graminicides_and_glyphosate_in_control_of_Vetiver_grass_Vetiveria_zizanioides_L_Nash

Benavidez, R., Jackson, B., Maxwell, D., & Norton, K. (2018). A review of the (Revised) Universal Soil Loss Equation ((R)USLE): with a view to increasing its global applicability and improving soil loss estimates. *Hydrology and Earth System Sciences*, *22*(11), 6059–6086. https://doi.org/10.5194/hess-22-6059-2018

Bracken, N., & Truong, P. (2000). Application of Vetiver Grass Technology to the Stabilization of Road Infrastructure in the Wet Tropical Region of Australia. *In Proceedings 2nd International Vetiver Conference. Thailand*, 448–452.

Breuning-Madsen, H., Kristensen, J. Å., Awadzi, T. W., & Murray, A. S. (2017). Early cultivation and bioturbation cause high long-term soil erosion rates in tropical forests: OSL based evidence from Ghana. *Catena*, *151*, 130–136. https://doi.org/10.1016/j.catena.2016.12.002

Central Intelligence Agency. (2020). *The World Factbook - Ghana*. https://www.cia.gov/library/publications/the-world-factbook/geos/gh.html

Chen, Y., Shen, Z., & Li, X. (2004). The use of vetiver grass (Vetiveria zizanioides) in the phytoremediation of soils contaminated with heavy metals. *Applied Geochemistry*, *19*(10), 1553–1565. https://doi.org/10.1016/j.apgeochem.2004.02.003

Dalton, P. A., Smith, R. J., & Truong, P. N. V. (1996). Vetiver grass hedges for erosion control on a cropped flood plain: Hedge hydraulics. *Agricultural Water Management*, *31*(1–2), 91–104. https://doi.org/10.1016/0378-3774(95)01230-3

Dampare, S. B., Ameyaw, Y., Adotey, D. K., Osae, S., Serfor-Armah, Y., Nyarko, B. J. B., & Adomako, D. (2006). Seasonal trend of potentially toxic trace elements in soils supporting medicinal plants in the Eastern Region of Ghana. *Water, Air, and Soil Pollution*, *169*(1–4), 185–206. https://doi.org/10.1007/s11270-006-2381-z

Dass, A., Sudhishri, S., Lenka, N. K., & Patnaik, U. S. (2011). Runoff capture through vegetative barriers and planting methodologies to reduce erosion, and improve soil moisture, fertility and crop productivity in southern Orissa, India. *Nutrient Cycling in Agroecosystems*, *89*(1), 45–57. https://doi.org/10.1007/s10705-010-9375-3

Donjadee, S., & Tingsanchali, T. (2016). Soil and water conservation on steep slopes by mulching using rice straw and vetiver grass clippings. *Agriculture and Natural Resources*, *50*(1), 75–79. https://doi.org/10.1016/j.anres.2015.03.001

Du, L. van, & Truong, P. (2003). *Vetiver grass system for erosion control on drainage and irrigation channels on severe acid sulfate soil in southern Vietnam*.

Earnshaw, K. M., & Orr, B. (2013). Soil moisture, field-scale toposequential position, and slope effects on yields in irrigated rice (Oryza sativa L.) fields in Honduras. *Agricultural Sciences*, *04*(08), 1–8. https://doi.org/10.4236/as.2013.48a001

Falconnier, G. N., Descheemaeker, K., Traore, B., Bayoko, A., & Giller, K. E. (2018). Agricultural intensification and policy interventions: Exploring plausible futures for smallholder farmers in Southern Mali. *Land Use Policy*, *70*(February 2017), 623–634. https://doi.org/10.1016/j.landusepol.2017.10.044

Foster, G. R., McCool, D. K., Renard, K. G., & Moldenhauer, W. C. (1981). Conversion of the universal soil loss equation to SI metric units. *Journal of Soil & Water Conservation*, *36*(6), 355–359.

Fosu-Mensah, B. Y., Vlek, P. L. G., & MacCarthy, D. S. (2012). Farmers' perception and adaptation to climate change: A case study of Sekyedumase district in Ghana. *Environment, Development and Sustainability*, *14*(4), 495–505. https://doi.org/10.1007/s10668-012-9339-7

Ganyaglo, S. Y., Banoeng-Yakubo, B., Osae, S., Dampare, S. B., Fianko, J. R., & A. H. Bhuiyan, M. (2010). Hydrochemical and Isotopic Characterisation of Groundwaters in the Eastern Region of Ghana. *Journal of Water Resource and Protection*, *02*(03), 199–208. https://doi.org/10.4236/jwarp.2010.23022

Gladwin, C. H., Thomson, A. M., Peterson, J. S., & Anderson, A. S. (2001). Addressing food security in Africa via multiple livelihood strategies of women farmers. *Food Policy*, *26*(2), 177–207. https://doi.org/10.1016/S0306-9192(00)00045-2

Howeler, R., Watananonta, W., Vongkasem, W., Klakhaeng, K., Jantawat, S., Randaway, S., & Vankaew, B. (2003). Working with Farmers: The Key to Adoption of Vetiver Grass Hedgerows to Control Erosion in Cassava Fields in Thailand. *Vetiver and Water. Proc. 3rd Intern. Conf. On Vetiver and Exhibition*.

