# BINDURA UNIVERSITY OF SCIENCE EDUCATION

## DEPARTMENT OF CROP SCIENCE


**MAIKA KUNDAI CHITURA**

**B212853B**


# Assessing the Relationship Between Soil pH and the Prevalence of Aflatoxins in Groundnuts Production: Implications for Reducing Aflatoxin Contamination and Improving Food Safety.

***A DISSERTATION SUBMITTED IN PARTIAL FULFILMENT OF THE REQUIREMENTS OF THE BACHELOR OF SCIENCE HONOURS DEGREE IN***

***AGRICULTURE***

***(CROP SCIENCE)***

# DEDICATION

This work is devoted to my beloved grandmother, whose unwavering dedication to groundnut farming inspired me deeply. Her hard work and passion for agriculture instilled in me a deep appreciation for the land and its bounty. Though she is no longer with us, her spirit and teachings continue to guide my academic journey.

## CERTIFICATION OF THE DISSERTATION

Bindura University of Science Education

Department of Crop Science

The undersigned certify that they have read and recommend to the Bindura University to accept this dissertation on:

**Assessing the Relationship Between Soil pH and the Prevalence of Aflatoxins in Groundnuts Production: Implications for Reducing Aflatoxin Contamination and Improving Food Safety.**

Submitted by

**Chitura Maika K.**

In partial fulfilment of the requirements of the Bachelor of Agricultural Science Honours Degree in Crop Science.

SUPERVISOR.................................................................................

DATE ................................................................................

## DECLARATION

I, MAIKA KUNDAI CHITURA, registration number B212853B do hereby affirm that this dissertation is a product of my efforts and investigations. I declare that such work has never been presented for any degree or university. I have acknowledged all the supplementary sources of information by means of references.

Signature of student                    Date 30/06/2023

# ACKNOWLEDGEMENTS

At first I want to give my obeisance to the ALMIGHTY, for I feel fortunate to be counted among HIS CREATION, which makes me very appreciative for HIS GUIDANCE throughout my research journey. I express my deep appreciation and heartfelt thanks to my supervisor, Professors Mandumbu who oversaw my project and expressed an interest in my academic growth and providing guidance, mentorship as well as support throughout the study. Im also pleased to convey my deep sense of regard and appreciation for his guidance, as well as Dr Mutsengi the faculty Chairman and Ms Kamota for continuing to inspire and assist me throughout my academic journey. Immense thanks are also due to the Chimuka Farm Management team for offered me permission to do this project at their farm, their heartfelt help is greatly appreciated.

With pride, I am profoundly indebted to my family, particularly my aunties, Mariah and Martha, who gave me unwavering support throughout my academic journey. I would also like to acknowledge with love and affection my friends, Trevor, Robin and Derick for their help and support during my academic period.

I also transcribe my genuine appreciation to everyone who assisted me in whatever way that has brought this work in this present form.

Finally, I want thank me for believing in myself, for doing all this hard work, for never quitting and doing more right than wrong.

# ABSTRACT

The contamination of groundnuts by Aflatoxin compromises the quality of groundnut kernels, particularly in regions where soil conditions favor Aspergillus sp. growth. Therefore, the core aim of this project was to find the relationship between soil potential hydrogen and aflatoxin prevalence in groundnut production, with implications for food safety and agricultural practices. The objectives were to determine how soil pH influences aflatoxin contamination, compare susceptibility between two groundnut varieties (Red Natal and Natal Common) and lastly, recommend mitigation strategies. Randomized Complete Block Design (RCBD) and factorial design was used to lay treatments. This work was done in the summer season of 2024 to 2025 at Chimuka Farm in Manicaland, Makoni district. The field experiment was conducted using soil pH levels ranging from 4.0 (strongly acidic) to 7.0 (neutral). Each variety was planted in all the 3 plots with different pH, separately and the treatments were replicated three times making them 18 in total. Groundnut plants were cultivated on an open field, and aflatoxin levels were quantified in percentage infestation per plant using visual method. Statistical analysis confirmed a highly significant relationship between soil pH and aflatoxin contamination ($p < 0.001$) ($R^2$=0.9969). Results showed that acidic soils (pH 4.0–5.0) had the highest aflatoxin levels, while soils close to neutral that is pH 6.0 to 7.0 exhibited significantly lower contamination. Between varieties, Natal Common did not show a statistical difference to aflatoxin accumulation compared to Red Natal, showing that genetic factors might not influence fungal susceptibility. The study concludes that soil pH management, particularly liming acidic soils to pH ≥ 6.0, can effectively suppress aflatoxin contamination. Recommendations include promoting liming practices and integrating soil health into national aflatoxin control policies. Future research should explore long-term pH effects and economic feasibility for smallholder farmers.

***Keywords:*** *aflatoxin, groundnuts, soil pH, food safety, Aspergillus sp.*

# TABLE OF CONTENTS

DEDICATION ........ i
CERTIFICATION OF THE DISSERTATION ........ ii
DECLARATION ........ iii
ACKNOWLEDGEMENTS ........ iv
ABSTRACT ........ v
TABLE OF CONTENTS ........ vi
APENDICES LIST ........ viii
LIST OF FIGURES ........ ix
CHAPTER ONE ........ 1
INTRODUCTION ........ 1
1.2 Problem Statement: ........ 2
1.3 Justification ........ 2
1.4 Objectives ........ 3
1.4.1 Main objective: ........ 3
1.4.2 Specific objectives: ........ 3
1.5 Hypothesis ........ 3
CHAPTER TWO ........ 4
2. LITERATURE REVIEW ........ 4
2.1 Introduction ........ 4
2.2 Groundnut Production and Aflatoxin Contamination ........ 4
2.3 Effect of aflatoxins on Groundnuts growth and development ........ 5
2.4 Aflatoxins and Their Healthy Impact ........ 5
2.5 Aflatoxin-Producing Fungi. ........ 6
2.6 Visual Signs of Aflatoxin Contamination ........ 6
2.7 Soil pH and Microbial Activity ........ 7
2.8 Soil pH Management as a Mitigation Strategy ........ 7
2.9 Conclusion ........ 8
CHAPTER THREE ........ 9
3. METHODOLOGY. ........ 9
3.1 Area of Study ........ 9
3.2 Experimental Design ........ 9

3.3 Materials and Methods ........ 10
3.4 Groundnut Sampling and Aflatoxin Analysis ........ 11
3.5 Final Yield Measurement ........ 11
3.6 Data Analysis. ........ 11
3.7 Ethical Considerations ........ 11
3.9 Limitations ........ 12
3.10 Achievement of Objectives ........ 12
3.11 Data analysis and presentation ........ 12
3.12 Conclusion ........ 13
CHAPTER FOUR ........ 14
4.1 Effects of soil pH on the occurrence of aflatoxin in groundnuts. ........ 14
4.2 Effects of soil pH on final yield (kg/ha) of groundnuts varieties Natal Common and Red Natal. . 15
4.3 Effects of soil pH and groundnut variety on the number of pods per plant in groundnuts. ........ 16
CHAPTER FIVE ........ 17
5. DISCUSSION OF RESULTS. ........ 17
5.1 Effects of soil pH on the occurrence of aflatoxin across different groundnut varieties ........ 17
5.2 Effects of soil pH and groundnut variety on the final yield of groundnuts. ........ 19
5.3 Effects of soil pH and groundnut variety on the number of pods per plant in groundnuts. ........ 21
CHAPTER SIX ........ 22
6. CONCLUSION & RECOMMENDATION ........ 22
6.1 CONCLUSIONS ........ 22
REFERENCES ........ 23
APPENDICES: ........ 26

