AGRICULTURAL ENGINEERING

ASSESSING THE IMPACT OF LIVESTOCK TRAMPLING ON SOIL COMPACTION ON INTUNJAMBILI WETLAND, MATOPO.

An Undergraduate Research Project Submitted in Partial Fulfillment of the Requirements of the Degree of Bachelor of Science Honours in Agricultural Engineering.

BY

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ABSTRACT

The effect of livestock trampling on soil compaction was studied on a natural pasture in Intunjambili wetlands. Soil compaction was quantified by means of bulk density, penetration resistance. A comparison of these soil properties was made between a grazed area and an ungrazed, which was used as a control. Field investigations showed that compaction due to livestock trampling had led to increased soil penetration resistance and bulk density. Statistical analysis of results showed that there were significant differences between grazed and ungrazed areas for both bulk density and penetration resistance ($P < 0.05$). Grazing had also led to a decline in the number of plant species and an increase in bare land. These transformations favour the development of aeolian erosion in dry areas, runoff on bare surfaces, and gully erosion on slopes (Peres, 1991).

DEDICATION

To my parents, Mr. and Mrs. Sibanda, my brothers and sisters for their patience, financial and moral support. May the good Lord bless you all.

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Firstly, I thank the Almighty creator for guiding and enlightening in this project. I express my utmost gratitude to my supervisor, Mr. K Motsi, for his unwavering support and expert guidance in the preparation of this project.

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CHAPTER 1

1.0 INTRODUCTION

1.1 BACKGROUND

Wetlands, in general, are among the most productive natural ecosystems in Zimbabwe. The ecological and socio-economic importance of wetlands cannot be overemphasized. They constitute a very important natural resource as evidenced by the growing importance now placed on wetlands at national level (Matiza and Crafter, 1994). They have been used for cultivation and livestock grazing since the Iron Age.

According to the Ramsar Convention (1971), wetlands are defined as areas of marsh, fern, peat land or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salty, including areas of marine water to a depth which at low tide does not exceed six metres (Denny, 1985).

Wetlands, like any other ecosystem are apparently threatened by modern hydrological and agricultural projects despite the fact that they are productive ecosystems, which can play a central role in strategies for sustainable development for local communities (Mhlanga, 1995). Research, policy makers and legislation have largely neglected wetlands. Apart from dams and river systems, wetlands were perceived as wastelands that should be drained (Matiza and Crafter, 1994).

Zimbabwe has experienced a progressive loss of wetlands during the past decades, for example, the Binga Swamp Forest. The swamp has completely dried up, as a result of lowering of the water table. Excessive disturbance by cattle around the fenced area caused trampling and defoliation of the grasses, which might have affected the mechanisms of ground water recharge. Wetland loss, coupled with frequent droughts, has contributed to the general scarcity of water that is experienced today in Zimbabwe.

(Matiza and Crafter, 1994). According to Owen et al (1995), the causes of wetland loss and degradation in Zimbabwe are deforestation, overgrazing, livestock trampling, eutrophication (growth of algae, causing water purification problems) and water pollution due to toxins secreted by algae.

Livestock grazing and trampling contributes to land degradation by soil compaction and local vegetation destruction, which favours runoff and channeling. These effects impact negatively on wetland hydrology (Perez, 1991). This study seeks to assess the impact of livestock trampling and grazing on vegetation and soil properties on Intunjambili wetland, Matopo, with a view of providing guidelines for sustainable use of wetlands as grazing areas.

1.2 WETLAND USES

Wetlands provide people directly or indirectly with an enormous range of products and services:

Livestock grazing, irrigated agriculture, domestic water supply, flood control, water quality improvement, and fisheries (Sather and Smith, 1984).

According to Owen (1997), livestock grazing contributes to wetland loss and degradation due to trampling effect, which causes soil compaction.

1.3 OBJECTIVES

1.3.1 MAIN OBJECTIVE

To assess the impact of livestock grazing on soil compaction as a result of trampling in grazed areas, with an ungrazed area used as a control.

1.3.2 SPECIFIC OBJECTIVES

To compare

- Soil penetration resistance
- Bulk density
- To determine soil moisture content, in a grazed and an ungrazed area.

1.4 HYPOTHESIS

Soil compaction in grazed areas is higher than that of ungrazed areas.

1.5 JUSTIFICATION

The current legislation, prescribing wetlands to be used mainly for grazing and isolated gardens after permission is granted, has faltered since it has allowed degradation to progress unchecked. Tree felling overgrazing and unmaintained conservation systems in the catchment areas, overgrazing and trampling of wetlands, uncontrolled populations have caused the failure of the system (Owen et.al, 1995). Livestock trampling has resulted in soil compaction, reduced infiltration hence reduced water retention capacities leading to lowering of water table and desiccation of wetlands. Wetland loss, coupled with frequent droughts, has contributed to the general scarcity of water, which is experienced in Zimbabwe today (Matiza and Crafter, 1994). This project, therefore, seeks to assess the impact of livestock grazing and trampling on soil compaction on wetlands.

CHAPTER 2

2 .0 LITERATURE REVIEW

2.1WETLAND TYPES IN ZIMBABWE

(i) RIVERINE SYSTEMS

These wetlands are localized along streams or major rivers and follow two hydrological systems in Zimbabwe, that is, along the Zambezi in the north, and Limpopo and Save in the south.