Hsu, H., & Lachenbruch, P. A. (2005). Paired t Test. In *Encyclopedia of Biostatistics*. John Wiley & Sons, Ltd. https://doi.org/10.1002/0470011815.b2a15112

Kearney, S. P., Fonte, S. J., García, E., & Smukler, S. M. (2018). Improving the utility of erosion pins: absolute value of pin height change as an indicator of relative erosion. In *Catena* (Vol. 163, pp. 427–432). Elsevier B.V. https://doi.org/10.1016/j.catena.2017.12.008

Lin, C., Tu, S., Huang, J., & Chen, Y. (2009). The effect of plant hedgerows on the spatial distribution of soil erosion and soil fertility on sloping farmland in the purple-soil area of China. *Soil and Tillage Research*, *105*(2), 307–312. https://doi.org/10.1016/j.still.2009.01.001

Logah, F. Y., Obuobie, E., Ofori, D., & Kankam-Yeboah, K. (2013). Analysis of rainfall variability in Ghana. In *International Journal of Latest Research In Engineering and Computing* (Vol. 1, Issue 1). www.ijlrec.com

Manik, T. K., Rosadi, B., Utomo, M., Senge, M., Adachi, T., & Oki, Y. (2003). *An Evaluation of Coffee Crop Factor under Different Weed Managements Using USLE Method in Hilly Humid Tropical Area of Lampung, South Sumatra, Indonesia*.

Mickovski, S. B., & van Beek, L. P. H. (2009). Root morphology and effects on soil reinforcement and slope stability of young vetiver (Vetiveria zizanioides) plants grown in semi-arid climate. In *Plant and Soil* (Vol. 324, Issue 1, pp. 43–56). https://doi.org/10.1007/s11104-009-0130-y

Morgan, R. P. C. (2005). Soil Erosion and Conservation. In *National Soil Resources Institute, Cranfield University* (3rd ed.). Blackwell Publishing. https://doi.org/10.1111/j.1365-2389.2005.0756f.x

Nimityongskul, P., Panichnava, S., & Hengsadeekul, T. (1991). Use of Vetiver Grass Ash as Cement Replacement Materials. *“The International Conference on Vetiver (ICV),”* 148–159.

Oshunsanya, S. O. (2013). Spacing effects of vetiver grass (Vetiveria nigritana Stapf) hedgerows on soil accumulation and yields of maize-cassava intercropping system in Southwest Nigeria. *Catena*, *104*(February), 120–126. https://doi.org/10.1016/j.catena.2012.10.019

Oshunsanya, S. O., Are, K., & Fagbenro, J. A. (2014). The use of vetiver grass (Vetivera nigritana Staph) Strips in checking soil loss and improving yields of maize-cassava-cowpea intercropping systems in Southwest Nigeria. *Journal of Applied Agricultural Research*, *6*(1), 237–244. Erosion; Vetiver Grass;

Pereira, C. C. (2018). *RPG Simple Dice* (1.9.4). Google Play Store. https://play.google.com/store/apps/details?id=com.ccp.rpgsimpledice&hl=en_US

Ritzema, R. S., Frelat, R., Douxchamps, S., Silvestri, S., Rufino, M. C., Herrero, M., Giller, K. E., López-Ridaura, S., Teufel, N., Paul, B. K., & van Wijk, M. T. (2017). Is production intensification likely to make farm households food-adequate? A simple food availability analysis across smallholder farming systems from East and West Africa. *Food Security*, *9*(1), 115–131. https://doi.org/10.1007/s12571-016-0638-y

Sagare, B. N., & Meshram, S. S. (1993). Evaluation of Vetiver Hedgerows Relative To Graded Bunds and Other Vegetative Hedgerows. In *Vetiver News Letter* (Issue 10).

Satterlee, B. M., Yemefack, M., & Orr, B. D. (2009). Maize yield and soil property responses to Entada abyssinica (Steud. ex A. Rich.) cuttings in the Adamawa Lowlands, Cameroon. *Journal of Food, Agriculture and Environment*, *7*(1), 192–196.

