



UNIVERSITY OF NAIROBI

**INVESTIGATION OF FILTER AID WASTE FOR USE AS A
FERTILIZER**

BY

MALING'A DANIEL KAPSANDUI

I56/68698/2013

**A Thesis Submitted in Partial Fulfillment of the Requirements for the
Award of the Degree of Master of Science in Industrial Chemistry of the
University of Nairobi.**

2016

DECLARATION

I declare that this thesis is my original work and has not been submitted elsewhere for award. Where other people's work or my own work has been used, this has properly been acknowledged and referenced in accordance with the University of Nairobi's requirements.

Sign:

Date:.....

Maling'a Daniel Kapsandui

I56/68698/2013

This Thesis has been submitted with our approval as the research supervisors:

Sign:

Date:.....

Dr. John M. Wanjohi

Department Of Chemistry

University Of Nairobi

Sign:

Date:.....

Dr. Damaris N. W. Mbui

Department Of Chemistry

University Of Nairobi

DEDICATION

I dedicate this work to my family, siblings for always being with me, both morally and financially, throughout my academic endeavors. To dad Patrick, Mum Rose, sisters Joy, Sophie, Margaret and Esther and also Milkah Nailantei thank you.

ACKNOWLEDGEMENT

I would like to thank my supervisors Dr. John Wanjohi and Dr. Damaris Mbui for their positive reinforcement and commendable input throughout the conception and actualization of this thesis project. I also wish to thank the Department of Chemistry of the University of Nairobi (UoN) plus its lecturers for helping me mature as a chemist. I would also like to acknowledge the East African Breweries Limited (EABL) for letting me use samples from their facility for my thesis work. My gratitude also extends to the Kenya Agricultural and Livestock Research Organization's (KALRO) National Potato Research Center (NPRC) for their assistance in securing high quality potato tubers for analysis and facilitation during analysis at the National Agricultural Research Laboratories (NARL). I also thank Milkah Nailantei for her tireless work in helping me take care of the plants. Lastly, my gratitude goes to all my classmates for helping me out with the necessary technical and logistical support.

ABSTRACT

One of the main brewers in Kenya is East African Breweries Limited (EABL) and it produces a lot of high organic load wastes. Most of these wastes have alternative uses except the diatomaceous earth filtration waste which represents a major challenge to the brewer. This project set out to investigate the use of the filter aid waste as a fertilizer that could be used by local farmers. The waste at various stages of deposition (fresh slurry to 1 year) was characterized. Characterization for all the deposition wastes revealed that the filtration waste could be used as a fertilizer either on its own or as a blend. The 1 year sample that was eventually chosen for further tests had an N, P, K, Ca and Mg content of 5300 ppm, 390 ppm, 1540 ppm, 89 ppm and 85 ppm respectively. The wastes had low compositional values as compared to other commonly used organic fertilizers. The waste on its own along with other blends was investigated for use as a fertilizer. A field test to check for the efficiency of the filtration waste was done using pure breeds of potatoes (*Asante* variety potatoes, *Solanum tuberosum*). Six plastic bags were separately loaded with soil containing unused filter aid (blank), filter aid waste, cow dung, goat droppings, blood meal, bone meal. Four other bags were each loaded with soil containing a mixture of the filter aid waste and the other four wastes (dung, blood, goat, bone). Monthly leaf uptake analysis, pre- and post-harvest soil and tuber analysis were conducted on the potatoes to investigate the viability of the various blends. The tests revealed that the uptake trends in all the bags showed a healthy uptake of the nutrients except for the levels of Zn in the plain soil and the filter aid waste bag. Post-harvest soil analysis was done so as to compare the nutrient levels in the top soil of the bags to pre-harvest compositions. Tuber analysis revealed that all the bags gave a healthy harvest without any obvious signs of deficiency visible. Due to the difficulties of classifying yield, this project came up with yield performance indices, for both chemical and physical parameters, so as to ably compare and express the yield of the potatoes. Physical parameters indicated that blending gave higher yield performance indices with the Goat Blend and Goat Droppings having a 70% and 32% index respectively. Chemical parameters for the same two bags however indicated that blending did not necessarily increase yield quality with Goat Droppings and Goat Blend having 65.56% and 72.22% respectively. Based on the physical yield parameters such as tuber size and weight of potato harvest, blending of the filter aid waste with other organic fertilizers resulted in better performance of the crop.

TABLE OF CONTENTS

DECLARATION	ii
DEDICATION	iii
ACKNOWLEDGEMENT	iv
ABSTRACT.....	v
TABLE OF CONTENTS.....	vi
LIST OF TABLES	xi
LIST OF FIGURES	xii
LIST OF ABBREVIATIONS.....	xiv
LIST OF APPENDICES	xv
CHAPTER ONE	1
INTRODUCTION	1
1.1 Background of the study	1
1.2 Statement of the Problem.....	7
1.3 Objectives of the study.....	8
1.3.1 General Objective.....	8
1.3.2 Specific Objectives.....	8
1.4 Justification	8
CHAPTER TWO	11
LITERATURE REVIEW	11
2.1 Introduction.....	11
2.2 Waste from beer manufacturing.....	11
2.2.1 Mashing Wastes	12
2.2.2 Boiling Wastes	14
2.2.3 Fermentation Wastes	15
2.2.4 Filtration Wastes	16
2.3 Organic Fertilizers	18
2.4 Soil Enrichment	19
2.5 Field Test	20
2.6 Pre Planting and Post-Harvest Tests for Macro and Micronutrients	21
2.6.1 Soil Test.....	21
2.6.1.1 pH	22
2.6.2 Available Macronutrients.....	22
2.6.2.1 Nitrogen	22
2.6.2.2 Carbon	23
2.6.2.3 Phosphorus.....	23
2.6.2.4 Potassium.....	24
2.6.2.5 Calcium.....	24
2.6.2.6 Magnesium	24
2.6.3 Available Micronutrients.....	25