These wetland systems are composed of floodplains and swamps. Overgrazing and desiccation currently threaten floodplains.

The wetland under study is a riverine system, located in the catchment of Tuli River, a tributary of Limpopo River.

(ii) LACUSTRINE SYSTEMS

These are situated in dammed river channels and are not well developed in Zimbabwe. Of most importance are Lakes Chivero, Kariba, Darwendale, and Kyle (Matiza and Crafter, 1994). This system is important for municipal and industrial water supply, hydroelectric power generation and recreation (Breen et al, 1997).

(iii) PALUSTRINE SYSTEMS

These are fresh water habitats occurring around ponds or springs. Of greatest importance are dambos, which are used intensively for dry season agriculture, grazing and water supply for domestic purposes (Breen et al, 1997).

2.2 THREATS TO WETLANDS IN ZIMBABWE

(i) OVERGRAZING

This is attributed to overstocking and lack of management. Communal land producers have always used rearing of livestock as a survival strategy. The level of stocking is determined by economic objectives rather than the ability of land to support large herds. Overstocking invariably leads to overgrazing, rendering the land susceptible to soil erosion and consequently river siltation as in the Save River system (Breen et al, 1997). Whitlow (1983) found that wetlands can be fragile and are especially susceptible to grazing, which degrades vegetation, thereby affecting dambo hydrology and encouraging soil erosion (Matiza and Crafter, 1994).

Runoff increases due to reduced infiltration as a result of soil compaction and loss of vegetation. Tainton (1995) reported that runoff from heavily grazed areas was twice that of rested areas. As a result of reduced infiltration, water-holding capacity of the soil is reduced resulting in lowering of the water table.

(ii) EUTROPHICATION AND POLLUTION

Sewage effluents and agricultural runoff can carry a variety of pollutants including plant nutrients and pesticides. This is especially so with lakes located near major towns and cities and the threat becomes more severe due to industrialization. The consequence of eutrophication in lakes is accelerated growth of algae, which causes water purification problems, leave unpleasant tastes and odours in the water and secret toxins, which cannot be removed by normal water purification methods (Matiza and Crafter, 1994; Chenje, 2000).

(iii) DEFORESTATION

This occurs around cities, towns and large rural settlements. Deforestation is a result of land clearing for agriculture and fuel wood collection. It is of particular concern in the Save and Limpopo river catchments since it causes erosion and consequently changes river flows from perennial to seasonal (Breen et al, 1997).

2.3 CURRENT LEGISLATION INVOLVING WETLANDS

(i) The Water Act of 1927(amended in1976):

The Act forbids wetland cultivation in order to preserve down stream dry season river flows

(ii) The Natural Resources Act of 1952(amended in 1975 and 1981):

This Act bans cultivation of any land within thirty meters of a stream bank in order to reduce erosion and river siltation (Owen et al, 1995).

The government enacted the two pieces of legislation in a bid to protect wetlands from degradation especially through cultivation. Wetlands were declared non-arable and demarcated as grazing areas, a position that has been maintained to this day. Wetland cultivation, however does take place due to land, water and population pressure. The use of wetlands as livestock-grazing areas, has however, led to degradation and desiccation of some of the wetlands due to poor management and conservation practices (Owen et al, 1995). McFarlane and Whitlow (1991) reported that intensive grazing was more destructive of wetlands than the ridge and furrow cultivation system.

(iii) The Environmental Management Act (EMA, 2003). (Cap 20:27)

Section 113 (2)

The Act bans reclamation, drainage and introduction of any plant or animal species into the wetland, except with written authorization from the Natural Resources Board.

2.4 EFFECTS OF LIVESTOCK GRAZING AND TRAMPLING ON AQUATIC AND RIPARIAN HABITATS.

Influence On	Response	Causes	Impacts	References
Stream channel morphology				
Channel depth	Increases	Downcutting from higher flood energy	Lowered groundwater table; narrowing of riparian zone; high flows contained within channel, thus precluding build-up of flood plain	Winegar 1977
Channel width	Increases	Breakdown of streambanks by trampling; increased erosion from greater flood velocity; erosion of stream banks due to loss of vegetation to cattle	Further loss of riparian vegetation; higher water temperatures; decreased water depth	Duff 1977, Marcuson 1977, Platts 1981a, Kauffman et al. 1983b, Hubert et al. 1985, Stuber 1985
Channel stability	Decreases	Bare streambanks and channel bed easily eroded. Wider stream bed	Widening of channel; loss of pools and meanders. Higher water temperatures; reduced habitat for aquatic organisms	Marcuson 1977m Dudley et al. (in prep), Platts 1981a, Hubert et al. 1985, Stuber