South Australian EPA. (2005). Composite soil sampling in site contamination assessment and management. https://www.epa.sa.gov.au/files/8370_guide_composite.pdf

Steel, R. G. D., & Torrie, J. H. (1960). *Principles and Procedures of Statistics*. McGraw-Hill.

Truong, P. N. V., & Loch, R. (2004). Vetiver system for erosion and sediment control. *Proceeding of 13th International Soil Conservation Organisation Conference*, *247*, 1–6.

USAID. (2018). *Climate Risk Profile - West Africa*. https://www.climatelinks.org/sites/default/files/asset/document/West_Africa_CRP_Final.pdf

Van Der Heijden, M. G. A., Bardgett, R. D., & Van Straalen, N. M. (2008). The unseen majority: Soil microbes as drivers of plant diversity and productivity in terrestrial ecosystems. *Ecology Letters*, *11*(3), 296–310. https://doi.org/10.1111/j.1461-0248.2007.01139.x

Wiggins, S., & Keats, S. (2013). *Leaping and Learning Linking Smallholders To Markets*. *000*(May), 2013.

Wischmeier, H., Dwight, D., & Smith, D. (1978). Predicting Rainfall Erosion Losses: A Guide to Conservation Planning - Walter H. Wischmeier, Dwight David Smith - Google Libros. In *United States Department of Agriculture*. Department of Agriculture, Science and Education Administration.

Wischmeier, W. H., & Smith, D. D. (1958). Rainfall energy and its relationship to soil loss. *Eos, Transactions American Geophysical Union*, *39*(2), 285–291. https://doi.org/10.1029/TR039i002p00285

Xia, H. P., Ao, H. X., He, D. Q., Liu, S. Z., & Chen, L. J. (1996). The function of vetiver on soil improvement and soil conservation. *Tropical Geography*, *15*(3), 265–270.

# A Composite Soil Sample

A composite soil sample was taken on April 30th, 2019 using guidelines from the South Australian Government EPA text on composite soil sampling (South Australian EPA, 2005). This was taken to represent the average soil conditions across the study area. For the samples taken equal soil material was taken for each subsample. Each subsample was taken an equally spaced distance from the previous sample, the lines intersecting the subsample locations did not intersect, four subsamples were taken for each composite sample, and the samples were collected from the same soil horizon and depth interval.

The process for each sample taken is as follows: all tools, including a plastic bucket, metal ruler, shovel, and farming machete were scrubbed and cleaned off to prevent cross contamination. An initial location was chosen in the buffer zone between plots as not to disturb the study area. The shovel was used to dig a uniform hole at least eight inches deep. The shovel was used to remove a vertical slice of soil from the side of the hole, making sure the amount is uniform in width along the blade of the shovel. The blade of the shovel was laid flat on the ground with the sample on top of it. Next the metal ruler was placed on top of the sample so that it measured 6 inches from the original surface of the soil. The area around the ruler was then cut away using the farming machete creating a rectangular prism shape of soil left on the shovel which was then added to the plastic bucket. The topsoil thickness was measured and recorded by using a ruler to measure the side of the hole and general description of the topsoil and subsoil were also recorded. Lastly a GPS coordinate was taken at the location the hole was dug. This was repeated for three more samples; each additional sample was taken 80 feet from the previous sample making sure to consider the previous requirements for each subsample. All subsamples were placed in the same bucket where they were left to dry indoors for one week until all moisture evaporated and then was packaged in a clean plastic bag so that it could be taken to the lab for analysis. The sample was taken to the Soil

Research Institute (SRI) within the Council for Scientific and Industrial Research (CSIR) in Accra, Ghana for simple physical and chemical analysis.

# B Copyright documentation

Both images, used to crate Figure 1, are from Wikimedia Commons. They are both in the public domain or licensed for reuse under Creative Commons license 4.0.  Please see below for full citation and attribution information.

Figure 1: “Ghana Districts” by Rarelibra, Wikimedia Commons Licensed under the Public Domain. Created using MapInfo Professional v7.5 and various mapping resources. Downloaded from https://commons.wikimedia.org/w/index.php?curid=891714 Accessed July 2020.

Figure 1: “2019 Regions of Ghana” by Rwhaun Licensed under CC BY-SA 4.0 via Wikimedia Commons. Downloaded from https://upload.wikimedia.org/wikipedia/commons/thumb/d/d5/2019_Regions_of_Ghana.png/858px-2019_Regions_of_Ghana.png Accessed July 2020.