# APENDICES LIST

**APPENDIX 1** ........................................ 26
**APPENDIX 2** ........................................ 28
**APPENDIX 3** ........................................ 30

# LIST OF FIGURES

FIGURE 4 1 EFFECTS OF SOIL PH ON THE OCCURRENCE OF AFLATOXIN IN GROUNDNUTS 14
FIGURE 4 2 EFFECTS OF SOIL PH AND GROUNDNUT VARIETY ON THE FINAL YIELD (KG/HA) OF GROUNDNUTS 15
FIGURE 4 3 EFFECTS OF SOIL PH ON THE AVERAGE NUMBER OF PODS PER PLANT IN GROUNDNUTS. 16

# CHAPTER ONE

## INTRODUCTION

*Arachis hypogaea* is a scientific name for a crop regularly known as groundnuts a commonly grown leguminous crop (Janila and Mula, 2015). It is an important crop for food security and economic stability in a number of countries in the world, mostly in the Africa and Asia. Their ironic in nutrients like oil, protein, and some essential nutrients makes them an important component of diets (FAO, 2017).

However, groundnuts are vulnerable to aflatoxin which is a secondary metabolite. Arachis hypogaea is highly susceptible to aflatoxin infection because of their soil contact during growth and development, making them a critical focus for food safety research (Wild and Gong, 2010).

The occurrence of aflatoxin in groundnuts gives a significant challenge to their safe consumption as well as trade. Current measure to mitigate aflatoxin have been promoted by the Ministry of Agriculture which include improved agricultural practices (Bandyopadhyay et al., 2016). Despite these efforts, aflatoxin contamination remains a persistent problem, highlighting the need for a deeper understanding of the environmental factors that contribute to Aspegillus survival.

The fungi Aspergillus flavus and Aspegillus parasiticus are responsible the production of this metabolite. The IARC (2012) classify these toxins as some of the most potent carcinogens known to humans. Aflatoxin-producing fungi favors specific environmental conditions such as high temperatures, high humidity, and poor soil health. Soil pH is as a possible cause of the occurrence of Aspergillus species in the soils (Horn and Dorner, 1999).

There is no much evidence on the specific relationship between soil pH and the prevalence of Aspegillus in groundnut production. By understanding this knowledge gap, it will be possible to have strategies that reduce aflatoxin contamination thereby improving food safety. Therefore, the determination of this project is to assess the correlation concerning soil pH and the prevalence of aflatoxin-producing fungi in groundnut production, with the aim of providing evidence-based recommendations for reducing aflatoxin contamination.

## 1.2 Problem Statement:

Aflatoxins are toxic carcinogenic compounds which contaminate groundnuts. It is not known how soil pH affects the prevalence of Aflatoxin under field conditions. The relationship between soil pH and the prevalence of aflatoxin-producing fungi in groundnut production systems remains poorly understood. This limits the ability of farmers to implement effective strategies for reducing aflatoxin contamination in their crops. By effectively addressing this problem, farmer will know the pH level that reducing aflatoxin in their crop and also promote the growing of groundnut.

## 1.3 Justification

Despite the well-documented literatures on the impact of environmental factors like temperature and humidity on aflatoxin, how soil pH affects aflatoxin contamination in groundnuts production remains understudied. Soil pH influences microbial activity, nutrient availability, and fungal growth, yet there is limited empirical evidence on its relationship with aflatoxin contamination in groundnuts (Horn and Dorner, 1999; Bhatnagar-Mathur et al., 2015). By clearly addressing this knowledge gap there would be a reduction in aflatoxin contamination in groundnuts. Soil pH management, such as liming acidic soils, offers a potential solution that is accessible to smallholder farmers and aligns with national efforts to improve food safety and public health.

## 1.4 Objectives.

### 1.4.1 Main objective:

To assess if there is a relationship between soil pH and the prevalence of aflatoxins in groundnut production and its purpose for reducing aflatoxin contamination and improving food safety.

### 1.4.2 Specific objectives:

i. To calculate the percentage infestation of aflatoxin causing fungi on groundnuts by inspecting harvested kernels and pods for signs of fungal contamination.
ii. To determine the relationship between soil pH and the final yield (kg/ha) of Natal common and Red Natal.
iii. To assess the average number of pods produced per each groundnut plant grown under different soil pH across both varieties.

## 1.5 Hypothesis

i. There is no difference in aflatoxin presence for groundnuts plants grown in different soil pH conditions
ii. There is no significant difference on final yield (kg/ha) of groundnuts varieties (Natal common and Red Natal) grown under different soil pH conditions
**iii.** Different soil pH does not significantly affect the average total number of pods per plant.

# CHAPTER TWO

## 2. LITERATURE REVIEW

### 2.1 Introduction

The secondary metabolites, Aflatoxin is formed primarily by a fungi called Aspergillus flavus and Aspergillus parasiticus (Kumar et al., 2021; Caceres et al., 2020). They pose health problems due to their carcinogenic property and they include like to immunosuppressive, hepatotoxic, carcinogenic, mutagenic, and teratogenic (Bishnu et al., 2022). Groundnuts vulnerable to aflatoxin contamination due to their soil contact during growth and development (Matumba et al., 2017a), making them a critical focus for research and intervention. This chapter will look at what different literatures suggest on the relationship between soil pH and occurring of aflatoxin in groundnut production.

### 2.2 Groundnut Production and Aflatoxin Contamination

The legume groundnut is vulnerable to the attack by Aspergillus flavus and Aspergillus parasiticus, causing aflatoxin production (Williams et al., 2004). The richness of groundnuts in healthy fats, proteins and essential nutrients makes them an important component of diets in resource-limited settings making them important for food security and contributing to the gross domestic product of a country (FAO, 2017).

The highly vulnerability of groundnuts to aflatoxin contamination is due to its high nutritional content of that makes them the ideal food for fungus promoting its growth and likely aflatoxin contamination occurs (Mupunga et al., 2017). The other factor that aid to the vulnerability of groundnuts to aflatoxin contamination is their contact with the soil during growth and development. This risk of contamination is also worsened by poor agricultural practices, inadequate storage conditions, and limited access to aflatoxin detection and mitigation technologies (Bishnu et al., 2022).

Current strategies for mitigating aflatoxin contamination in groundnuts include improved agricultural practices, post-harvest management, and the use of biocontrol agents. For example, the Aspegillus flavus atoxigenic stains can be applied and it has been shown to competitively fight strains of this fungi and reduces aflatoxin levels in crops (Bandyopadhyay et al., 2016). However, these strategies are often limited by cost, accessibility, and the complexity of implementation, particularly for smallholder farmers. This result in the rising demand in exploring alternative approaches, such as soil health management, to reduce aflatoxin contamination.

## 2.3 Effect of aflatoxins on Groundnuts growth and development

Aflatoxins are dangerous to groundnut, they damage the cells of a host plant thereby leading to impairing plant's physiological processes such as photosynthesis, respiration and nutrient transportation (Dorner, 2008). The Aflatoxin Producing fungi, Aspegillus species, are parasitic because they compete with the plant for nutrients and water (Hell et al., 2008). This will lead the affected groundnuts plants to produce fewer pods, and the pods that are formed will be smaller or malformed and this reduces the final pod yield. And studies have also shown that aflatoxin contamination in groundnuts has a probability of reducing groundnuts yield by up to 30–50% (Waliyar et al., 2015, Craufurd et al., 2006). Also, infected groundnuts have shriveled, discolored, or smallsized kennels and they have a low market value. The contamination of groundnuts by aflatoxins in the field makes it susceptibility to further contamination during storage (Turner et al., 2005). Furthermore, aflatoxin contamination reduces the nutritional quality of groundnuts by taking the nutrients like proteins, fats, and vitamins that are in the kennels, making them less nutritional (Shephard, 2008).