				1985
Hydrology (stream flow patterns)				
Overland flow (runoff)	Increases	Reduced water infiltration into soils due to compaction and loss of streamside vegetation	Increase in sheet and rill erosion; increased flooding; reduced groundwater recharge; lowered water table	Orr 1975, Meehan and Platts 1978, Stevens et al. 1992
Peak flow	Increases	Larger volume of runoff flowing directly into channel	Increased stream energy for channel erosion, downcutting of channel bed .	
Flood water velocity	Increases	Reduced resistance from streambank and instream vegetation; increased flood water volume	Increased erosive energy and downcutting; removal of submerged vegetation and woody debris for pool formation; reduced habitat diversity	Platts 1981a
Summer and late-season flows	Decrease	Less water stored in soil; lowered water table	Aquatic organisms stressed by degraded water quality; less aquatic habitat; livestock impacts magnified	Kovalchik and Elmore 1992
Water table	Lowered	Reduced water infiltration and	Loss of aquatic and riparian species;	Kovalchik and Elmore 1992

		increased runoff; incised stream channel	perennial streams become ephemeral; loss of ephemeral streams	
Riparian zone soils				
Compaction	Increases	Trampling by livestock on wet, heavy soils; reduced litter and soil organic matter	Decreased infiltration rates and more runoff; reduced plant productivity and vegetative cover	Orr 1975, Clary and Medin 1990m Clary 1995
Infiltration	Decreases	Increased soil compaction from hoof action; reduced plant cover, litter, and organic matter	Increased overland flow and erosion; reduced soil water content and plant growth; lowered water table	Orr 1975, Bohn and Buckhouse 1985a
Influence On	Response	Causes	Impacts	References
Fertility	Declines	Less soil organic matter; loss of top soil; loss of soil structure due to trampling	Fewer soil organisms; reduced plant growth	Marcuson 1977

Streambank vegetation				
Species composition	Altered	Lowered water table; warmer, drier environment; livestock selection of palatable species; compacted and disturbed soils	Replacement of riparian species by upland species and exotic weeds; reduction in riparian area	Kauffman et al. 1983a, Clary and Medin 1990, Schulz and Leininger 1990, Green and Kauffman 1995

(www.highsierrahikers.org/issue_grazing_table.html)

2.5 SOIL COMPACTION

This is the increase in the density of soil as a result of applied loads or pressure (Baruah and Barthakur, 1997). The density to which a given soil can be compacted is a function of both the compactive effort and moisture content. Cattle hooves exert large stresses on the soil (Webb and Clark, 1981) and the amount of resultant deformation depends on bulk density, moisture and organic contents (Schothorst, 1964). When soil of low to medium moisture content is trampled, the main process is compression beneath the hooves (Scholefield et al, 1985) This collapses the larger soil pores by mechanical disruption of aggregates (Beckman and Smith, 1974); Warren et al, 1986). When wetter soil is trampled, there is plastic flow around the hooves. Compaction as a result of livestock trampling tends to be shallow (Scholefield et al, 1985) but can lead to ponding. Beamish (1977) found that trampling increased the penetration resistance of soil. Livestock grazing removed the protective plant cover, and trampling (Bari et al, 1993) and overgrazing (Zobisch, 1993) can damage soil devoid of foliar cover. When vegetation cover declines, rate of water infiltration decreases and sediment production increases (Bari et al, 1995).

Soil compaction is quantified by measuring a soil property that is relevant both to the process and   the interpretation of the resulting soil conditions. The most widely used properties are dry bulk density, penetration resistance, infiltration rate and fluid hydraulic conductivity (Barnes et al, 1971).

2.5.1 BULK DENSITY

This is the ratio of mass of dry soil to the total volume of the soil. Because bulk density takes into account the pore space in the soil, it can give an indication of the level of compaction or, conversely, porosity of the soil (McLaren and Cameron, 1990). Dry bulk density allows soils at different moisture contents to be compared hence it is usually used to describe soil compaction (Soane and Ouweker, 1994). Methods of measuring soil bulk density include the tube core and the clod method (Baruah and Barthakur, 1997).

2.5.2 INFILTRATION

Infiltration is the process of water entry into the soil generally vertically. The process can also be horizontal depending on the micro relief and source of water. Infiltration is a very important soil property, which influences to a great extent the hydrology of the soil. Low infiltration rates often result in inadequate profile water recharge and high runoff volumes accompanied by high soil loss. The initial infiltration rate depends on such factors as the initial soil moisture content, hydraulic conductivity and soil surface conditions. According to Baruah and Barthakar (1997), infiltration is lowered in compacted soils as a result of reduced porosity. However, Tainton (1995) hypothesized that livestock trampling, which causes soil compaction, improves infiltration by breaking the surface soil crust.

2.5.3 PENETRATION RESISTANCE

Measuring the penetration resistance of the soil can indirectly assess soil strength. The value of penetration resistance that is measured in any soil represents the combined influence of both cohesive and frictional characteristics of the soil (Meigh, 1987). Penetration resistance is often measured by means of a penetrometer. Although this measure includes forces of compression in front of the probe, and friction between the probe and the soil, the penetrometer is widely used for estimating the resistance of soil to root penetration, compaction, traffic loading and tillage (Barnes et al, 1971).

2.5.4 MOISTURE CONTENT

Moisture content governs the behaviour of fine-grained soils (McLaren and Cameron, 1990). It is the moisture content which changes the soils from liquid state to plastic and solid states. Its quantity controls the shear strength and vulnerability of the soil to compaction. Bayfield (1973) found that water content is the most important factor determining the susceptibility of soil to compaction. He found that wet mineral soils were prone to compaction from trampling by livestock than dry organic soils.

CHAPTER 3

3.0 METHODOLOGY

Site description

The study was conducted on wetlands at Intunjambili, in Matopo, located 43 km from Bulawayo along old Gwanda road, between January and March, 2005.The wetland covers 30 hectares and is bordered by rock outcrops. Since there are no climatic stations in the area, a general description of the climate can be given. The area receives unimodal rainfall, between September and April and is in agro-ecological region 4.The driest period is between May and August. According to Anon (1982), rainfall ranges from 470 mm to 650 mm in natural region 4 and the annual rainfall is 570 mm for Matopo, the study area. During the three-month period surrounding the study, rainfall ranged from 1 mm to 20.6 mm per rainfall event. Nyamapfene (1991) reported that the soils of the area are classified as clayey, mixed, thermicTypic Argiudoll according to the United States Department of Agriculture (USDA) and as Luvic Phaeozem according to the Food and Agriculture Organisation (FAO). The soils of the lower part of the wetland are frequently waterlogged and this might explain why livestock grazing is not common in this part of the wetland. The wetland is used for grazing all year round. Nyamapfene (1991) reported that indicators of rangeland degradation were primarily found in the soil and vegetation change. Vegetation indicators of rangeland degradation include a decline in plant cover and plant species composition. The present grazing is considered as overgrazing since there were clear indications of degradation by loss of vegetation cover, which is largely grass. Livestock found in the locality of the study area included donkeys (15), goats (20) and cattle (50). Gammon (1983) reported that the general recommended stocking rate in agro-ecological region 4 was 8 livestock units per hectare (8 LU ha^{-1}). A livestock unit is equivalent to an animal weighing between 350 kg and 500 kg (Gammon, 1983). Cattle grazing is the most important form of animal husbandry. Currently, there are no livestock management systems in place, except for goats, which were tethered by a few families.

During the dry season, grazing pressure increases, as the wetland is often the only place that continues to be productive. This is due to the fact that wetlands have:

- High primary production due to long growing season
- Plant food values with high water content
- Grasses which are generally palatable (Breen et al, 1997)

Besides livestock grazing and watering, the wetland was also used for crop production, and domestic water supply.

3.1 FIELD MEASUREMENTS

Treatments:

The study was conducted on two areas:

1) Grazed area: grassland grazed all year round and covers three hectares.

2) Ungrazed area: located in the gardens of the farmers, from which livestock has been excluded for the past five years and covers 2.5 hectares.

3.2 EXPERIMENTAL DESIGN

A completely randomised block design was used, in which each area was divided into three equal strips running parallel to the slope of the wetland. Sampling was done at randomly chosen points in each strip, using the simple random technique. There were 5 replicates per strip, giving a total of 15 replicates per treatment. To quantify compaction, the following parameters were measured in each treatment:

i) SOIL MOISTURE CONTENT

For moisture content determination, soil samples were collected by means of a cylindrical core sampler, 5cm long and 3.8cm internal diameter. The samples were stored in sealable plastic bags for laboratory analysis. According to Bayfield (1973), moisture content is the most important factor determining the susceptibility of a soil to compaction. Moisture content determination was done in the laboratory using the oven dry (gravimetric method). The soil samples were weighed and dried in an oven at 105ºC for 24 hours, until all the moisture was driven off. After removing the soil samples from the oven, they were slowly cooled to room temperature and weighed again (Hillel, 1980). Moisture content was determined using the following equation;

$$M_c = \frac{M_w - M_d}{M_d}$$

M_c =moisture content

M_w=mass of soil sample before drying

M_d=mass of soil sample after oven drying.

ii) PENETRATION RESISTANCE.

This property was measured by means of a hand-pushed mechanical penetrometer (Meigh, 1987).

The penetrometer was advanced into the soil at a steady rate and a continuous record of penetration resistance versus depth was obtained. The readings were taken at 3.5 cm depth intervals up to a depth of 45.5 cm (the penetrometer could not be pushed beyond this depth). According to Barnes (1971), the value of penetration resistance that is measured in any soil represents the combined influence of both cohesive and frictional characteristics of the soil. The penetrometer was inserted at randomly chosen points in each strip.

iii) BULK DENSITY

Soil samples were taken at 5 cm depth intervals up to a depth of 25 cm with the help of a core sampler whose inner volume is known. The soil samples were taken from randomly chosen plots by hammering the cores into the soil and then excavating them, in both grazed and ungrazed areas. The samples collected were dried at 105ºC for 24 hours. The oven dry mass, of the soil samples was measured by means of a mass balance. Dry bulk density of the soil samples was determined using the equation

$$B.D = \frac{W}{V}$$

B.D=dry bulk density

W = oven dry weight of the soil sample, and,

V= inner volume of the cylindrical core.

$V = \frac{\pi D^2 * L}{4}$ where D is the internal diameter of the core and L is its length

Since D=3.8cm and L =5cm, V = 57cm^3.

3.3 DATA ENTRY

Data was entered using Microsoft Excel.

3.4 DATA ANALYSIS

Minitab (One way ANOVA, unstacked) was used to analyse data. This analysis was used to test if there were significant differences between treatment means and was carried out on both bulk density and penetration resistance. A p-value less than 0.05 indicates that the treatment means are significantly different implying that livestock grazing has effect on the bulk density and penetration resistance of soil. A value greater than 0.05 indicates that there is no significant difference between treatment means.