## 2.4 Aflatoxins and Their Healthy Impact

Aflatoxins are toxic carcinogens that belongs under the category of mycotoxins. The major types of aflatoxins are $B_1$, $B_2$, $G_1$, and $G_2$., with aflatoxin B1 being the predominant and powerful one (IARC, 2012). The fungal species, A. flavus and A. parasiticus, thrive in warm and tropical environments and these are the two fungus responsible for the production of aflatoxin. The prevalence of Aflatoxins is a global concern especially in developing countries where food safety regulations and monitoring systems are often inadequate (Wild and Gong, 2010).

The health implications of aflatoxin exposure are severe. Consumption of aflatoxin-contaminated food causes liver cancer, suppression of immune as well as stunted growth in children amongst other adverse health outcomes (Williams et al., 2004). Besides health risks, the prevalence of aflatoxin has significant economic disadvantages. Contaminated crops are often rejected by international markets, leading to trade restrictions and financial losses for farmers and exporters (Wu and Khlangwiset, 2010). Groundnuts, a major cash crop in many developing countries, are particularly vulnerable to these trade restrictions due to their high susceptibility to aflatoxin contamination.

### 2.5 Aflatoxin-Producing Fungi.

The species Aspergillus flavus and Aspergillus parasiticus remain the two fungi that mainly produce aflatoxins. These fungi that produce aflatoxin occur in soil and they can contaminate groundnuts both before and after harvest. Various environmental factors like, temperature, humidity, and soil conditions influences the growth and production of these aflatoxin-producing fungi (Horn and Dorner, 1999). For example, high temperatures range of 25–35°C and high humidity over 85% create favourable conditions for Aspegillus sp. growth and aflatoxin formation (Bhatnagar-Mathur et al., 2015).

Recent studies have shown that Aspergillus species thrive in acidic environments while alkaline one may suppress fungal activity (Bhatnagar-Mathur et al., 2015).

### 2.6 Visual Signs of Aflatoxin Contamination

Horn (2005) mentioned that the key visual sign that is shown by groundnuts contaminated with aflatoxin is the presence of fungal growth on pods and kernels. When Aspergillus s.p colonize groundnuts under favorable conditions and causes a powdery, yellow-green or gray-black mold on the pod (Horn, 2005). The formed mold appears in patches and is accompanied by a musty odor, signaling active fungal proliferation.

Another key indicator that shows infestation in discoloration of kernels. Infected kernels develop brown, black, or olive-green stains, which contrast sharply with the creamy-white or pinkish hue of healthy groundnuts (Waliyar et al., 2015). If the kernnels are serverely affected, the causes a radial sunburst pattern of fissures and mold growth on the kennels and these reflect the spread of hyphae through the kernel (Udoh et al., 2000).

Moreover, the pods and kennels will have physical deformities further showing contamination. Aflatoxin-infected groundnuts kennels are also sometimes shriveled, undersized, or misshapen due to nutrient depletion by the fungus Aspergillus (Dowell et al., 2002). When split open, the contaminated kernels may reveal hollow cotyledons or internal discoloration, transitioning from healthy white to yellowish or brown hues (Turner et al., 2005). These symptoms are often linked to compromised seed viability and reduced germination rates, indirectly hinting at mycotoxin presence. For farmers, harvest-time visual inspection remains a first-line defense. The Food and Agriculture Organization (FAO) recommends discarding pods with visible mold, discoloration, or shriveling to reduce contamination risks (FAO, 2013). Training programs in sub-Saharan Africa have demonstrated that farmers taught to recognize these symptoms reduce aflatoxin exposure by 30–50% (Hell et al., 2008). Nevertheless, challenges persist. Observer subjectivity in scoring symptoms and the lack of standardized visual grading systems can lead to inconsistent results (Torres et al., 2014).

### 2.7 Soil pH and Microbial Activity

Soil pH is a key factor of microbial activity in agricultural soils. It affects the availability of nutrients, the activities of enzymes and the microbial interactions between different microorganisms (Fierer and Jackson, 2006). For example, acidic soils favor fungal activities while alkaline soils do not favor it but rather tend favor bacterial life. Several studies like Horn and Dorner (1999) have studied the relationship between soil pH and the prevalence of Aspergillus species. For instance, found that acidic soils in the southeastern United States were encouraging the growth of the Aspegillus sp leading to the aflatoxin contamination. Similarly, the work of Bhatnagar-Mathur et al. (2015) stated how soil pH significantly influenced the colonization of Aspergillus species in groundnut fields, with lower pH levels associated with higher fungal prevalence. These findings suggest that soil pH management could be a potential strategy for reducing aflatoxin contamination in groundnuts.

### 2.8 Soil pH Management as a Mitigation Strategy

Soil health management, including the regulation of soil pH, has emerged as a potential strategy for reducing aflatoxin contamination in groundnuts. By optimizing soil conditions, farmers may be able to create an environment that is less conducive to the growth of aflatoxin-producing fungi. For example, liming acidic soils to raise pH levels has been shown to suppress fungal activity and reduce aflatoxin occurrence in some plants (Bhatnagar-Mathur et al., 2015). However, effective soil pH management as a mitigation strategy depends on various factors, including soil type, crop variety, and local environmental conditions.

Despite the potential benefits of soil pH management, there is limited empirical evidence on its effectiveness in reducing aflatoxin contamination in groundnuts. Most studies have focused on other crops, such as maize, or have been conducted under controlled laboratory conditions rather than in field settings. This highlights the need for further research to evaluate the relationship between soil pH and the prevalence of aflatoxin in groundnut as well as developing targeted interventions that can be implemented by farmers.

## 2.9 Conclusion

The relationship between soil pH and the prevalence of aflatoxin-producing fungi in groundnut production is a critical concern of this research study. Current studies have shown that soil pH has an effect on the growth aflatoxin producing fungi, but there is a need for more comprehensive research to get a deep understanding on this this relationship in relation to groundnut production. By clearly addressing this knowledge gap, this research aims to give evidence-based advice to farmers on how to reducing aflatoxin contamination and improving food safety in groundnuts production.

# CHAPTER THREE

## 3. METHODOLOGY.

### 3.1 Area of Study.

This work was done under field conditions at Chimuka Farm near Nyazura Growth point in Makoni District, Zimbabwe. The Farm is located at coordinates -18.670163, 32.1712950 in Manicaland Province. The research site is characterized with sandy soil with a pH range from 4.0 to 4.5, which is considered strongly acidic on the Calcium Chloride scale. The area is within Agro-ecological Region III in Zimbabwe, which has an average rainfall of 800-1000 millimeters per annum (Soil Survey Branch, 2002). It was carried out using rain-fed irrigation and the season ran from December 2024 until April 2025.

### 3.2 Experimental Design

The experiment was conducted using a Factorial Randomized Complete Block Design (RCBD). There were two factors that were under study and these were groundnut variety and soil pH level. Two groundnut variety were used these are Natal Common (V1) and Red Natal (V2) and they were grown in 3 different soil and they were tagged pH P1, P2 and P3. Each variety was planted in all the 3 plots according to pH, separately and the treatments were replicated three times, totaling 18 experimental units and this helped to ensure there is reliability and accuracy in the results. Soil pH treatments were established as P1 with a pH level of 4.0-5.0, P2 with pH 5.0-6.0 and P3 with 6.0-7.0. Each replicate consisted of 30 plant per plot.
This design allowed for the evaluation of the effects of soil pH on aflatoxin contamination, fungal prevalence, and groundnut yield.