CHAPTER 4

4.0 RESULTS AND DISCUSSION

4.1 MOISTURE CONTENT

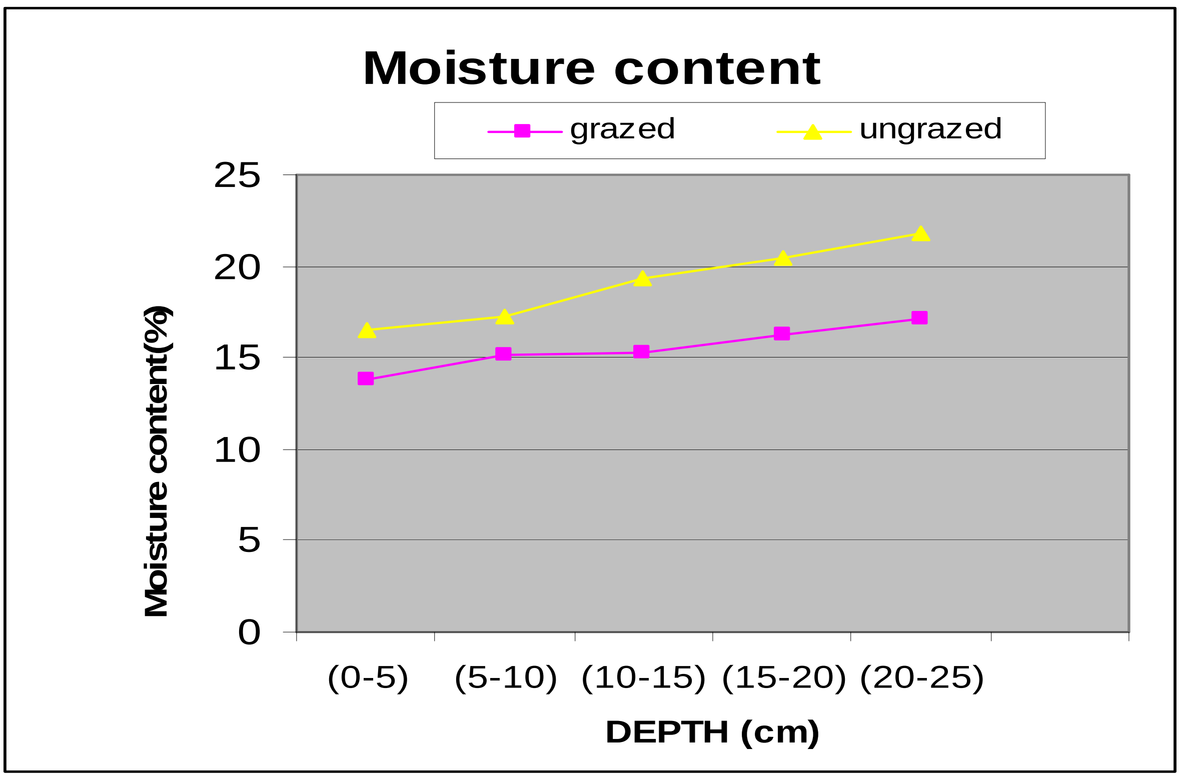

FIG 4.1. Mean moisture content for grazed and ungrazed areas.

4.2 BULK DENSITY

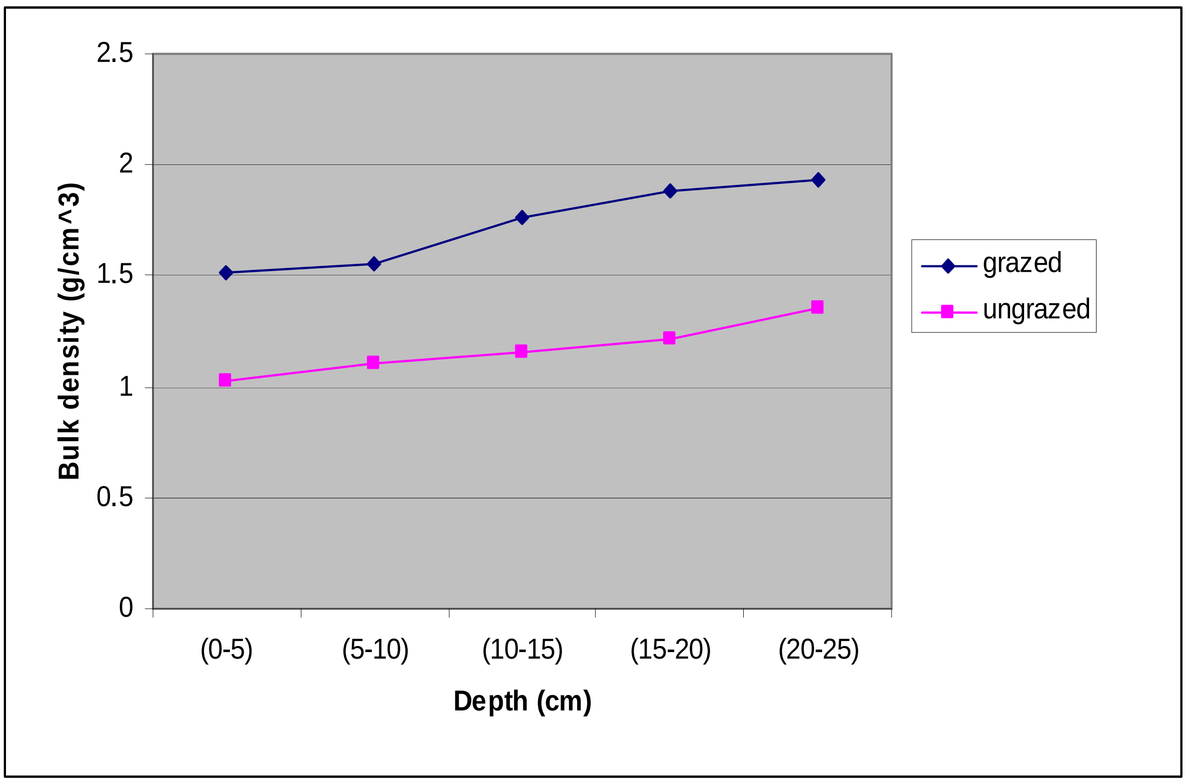

FIG 4.2. Mean dry bulk density for grazed and ungrazed areas.