#### 3.2.1 Experimental Layout

Each plot measured $6m^2$ and had 30 groundnuts plants. The length of the plot was 3m and width 2m. The inter-row space was 30 cm with an in-row space of 20 cm. A total of 18 plots were made, each plot with different pH was replicated 3 times.

## 3.3 Materials and Methods

A pH meter was used to measure soil pH, calibrated with standard buffer solutions. The soil-water suspension was prepared in a 1:2.5 ratio for accurate pH measurement. Soil samples were collected from the root zones of groundnut plants on 0–20 cm deep before planting the seeds. At each plot 6 soil samples were collected and mixed to form a composite sample. Soil pH was measured using a pH meter calibrated with standard buffer solutions. The soil-water suspension was prepared in a 1:2.5 ratio for accurate pH measurement. The pH levels were recorded and adjusted into three groups which are strongly acidic moderately acidic and neutral that is pH 4.0-5.0, 5.0-6.0, 6.0–7.0 respectively. Lime ($CaCO_3$) was used to adjust the soil pH of each plot to the desired range.

### 3.3.1 PH adjustments

Lime requirements was calculated based on initial soil pH of 4.5. For the first plot (P1) no lime was added because the pH was already between this range, adjustments were only done for to get 5.0-6.0 (P2) and 6.0-7.0 (P3). To get the lime requirement for P2 the following Adams-Evans buffer method was used :

Lime Requirement (kg $CaCO_3$/ha) = (Target pH - Initial pH) × CEC × 1.5

*Whereas for P2 was*

Target pH is 5.5

Initial pH is 4.5

8×1.5 = 1,200 kg $CaCO_3$/ha (120g/m²)

Calculations

(5.5-4.5)×8×1.5 =

1,200 kg of lime ($CaCO_3$) per ha

Giving 120g/m², therefore, for 6m2 the lime requirement was 720g

*Calculation for P3 is*

Target pH is 6.5

Initial pH is 4.5

(6.5-4.5)×8×1.5

2,400 kg $CaCO_3$/ha that is 240g/m²

Per plot of $6m^2$, 1,440g $CaCO_3$ was use.
Liquid lime ($Ca(OH)_2$) was applied at 80% of these values (576g and 1,152g per plot respectively) due to higher reactivity.

### 3.4 Groundnut Sampling and Aflatoxin Analysis

The groundnuts plants were harvested at maturity and from each plot, 5 groundnut plants were randomly selected from every plot and taken for sampling according to the objectives to ensure statistical reliability. Mature groundnut pods were plucked off from the plants and visually inspected for signs of fungal contamination, such as discoloration, mold growth, or shriveling. The number of infected and healthy pods per plant was recorded.

### 3.5 Final Yield Measurement

The final yield of groundnuts was determined by harvesting 5 groundnuts plants from all the 18 plot at maturity. Pods were cleaned to remove soil debris and then dried and weight was measured by a digital scale to get average pod yield per plot. Yield data were recorded in kilograms per hectare (kg/ha) for comparison across different soil pH levels. This allowed for the assessment of the final yield of groundnuts grown under varying soil pH conditions.
The number of pods produced by each plant was also counted and quantified to determine whether plants grown under different pH have different number of pod yield.

### 3.6 Data Analysis.

The model used for analyzing the results is $Yijk = \mu+Bi+\tau j+\gamma k+\epsilon ijk$ or being substituted it become $Yijk = \mu+Blocki+pHj+Varietyk+(pH\times Variety)jk+\epsilon ijk$
Descriptive statistics was used to analyze data as well as summarizing soil pH, aflatoxin contamination levels, and pod yield. Two way analysis was conducted using ANOVA to evaluate differences in pod yield, kernel production, and aflatoxin levels across different soil pH categories.

### 3.7 Ethical Considerations

Permission was obtained from the farm management before conducting the study. All data collected were treated with confidentiality, and no personal information was disclosed without consent. The research results were relayed to the farm management to help improve groundnut production and food safety.

### 3.9 Limitations

The study was limited to The Chimuka Farm, and the results may not be generalized to all groundnut-producing areas. Climatic variations during the study period may have influenced fungal prevalence and pod yield. There was no use of laboratory methods to determine Aflatoxin contamination.

### 3.10 Achievement of Objectives

The objectives that were being studied had different ways of attaining them. The first objective which looked on determining the percentage of aflatoxin contamination in groundnuts from plots with varying soil pH levels was achieved by collecting groundnut samples from plots with different soil pH levels after harvest and visually analyze the pods and kennels for any signs of Aflatoxin contamination. Data was recorded in a notebook.

Secondly, the other objective was to assess the final yield of groundnuts grown under different soil pH by determining the pod yield. This objective was achieved by randomly select 5 plants from all the 18 plots, weigh the pods to obtain the final average pod weight for each plot and then average it to to kg/ha.

Lastly, the number of pods produced by each plant from different plots was also counted and quantified to compare whether soil pH has an influence on the number of pod produced by different plant. The pod number was averaged per plant.

### 3.11 Data analysis and presentation

The model used for the results is $Yijk = \mu + Bi + \tau j + \gamma k + \epsilon ijk$ or being substituted it remain like

$Yijk = \mu + Blocki + pHj + Varietyk + (pH \times Variety)jk + \epsilon ijk$

Data analysis was done through organizing collected variables that is percentage aflatoxin infestation and pod yield into tables. The means across soil pH levels among different groundnuts varieties were compared using Analysis of variance (ANOVA) as well as finding significant differences. Results are visualized using graphs and tables.

### 3.12 Conclusion

This methodology is going to provide a systematic approach to investigating the relationship between soil pH, Aflatoxin contamination, fungal prevalence, and groundnut yield. The use of RCBD method together with factorial arrangement ensures reliability and accuracy for results, while the combination of field and theoretical knowledge provided a comprehensive understanding of the study objectives.

# CHAPTER FOUR

**4.1 Effects of soil pH on the occurrence of aflatoxin in groundnuts.**

The interaction effect between variety and pH on the occurrence of aflatoxin was not statistically significant. Also different varieties did not show and significant difference on the occurrence of aflatoxin. However, there was a strong negative relationship between soil pH and the occurrence of aflatoxins in groundnuts ($R^2$=0.9969) (p<001). The percentage infestation of aflatoxin producing fungi decreases as the pH increase (Figure 4.1).

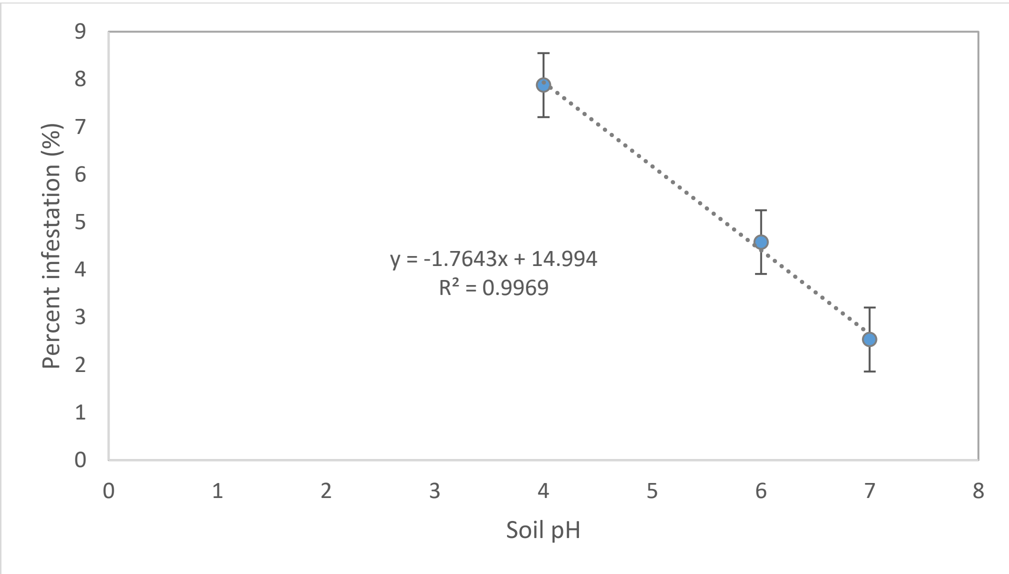


*Figure 4 1 Effects of soil pH on the occurrence of aflatoxin in groundnuts*

### 4.2 Effects of soil pH on final yield (kg/ha) of groundnuts varieties Natal Common and Red Natal.

The pH level of soil showed strong significant effect on the final yield ($p < 0.001$). Soil pH of 4.0 to 5.0 had the lowest yield. The pH of 5.0 to 6.0 had the highest yield whilst the medium yield was got from pH range 6.0 to 7.0. The two variety also showed significant difference on pod yield ($p < 0.001$), as Natal Common outperformed the Red Natal in terms of weight. However, there was no interaction between variety and soil pH ($P=0.978$) on the final yield in terms of kg/ha. These results are shown on figure 4.2 below.

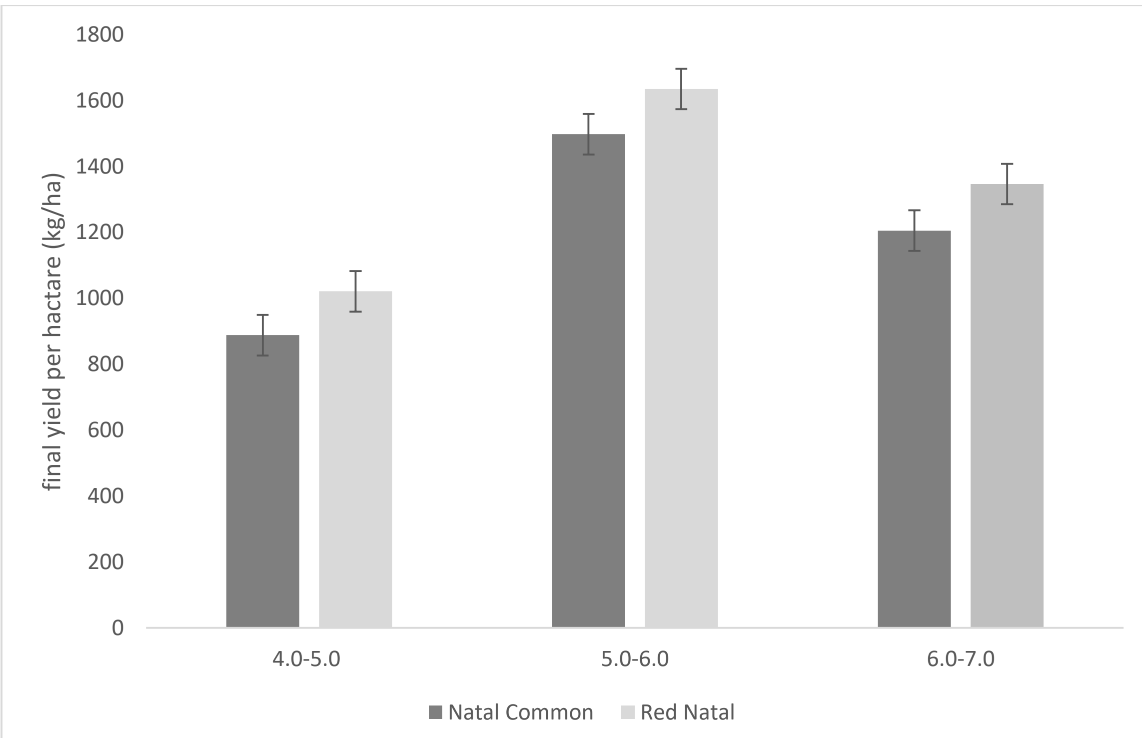


Figure 4 2 Effects of soil pH and groundnut variety on the final yield (kg/ha) of groundnuts

### 4.3 Effects of soil pH and groundnut variety on the number of pods per plant in groundnuts.

The results showed that soil pH and variety did not interact significantly to alter average pod number per plant (P=0.912). However, the results show a significant relationship, where soil pH highly influences the number of pods per plant ($p<0.001$) as shown in Figure 4.3.1. Another significant relationship was also seen between varieties ($p<0.001$) as shown in Figure 4.3.2.

| PH LEVEL | NUMBER OF PODS |
|---|---|
| **4.0-5.0** | 19.17$^{a}$ |
| **5.0-6.0** | 31.33$^{b}$ |
| **6.0-7.0** | 25.50$^{c}$ |
| **P. Value** | **<.001** |
| **CV%** | **3.1** |
| **L.S.D** | **0.996** |

*Figure 4 3 Effects of soil pH on the average number of pods per plant in groundnuts.*

# CHAPTER FIVE

## 5. DISCUSSION OF RESULTS.

### 5.1 Effects of soil pH on the occurrence of aflatoxin across different groundnut varieties

The statistical analysis showed that there was no significant interaction between groundnut varieties and soil pH levels on aflatoxin occurrence, indicating that the relationship between pH and aflatoxin contamination remains consistent across different varieties. This finding is particularly important for agricultural management, as it suggests that pH modification strategies can be implemented without needing variety-specific approaches for aflatoxin control.

Furthermore, the study found no significant difference ($p=0.211$) in aflatoxin occurrence between the tested groundnut varieties. This is difference with some previous studies like Mutegi et al. (2013), who reported varietal differences in aflatoxin susceptibility, and suggests that breeding programs focusing solely on varietal resistance may need to be reevaluated in this context. The lack of varietal effect implies that other factors, particularly environmental and soil conditions, may play more crucial roles in determining aflatoxin risk than genetic differences between these particular varieties.

However, the most striking finding is the exceptionally strong negative relationship between soil pH and the occurrence of aflatoxin producing fungi in groundnuts, demonstrated by an $R^2$ value of 0.9969 ($p<0.001$). This near-perfect correlation indicates that the acidic the soils (pH 4.0 to 5.0) have a higher risk of fungal growth and toxin production especially aflatoxins whilst aflatoxin infestation decreases as soil pH increases. As soil pH increases towards the neutral range (pH 6.0 to 7.0), aflatoxin levels dropped and this was observed in both varieties that are Red Natal and Natal Common groundnut varieties. These results reach agreement with what Hell et al., (2008), who mentioned that neutral soils suppress the growth of Aspergillus flavus whereas acidic soils favor its proliferation. Aspergillus flavus, the fungus responsible for aflatoxin, struggles in neutral conditions but thrive in less acidic environments.