Results show that bulk density is higher in grazed areas compared to ungrazed (FIG 2). This might be due to soil compaction resulting from trampling by livestock. Compaction reduces the volume of soil micro –pores resulting in the densification of soils. Water retention and transmission are very sensitive to the location of the compact layers because infiltration characteristics are affected. Compaction decreases water movement by decreasing the void volume, and also possibly by changing the void size distribution to block some connections between voids (Barnes et al, 1971). As a result of reduced infiltration rates, runoff volumes increase leading to soil erosion especially in areas devoid of foliar cover due to overgrazing. A decrease in pore size can restrict the rooting of grass, which is the dominant vegetation in the study area, and inhibit air movement, which makes the grass cover more vulnerable to further hoof damage. High organic matter lowers bulk density, whereas compaction increases bulk density (Biswar et al, 1994). This might explain why the topsoil (0-10 cm) showed lower values of bulk density since it consists largely of organic matter. Bulk density was shown to increase with depth and this is attributed to migration of clay particles from the topsoil to the subsoil where the particles fill the existing pore spaces, resulting in a decrease in pore space volume and an increase in bulk density.

4.3 PENETRATION RESISTANCE

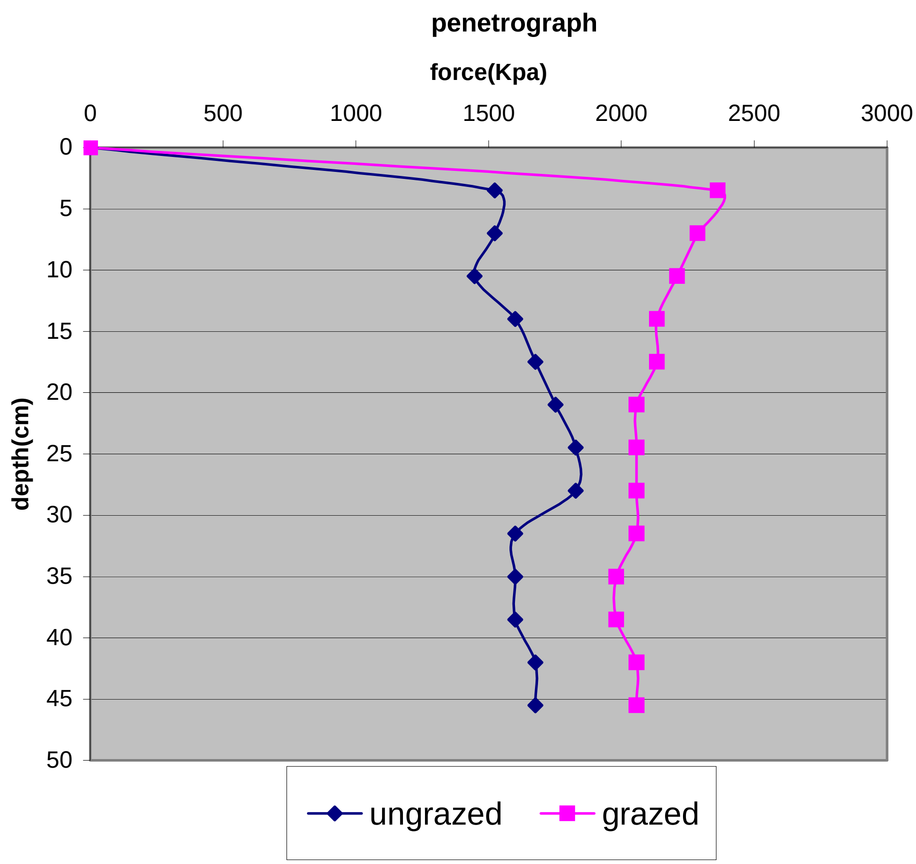

FIG 4.3. Mean penetration resistance for grazed and ungrazed areas.

Maximum penetration resistance in grazed areas occurred at a soil depth of 0 to 5 cm and this indicates the presence of a compacted layer (FIG 3). This might be attributed to low moisture contents (Fig 1) of the organic layer resulting in dry soil conditions. Higher moisture contents however, allow soil particles to flow as a viscous liquid when trampled and this avoids compaction (Hillel, 1980). The cohesive forces between the soil particles are decreased as water molecules separate and lubricate them (Baver et al, 1972). Less compaction in the sub soils than in the top soils is also related to the decrease in stress with increasing distance from the forces of trampling hence cone resistance decreases with depth (Catt, 1992). For the ungrazed area, the maximum penetration resistance occurred at a depth of 25-30 cm. This might have been due to the presence of a plough pan since this area was once cultivated. Cone resistance results agree with topsoil compressibility results of Scholefield et al. (1985) who found that most structural damage as a result of livestock grazing and trampling occurred in the top 100 mm of the soil.