The reduction in aflatoxin contamination with increasing pH can be the reason of different factor. The first one being that high pH soils inhibit fungal growth. Aspergillus species thrive in acidic environments while neutral to alkaline conditions inhibit their growth and toxin production (Jaime-Garcia & Cotty, 2004). Another reason might be the availability of nutrients like calcium and magnesium in higher pH soil. These nutrients have the ability to strengthen pod development and reduces fungal penetration (Dorner & Cole, 2002). Also, there is low microbial interaction in high pH soils as the beneficial soil microbes that suppress A. flavus are more active in neutral soils, creating a biocontrol effect (Bandyopadhyay et al., 2016).

From an agricultural management point of view, the results that were shown reflect that the modifying soil pH could be the most effective strategy for aflatoxin control in groundnut production.

However, the exact optimal pH range would require further investigation because the inverse relationship shows that even increases in pH could significantly reduce the risk of aflatoxin. This would be important as it appears effective across all tested varieties. Also. these results raise important questions for future research, especially in regards to the mechanisms behind pH's protective effect and whether these results hold across different soil types and environmental conditions. Additionally, economic analyses would be valuable to determine the cost-effectiveness of pH modification compared to other aflatoxin control strategies. Nevertheless, these results show a convincing evidence that soil pH management should be a central component of integrated strategies to reduce aflatoxin contamination in groundnuts.

### 5.2 Effects of soil pH and groundnut variety on the final yield of groundnuts.

The results achieved shows that soil pH has a strong and highly significant influence ($p < 0.001$) on pod yield, with a uniform response pattern across the tested pH ranges. Yields were lowest in highly acidic soils at pH 4.0-5.0, and this is supported with already established literature on aluminum toxicity and phosphorus fixation in strongly acidic conditions (Kochian et al., 2015). The low yields in this range might also be a reflection of multiple stress factors caused by low pH and these includes compromised root proliferation and reduced nutrient availability. Optimal yields were noticed in the moderately acidic (pH 5.0-6.0), supported by the findings of Fageria and Baligar's (2008) that this pH range maximizes accessibility of essential elements like molybdenum and phosphorus for legume crops. A sudden decline in yield at pH 6.0–7.0 may be caused by micronutrient deficiencies, particularly manganese and zinc, which become less plant-available at higher pH levels (Alloway, 2008). These results give emphasis to the importance of soil testing and targeted liming programs to optimize pH for legume production.

Varietal differences also significantly affected yield ($p < 0.001$), with Natal Common consistently outperforming Red Natal across all pH levels. This superior performance likely stems from genetic differences in yield potential, possibly related to better resource partitioning or stress tolerance (Okello et al., 2019). Notably, the absence of a significant interaction between variety and soil pH ($p = 0.978$) indicates that Natal Common's advantage is stable regardless of soil acidity. This contrasts with some previous studies, such as Monyo et al. (2012), who reported pH-dependent varietal responses in Tanzanian groundnuts, suggesting that genotype and environment interactions may be context-specific. The better performance of Natal Common simplifies farmer recommendations, as its benefits are maintained across diverse soil conditions.

In conclusion, these results reflect soil pH management as the primary effect for yield improvement. Investments in liming could generate substantial returns, particularly for smallholder farmers working with highly acidic soils. This aligns with economic analyses by Vanlauwe et al. (2015), who stated the cost-effectiveness of integrated soil fertility management in similar agroecosystems. Meanwhile, the varietal results support the adoption of Natal Common as a reliable high-yielding cultivar, though further research should investigate the physiological basis for its superior performance.

Yet, several knowledge gaps remain. Long-term studies are needed to assess whether yield advantages persist over multiple growing seasons, especially under changing climate conditions. Furthermore, investigations into the genetic and physiological mechanisms behind Natal Common's pH tolerance could inform breeding programs, potentially transferring these traits to other varieties.

### 5.3 Effects of soil pH and groundnut variety on the number of pods per plant in groundnuts.

The study revealed that there was no statistical significant interaction between soil pH and variety on pod yield per plant ($p<0.001$), demonstrating that the effect of soil pH on pod production remains consistent across both tested varieties, and conversely, the performance difference between varieties is maintained regardless of soil pH levels.

However, soil pH emerged as a strong statistically significant factor ($p<0.001$) affecting the number of pods produced by each plant. This demonstrates the crucial role of soil pH in plant reproductive development. In acidic conditions (pH <5.0), aluminum toxicity may impair root function and reduce nutrient uptake, while in optimal pH ranges (5.0-6.0), improved availability of phosphorus and micronutrients probably enhances flower formation and pod retention. These results are supported with established agronomic principles showing that soil pH strongly influences nutrient solubility and microbial activity in the rhizosphere (Kochian et al., 2015). The clear response curve visible in Figure 4.3.1 suggests that even modest pH adjustments could substantially improve pod production, particularly in soils with extreme acidity.

Varietal differences also showed highly significant ($p<0.001$), with one variety consistently outperforming the other in pod production across all pH levels, as depicted in Figure 4.3.2. This consistent performance pattern, unaffected by pH variation, suggests that the superior variety possesses inherent genetic advantages in pod formation that are expressed independently of soil conditions. Such traits might include better flower fertility, more efficient photosynthate partitioning to reproductive structures, or improved stress tolerance during critical flowering periods (Okello et al., 2019). The stability of this varietal advantage simplifies breeding and recommendation strategies, as the superior variety can be promoted for widespread use without need for pH-specific adaptation.

In conclusion, the a two-pronged approach to improving groundnut production could be adopted. Firstly, correcting soil pH to optimal levels, around 5.0-6.0 based on the response curve can help create favorable growing conditions for the plant. Secondly, adopting higher performing groundnuts varieties can be done to capitalize on its genetic potential.

# CHAPTER SIX

## 6. CONCLUSION & RECOMMENDATION

### 6.1 CONCLUSIONS

A clear evidence was obtained through this study that soil pH significantly influences aflatoxin contamination in groundnut production, with higher pH levels (neutral) demonstrating a suppressive effect on Aspergillus flavus growth and toxin production. The highly statistical significant relationship between soil pH and aflatoxin prevalence confirms that acidic soils create favorable conditions for fungal infestation, while soils with pH levels above 6.0 reduce contamination risks. Between the two varieties studied, there was no significant difference in as far as exhibition of susceptibility to aflatoxin accumulation is concerned, suggesting that genetic factors might not have an important duty in resistance mechanisms.

The findings contribute to the existing body of knowledge by establishing a direct link between soil pH management and food safety in groundnut production. This research confirms that modifying soil pH can be an effective, low-cost strategy for mitigating aflatoxin risks, particularly in smallholder farming systems where chemical controls may be inaccessible. The study also highlights the less importance of varietal selection, as genotypes has showed not to inherently resist fungal infection better than others.

### 6.2 RECOMMENDATION

To reduce aflatoxin contamination in groundnuts, farmers may apply lime to acidic soils (pH $<6.0$) to raise pH to 6.0-7.0. Agricultural extension services should promote soil testing and provide lime application guidelines.

Governments might also support these efforts through policies promoting soil testing, subsidizing lime, and monitoring aflatoxin levels. It might be also important to do public awareness campaigns educating stakeholders about aflatoxin risks.

# REFERENCES

Alloway, B.J. (2008). Micronutrient deficiencies in global crop production. Springer.

Bandyopadhyay, R., Ortega-Beltran, A., Akande, A., Mutegi, C., Atehnkeng, J., Kaptoge, L., Senghor, A.L., Adhikari, B.N. and Cotty, P.J., 2016. Biological control of aflatoxins in Africa: current status and potential challenges in the face of climate change. World Mycotoxin Journal, 9(5).

Bhatnagar-Mathur, P., Sunkara, S., Bhatnagar-Panwar, M., Waliyar, F. and Sharma, K.K., 2015. Biotechnological advances for combating Aspergillus flavus and aflatoxin contamination in crops. Plant Science, 234, pp.119-132.

Bishnu, P., De, P., Hayat, A., Roy, D., Das, S., & Mahato, M. K., 2022. Modern approaches in aflatoxin free groundnut production. In R. K. Naresh (Ed.), Advances in agriculture sciences (p. 24). AkiNik Publications.

Cáceres, I., Khoury, A.A., Khoury, R.E., Atoui, A., Verheecke-Vaessen, C., Medina, Á. and Magan, N. (2020) 'Impact of climate change factors on growth and aflatoxin $B_1$ production by Aspergillus flavus on peanuts', Journal of Applied Microbiology, 128(1), pp. 171-181. https://doi.org/10.1111/jam.14456

Craufurd, P.Q., Prasad, P.V.V., Waliyar, F. and Taheri, A. (2006) 'Drought, pod yield, pre-harvest Aspergillus infection and aflatoxin contamination on peanut in Niger', Field Crops Research, 98(1-3), pp. 20-29. https://doi.org/10.1016/j.fcr.2005.12.004

Dorner J.W., Cole R.J., Sanders T.H., Blankenship P.D. 1989. Interrelationship of kernel water activity, soil temperature, maturity, and phytoalexin production in preharvest aflatoxin contamination of drought-stressed peanuts. Mycopathologia, 105:117-128.

Dorner, J.W. (2018) 'Management and prevention of mycotoxins in peanuts', Food Additives & Contaminants: Part A, 35(9), pp. 1712-1721. https://doi.org/10.1080/19440049.2018.1492876

FAO, 2017. The future of food and agriculture: Trends and challenges. Food and Agriculture Organization of the United Nations, Rome.

Fierer, N. and Jackson, R.B., 2006. The diversity and biogeography of soil bacterial communities. Proceedings of the National Academy of Sciences, 103(3).

Fageria, N.K., & Baligar, V.C. (2008). Ameliorating soil acidity of tropical Oxisols by liming for sustainable crop production. Advances in Agronomy, 99, 345–399.

Hell, K., Mutegi, C. and Bandyopadhyay, R. (2008) 'Aflatoxin control and prevention strategies in maize for sub-Saharan Africa', African Journal of Biotechnology, 7(25).

Hell, K., K. F. Cardwell, M. Setamou, H. M. Poehling, and C. Mutegi. 2011. "Review: Aflatoxin Control and Prevention Strategies in Kenya Crops of Sub-Sahara Africa." African Journal of Microbiology Research 5.

Horn, B.W. and Dorner, J.W., 1999. Regional differences in production of aflatoxin B1 and cyclopiazonic acid by soil isolates of Aspergillus flavus along a transect within the United States. Applied and Environmental Microbiology.

IARC, 2012. Chemical agents and related occupations: A review of human carcinogens. International Agency for Research on Cancer, Lyon, France.

International Agency for Research on Cancer (IARC) (2008) Some traditional herbal medicines, some mycotoxins, naphthalene and styrene. IARC Monographs on the Evaluation of Carcinogenic Risks to Humans, Volume 82. Lyon: IARC Press.

Janila P, Mula MG (2015. Cultural management practices of groundnut. J. Agric. Sc.

Khan, M.A., Asghar, M.A., Iqbal, Q., Ahmed, A. and Shamsuddin, Z.A. (2006) 'Aflatoxins contamination and prevention in red chillies', Journal of Food Protection, 69(11). https://doi.org/10.4315/0362-028X-69.11.2751

Kochian, L.V., et al. (2015). Plant adaptation to acid soils: The molecular basis for crop aluminum resistance. Annual Review of Plant Biology.

Kumar, A., Pathak, H., Bhadauria, S., & Sudan, J., 2021. Aflatoxin contamination in food crops: Causes, detection, and management: A review. Food Production, Processing and Nutrition https://doi.org/10.1186/s43014-021-00064-y

Matumba, L., Monjerezi, M., Biswick, T., Mwatseteza, J., Makumba, W., Kamangira, D., Mtukuso, A., 2014. A survey of the incidence and level of aflatoxin contamination in a range of locally and imported processed foods on Malawian retail market.

Matumba, L., Singano, L., Pungulani, L., Mvula, N., Matumba, A., Singano, C., & Matita, G., 2017. Aflatoxins, discolouration and insect damage in dried cowpea and pigeon pea in Malawi and the effectiveness of flotation/washing operation in eliminating the aflatoxins.

Monyo, E.S., Njoroge, S.M.C., Coe, R., et al. (2012). Occurrence and distribution of aflatoxin contamination in groundnuts (Arachis hypogaea L) and population density of Aflatoxigenic Aspergilli in Eastern Kenya. https://doi.org/10.1111/j.1365-3059.2011.02543.x

Mutegi, C.K., Hendriks, S.L., Jones, R.B. (2013). Prevalence and factors associated with aflatoxin contamination of peanuts from Western Kenya. International Journal of Food Microbiology, 162(1), 1-9. https://doi.org/10.1016/j.ijfoodmicro.2012.12.015

Mupunga, I., Mngqawa, P., & Katerere, D. R., 2017. Peanuts, aflatoxins and undernutrition in children in Sub-Saharan Africa. Nutrients

Okello, D.K., et al. (2019). Overview of groundnuts research in Uganda: Past, present and future. African Journal of Biotechnology, 18(25)

Shephard, G.S. (2008) 'Risk assessment of aflatoxins in food in Africa', Food Additives & Contaminants: Part A, 25(10) https://doi.org/10.1080/02652030802036222

Turner, P.C., Sylla, A., Gong, Y.Y., Diallo, M.S., Sutcliffe, A.E., Hall, A.J. and Wild, C.P. (2008) 'Reduction in exposure to carcinogenic aflatoxins by postharvest intervention measures in West Africa: a community-based study', The Lancet, 365(9475) https://doi.org/10.1016/S0140-6736(05)66661-5

Vanlauwe, B., et al. (2015). Integrated soil fertility management in sub-Saharan Africa: Unravelling local adaptation.

Waliyar F., Osiru M., Sudini H.K., Njoroge, S. 2013. Aflatoxins: Finding solutions for improved food safety-reducing aflatoxins in groundnuts through integrated management and biocontrol. International Food Policy Research Institute, 2033 K Street, NW, Washington, DC 20006-1002 USA.

Waliyar F.V Osiru M. Ntare B. R. Kumar K. V. K. Sudini H.V Traore A. P Diarra B. 2015. Postharvest management of aflatoxin contamination in groundnut. World Mycotoxin Journal. https://doi.org/10.3920/WMJ2014.1766

Wild, C.P. and Gong, Y.Y., 2010. Mycotoxins and human disease: a largely ignored global health issue. Carcinogenesis

Williams, J.H., Phillips, T.D., Jolly, P.E., Stiles, J.K., Jolly, C.M. and Aggarwal, D., 2004. Human aflatoxicosis in developing countries: a review of toxicology, exposure, potential health consequences, and interventions. The American Journal of Clinical Nutrition

World Health Organization (WHO) and Food and Agriculture Organization (FAO) (2017) Evaluation of certain contaminants in food: eighty-third report of the Joint FAO/WHO Expert Committee on Food Additives. WHO Technical Report Series, No. 1002. Geneva: World Health Organization.

Wu, F. and Khlangwiset, P., 2010. Health economic impacts and cost-effectiveness of aflatoxin-reduction strategies in Africa: case studies in biocontrol and post-harvest interventions. Food Additives & Contaminants.