4.4 STATISTICAL ANALYSIS OF RESULTS

TABLE 1

	Bulk density	Penetration resistance
Grazed (mean)	1.726	27.692
Ungrazed (mean)	1.740	21.538
P-value	0.001	0.0002

The analysis shows that there is a significant difference between treatment means for both bulk density and penetration resistance since the p-values are less than 0.05. The hypothesis that soil compaction is higher in grazed areas compared to ungrazed areas is therefore accepted. This implies that livestock trampling has an effect on soil compaction.

CHAPTER 5

5.0 CONCLUSSION AND RECOMENDATIONS

5.1CONCLUSSION

Trampling by livestock increases penetration resistance and soil bulk density especially on soils devoid of foliar cover as a result of overgrazing. Overgrazing results in an increase of the bare surface due to trampling with the risk of water channeling and aeolian erosion. These changes contribute to a drastic reduction of the water retention capacity of the soil, due to reduced porosity, which in turn reduces the infiltration rate and increases overland flow. This retards development of vegetation cover and causes more land degradation.

5.2 RECOMMENDATIONS

- Wetlands should be used for grazing mainly in the dry season so that cattle do not churn up very wet soils, making them susceptible to erosion. During the rainy season or when the ground is very wet, cattle may dig up lots of soil and make the water muddy, polluting it for downstream users. They may cut channels with their hooves which can erode into dongas and dry out the wetland
- Keep cattle on the outer edges of the wetland, away from permanently flooded areas.
- Heavy grazing without rest periods should not be allowed since it may cause valuable, sweet (or highly nutritional) grasses to be replaced by less tasty or useful species.

- Overgrazing and trampling can cause gully erosion, which destroys the wetland. Overgrazing can be avoided by rotating grazing over different parts of the wetland. Livestock can be allowed to graze a certain part of the wetland until the grass is short and then be moved onto another area.

- Trampling and overgrazing can be limited by encouraging farmers to grow fodder grasses such as bana grass.

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APPENDICES

1.0 STATISTICAL ANALYSIS OF RESULTS

1.1 One-way Analysis of Variance for bulk density

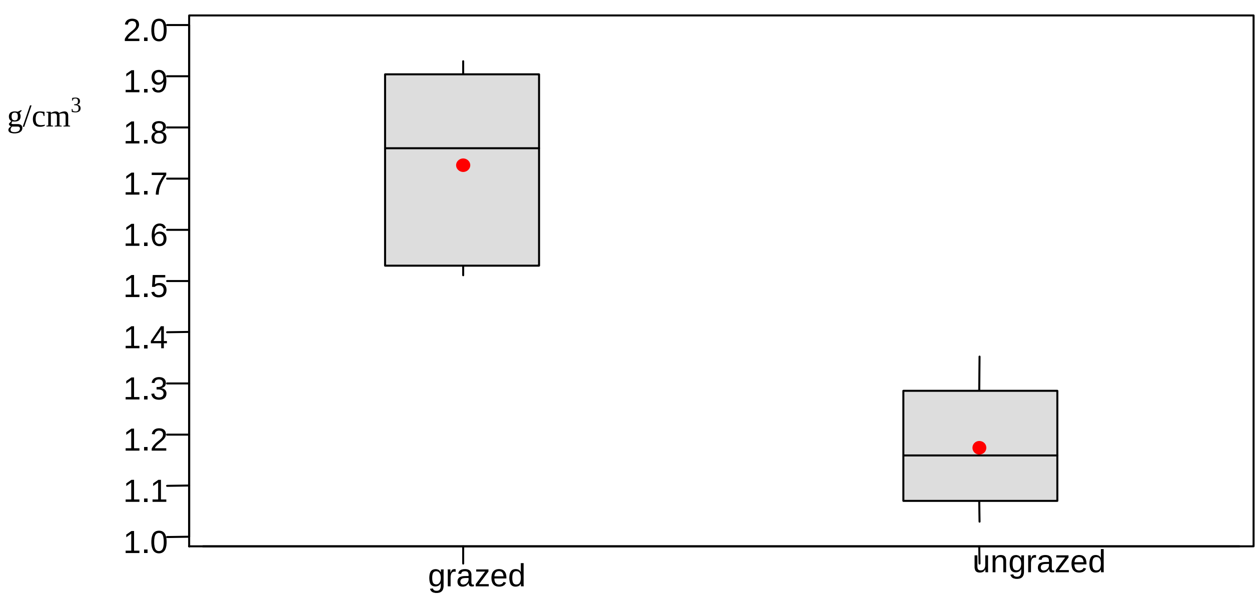
Analysis of Variance for bulk density

Source	DF	SS	MS	F	P
Factor	1	0.7618	0.7618	30.13	0.001
Error	8	0.2022	0.0253		
Total	9	0.9640			

```
                              Individual 95% CIs For Mean
                              Based on Pooled StDev
Level      N     Mean     StDev  ----------+---------+---------+------
grazed     5   1.7260    0.1898                  (------*------)
ungrazed   5   1.1740    0.1205  (------*------)
                              ----------+---------+---------+------
Pooled StDev =   0.1590             1.25      1.50      1.75
```

Boxplots of bulk density: grazed - ungrazed

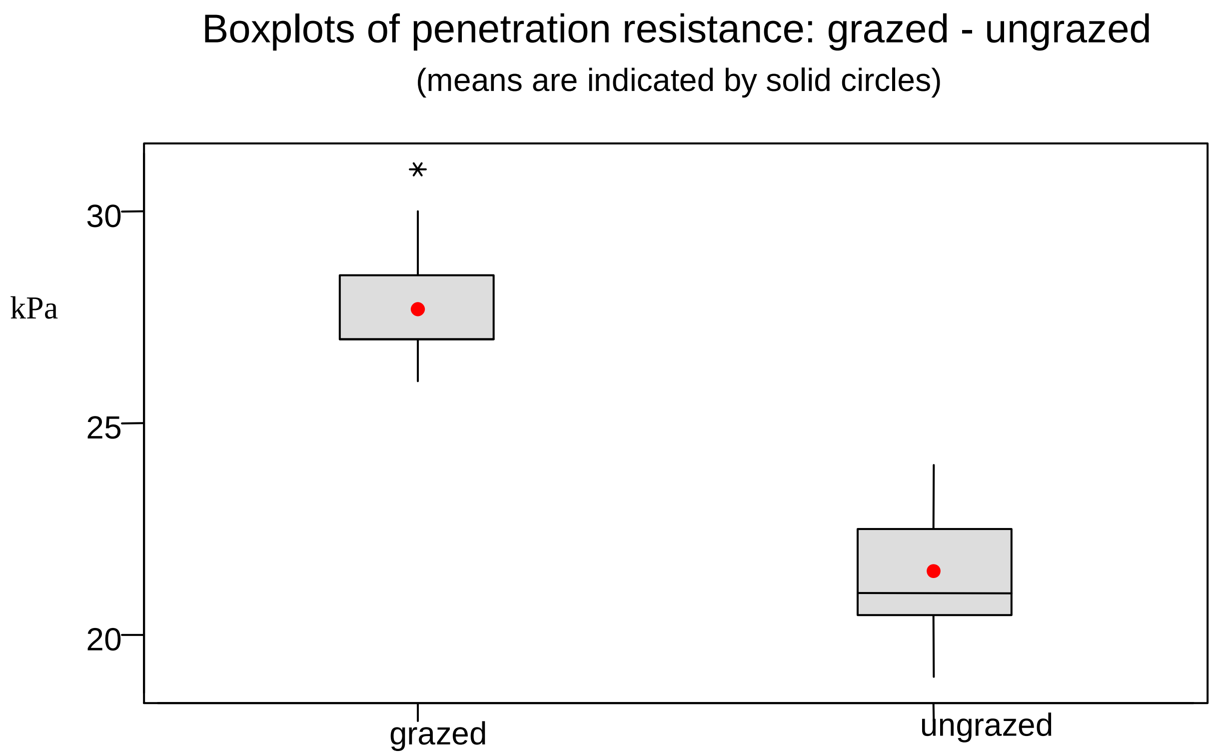
(means are indicated by solid circles)



Analysis of Variance

Source	DF	SS	MS	F	P
Factor	1	246.15	246.15	109.40	0.000
Error	24	54.00	2.25		
Total	25	300.15			

```
                           Individual 95% CIs For Mean
                           Based on Pooled StDev
Level       N     Mean     StDev  --------+---------+---------+--------
grazed     13    27.692    1.494                      (---*--)
ungrazed   13    21.538    1.506   (--*---)
                                  --------+---------+---------+--------
Pooled StDev =    1.500               22.5      25.0      27.5
```


Boxplots of penetration resistance: grazed - ungrazed
(means are indicated by solid circles)
kPa
30
25
20
grazed
ungrazed

2.0 RAINFALL

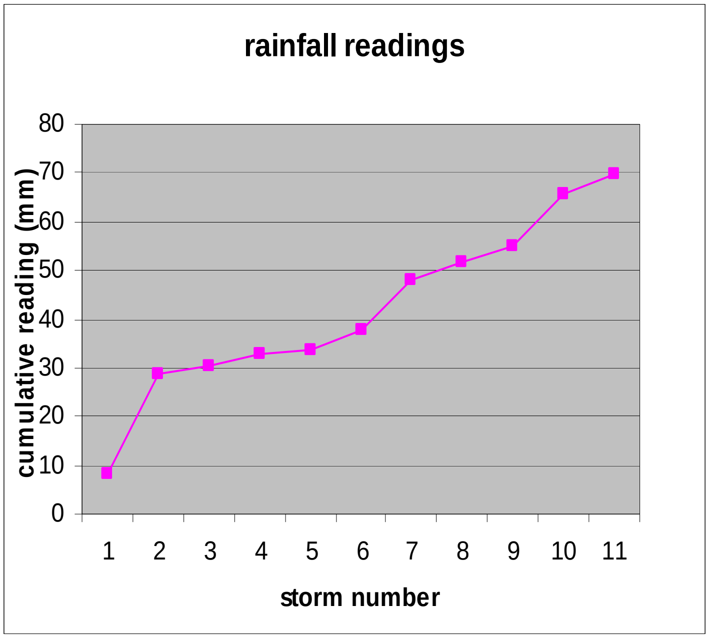


Fig 4. Cumulative rainfall measured during the study period.