# APPENDICES:

## Appendix 1

ANALYSIS OF VARIANCE ON AFLATOXIN INFESTATION %

| Source of variation | d.f. | s.s. | m.s. | v.r. | F pr. |
|---|---|---|---|---|---|
| Block stratum | 2 | 9.490 | 4.745 | 3.51 | |
| Block.*Units* stratum | | | | | |
| pH_Level | 2 | 87.430 | 43.715 | 32.29 | <.001 |
| Variety | 1 | 2.420 | 2.420 | 1.79 | 0.211 |
| pH_Level.Variety | 2 | 0.143 | 0.072 | 0.05 | 0.949 |
| Residual | 10 | 13.537 | 1.354 | | |
| Total | 17 | 113.020 | | | |

### Information summary

All terms orthogonal, none aliased.

* MESSAGE: the following units have large residuals.

Block 3 *units* 1 -1.80 s.e. 0.87

### Tables of means

**Variate: Aflatoxin Infestation %**

Grand mean 5.00

| pH_Level | P1 | P2 | P3 |
|---|---|---|---|
| | 7.88 | 4.58 | 2.53 |

| Variety | 1 | 2 |
|---|---|---|
| | 5.37 | 4.63 |

| pH_Level | Variety | 1 | 2 |
|---|---|---|---|
| P1 | | 8.37 | 7.40 |
| P2 | | 4.93 | 4.23 |
| P3 | | 2.80 | 2.27 |

### Standard errors of means

| Table | pH Level | Variety | pH_Level Variety |
|---|---|---|---|
| rep. | 6 | 9 | 3 |
| d.f. | 10 | 10 | 10 |
| e.s.e. | 0.475 | 0.388 | 0.672 |

## Standard errors of differences of means

| Table | pH Level | Variety | pH Level Variety |
|---|---|---|---|
| rep. | 6 | 9 | 3 |
| d.f. | 10 | 10 | 10 |
| s.e.d. | 0.672 | 0.548 | 0.950 |

## Least significant differences of means (5% level)

| Table | pH Level | Variety | pH Level Variety |
|---|---|---|---|
| rep. | 6 | 9 | 3 |
| d.f. | 10 | 10 | 10 |
| l.s.d. | 1.497 | 1.222 | 2.117 |

## Stratum standard errors and coefficients of variation

**Variate: Aflatoxin Infestation %**

| Stratum | d.f. | s.e. | cv% |
|---|---|---|---|
| Block | 2 | 0.889 | 17.8 |
| Block.*Units* | 10 | 1.163 | 23.3 |

# Appendix 2

ANALYSIS OF VARIANCE ON POD YIELD KG PER HA

| Source of variation | d.f. | s.s. | m.s. | v.r. | F pr. |
|---|---|---|---|---|---|
| Block stratum | 2 | 11168. | 5584. | 4.88 | |
| | | | | | |
| Block.*Units* stratum | | | | | |
| pH_Level | 2 | 1122747. | 561374. | 490.84 | <.001 |
| Variety | 1 | 84735. | 84735. | 74.09 | <.001 |
| pH_Level.Variety | 2 | 52. | 26. | 0.02 | 0.978 |
| Residual | 10 | 11437. | 1144. | | |
| | | | | | |
| Total | 17 | 1230140. | | | |

## Information summary

All terms orthogonal, none aliased.

* MESSAGE: the following units have large residuals.

Block 1 *units* 2 -61.1 s.e. 25.2

## Tables of means

**Variate: Pod Yield kg ha**

Grand mean 1265.7

| pH_Level | P1 | P2 | P3 |
|---|---|---|---|
| | 954.8 | 1566.3 | 1276.0 |

| Variety | 1 | 2 |
|---|---|---|
| | 1197.1 | 1334.3 |

| pH_Level | Variety | 1 | 2 |
|---|---|---|---|
| P1 | | 888.3 | 1021.3 |
| P2 | | 1497.7 | 1635.0 |
| P3 | | 1205.3 | 1346.7 |

## Standard errors of means

| Table | pH Level | Variety | pH Level Variety |
|---|---|---|---|
| rep. | 6 | 9 | 3 |
| d.f. | 10 | 10 | 10 |
| e.s.e. | 13.81 | 11.27 | 19.53 |

## Standard errors of differences of means

| **Table** | **pH Level** | **Variety** | **pH Level Variety** |
|---|---|---|---|
| rep. | 6 | 9 | 3 |
| d.f. | 10 | 10 | 10 |
| s.e.d. | 19.53 | 15.94 | 27.61 |

## Least significant differences of means (5% level)

| **Table** | **pH Level** | **Variety** | **pH Level Variety** |
|---|---|---|---|
| rep. | 6 | 9 | 3 |
| d.f. | 10 | 10 | 10 |
| l.s.d. | 43.50 | 35.52 | 61.52 |

## Stratum standard errors and coefficients of variation

**Variate: Pod Yield kg per ha**

| Stratum | d.f. | s.e. | cv% |
|---|---|---|---|
| Block | 2 | 30.51 | 2.4 |
| Block.*Units* | 10 | 33.82 | 2.7 |

# Appendix 3

ANALYSIS OF VARIANCE ON PODS PER PLANT

| Source of variation | d.f. | s.s. | m.s. | v.r. | F pr. |
|---|---|---|---|---|---|
| Block stratum | 2 | 4.0000 | 2.0000 | 3.33 | |
| Block.*Units* stratum | | | | | |
| pH_Level | 2 | 444.3333 | 222.1667 | 370.28 | <.001 |
| Variety | 1 | 37.5556 | 37.5556 | 62.59 | <.001 |
| pH_Level.Variety | 2 | 0.1111 | 0.0556 | 0.09 | 0.912 |
| Residual | 10 | 6.0000 | 0.6000 | | |
| Total | 17 | 492.0000 | | | |

## Information summary

All terms orthogonal, none aliased.

## Tables of means

**Variate: Pods_per_Plant**

Grand mean 25.33

| pH_Level | P1 | P2 | P3 |
|---|---|---|---|
| | 19.17 | 31.33 | 25.50 |

| Variety | 1 | 2 |
|---|---|---|
| | 23.89 | 26.78 |

| pH_Level | Variety | 1 | 2 |
|---|---|---|---|
| P1 | | 17.67 | 20.67 |
| P2 | | 30.00 | 32.67 |
| P3 | | 24.00 | 27.00 |

## Standard errors of means

| Table | pH_Level | Variety | pH_Level Variety |
|---|---|---|---|
| rep. | 6 | 9 | 3 |
| d.f. | 10 | 10 | 10 |
| e.s.e. | 0.316 | 0.258 | 0.447 |

## Standard errors of differences of means

| Table | pH_Level | Variety | pH_Level Variety |
|---|---|---|---|
| rep. | 6 | 9 | 3 |
| d.f. | 10 | 10 | 10 |
| s.e.d. | 0.447 | 0.365 | 0.632 |

## Least significant differences of means (5% level)

| Table | pH_Level | Variety | pH_Level<br>Variety |
|---|---|---|---|
| rep. | 6 | 9 | 3 |
| d.f. | 10 | 10 | 10 |
| l.s.d. | 0.996 | 0.814 | 1.409 |

## Stratum standard errors and coefficients of variation

**Variate: Pods_per_Plant**

| Stratum | d.f. | s.e. | cv% |
|---|---|---|---|
| Block | 2 | 0.577 | 2.3 |
| Block.*Units* | 10 | 0.775 | 3.1 |