2.6.3.1	Manganese	25
2.6.3.2	Copper	26
2.6.3.3	Iron.....	26
2.6.3.4	Zinc	27
2.6.4	Nutrient Uptake Trends During the Grow Period	27
2.6.4.1	Biological Absorption Coefficient (BAC)	28
2.6.5	Plant Processes	28
2.6.5.1	Root Uptake	28
2.6.5.2	Absorption	30
2.6.5.3	Translocation	31
2.6.6	Effects of Nutrients on the Leaves	32
2.6.7	General Nutrient Trends in the Monthly Leaf Uptake Analysis	32
2.6.7.1	Nitrogen	32
2.6.7.2	Phosphorus.....	33
2.6.7.3	Potassium.....	33
2.6.7.4	Calcium.....	33
2.6.7.5	Magnesium	34
2.6.7.6	Iron.....	34
2.6.7.7	Copper	34
2.6.7.8	Manganese	35
2.6.7.9	Zinc	35
2.7	Tuber Development	35
2.7.1	Factors Affecting Tuber Development.....	36
2.7.1.1	Soil.....	36
2.7.1.2	Size of the seed	36
2.7.1.3	Fertilizer.....	37
2.7.2	Effects of Various Nutrients on the Tuber	37
2.7.2.1	Nitrogen	37
2.7.2.2	Phosphorus.....	37
2.7.2.3	Potassium.....	38
2.7.2.4	Calcium.....	38
2.7.2.5	Magnesium	38
2.7.2.6	Iron.....	39
2.7.2.7	Copper	39
2.7.2.8	Manganese	39
2.7.2.9	Zinc	39
2.7.3	Effects of Various Factors on Tuber Quality	39
2.7.3.1	Cultivation	40
2.7.3.2	Defoliation	40
2.8	Tuber Characterization.....	41
2.8.1	Physical Characterization	41
2.8.1.1	Potato Colour	41
2.8.1.2	Brown and Black Spot.....	41
2.8.1.3	Potato Skin and Bruising	42

2.8.1.4	Potato Weight and Size.....	42
2.8.2	Chemical Characterization	42
2.9	Yield Performance	43
2.9.1	Yield Performance Index - Physical Parameters.....	45
2.9.2	Yield Performance Index - Chemical Parameters	45
CHAPTER THREE		46
METHODOLOGY		46
3.1	Sampling	46
3.1.1	Sampling Area.....	46
3.1.2	Sample Collection Procedure	47
3.1.3	Sample Treatment	47
3.2	Experimental Procedures	48
3.2.1	Determination of pH.....	48
3.2.2	Analysis of Nitrogen	48
3.2.3	Determination of Ammonium (NH ₄) in the digest by distillation.....	49
3.2.4	Determination of Phosphorus.....	50
3.2.5	Analysis of Potassium	51
3.2.6	Determination of Calcium and Magnesium	52
3.3	Field Test	53
3.3.1	Field Arrangement.....	54
3.3.2	Blending with Organic Fertilizers	54
3.3.3	Planting Procedure	54
3.3.4	Plant Tissue Analysis	55
3.3.4.1	Sample Preparation.....	56
3.4	Monthly Nutrient Uptake Analysis	56
3.4.1	Elemental analysis.....	57
3.5	Post-Harvest Tuber Analysis	58
3.5.1	Physical Characterization.....	58
3.5.2	Chemical Characterization	58
3.6	Post-Harvest Soil Analysis	58
3.6.1	Determination of Total Organic Carbon	59
3.6.2	Total Nitrogen	59
3.6.3	Phosphorus Determination	60
3.6.4	Determination of available nutrient elements	60
3.6.4.1	Atomic Absorption Spectrophotometer (AAS).....	61
3.6.4.2	UV/VIS Spectrophotometer	62
3.6.4.3	Flame Photometer.....	62
CHAPTER FOUR.....		64
RESULTS AND DISCUSSION		64
4.1	Pre Planting Analysis	64
4.1.1	Soil Analysis	65
4.1.1.1	pH.....	68
4.1.1.2	Nitrogen	68
4.1.1.3	Total Carbon	68

4.1.1.4	Phosphorus.....	68
4.1.1.5	Potassium.....	68
4.1.1.6	Calcium.....	68
4.1.1.7	Magnesium.....	68
4.1.1.8	Manganese.....	69
4.1.1.9	Copper.....	69
4.1.1.10	Iron.....	69
4.1.1.11	Zinc.....	69
4.2	Monthly Leaf Uptake Analysis.....	69
4.2.1	General Nutrient Trends in the Monthly Leaf Uptake Analysis.....	70
4.2.1.1	Nitrogen.....	70
4.2.2.2	Phosphorus.....	71
4.2.2.3	Potassium.....	73
4.2.2.4	Calcium.....	75
4.2.2.5	Magnesium.....	78
4.2.2.6	Iron.....	79
4.2.2.7	Copper.....	81
4.2.2.8	Manganese.....	83
4.2.2.9	Zinc.....	85
4.3	Tuber Analysis.....	87
4.3.1	Physical Characterization.....	87
4.3.1.1	Potato Colour.....	87
4.3.1.2	Brown and Black Spot.....	87
4.3.1.3	Potato Skin and Bruising.....	87
4.3.1.4	Potato Weight and Size.....	87
4.3.2	Chemical Characterization.....	89
4.3.2.1	Nitrogen.....	89
4.3.2.2	Phosphorus.....	90
4.3.2.3	Potassium.....	91
4.3.2.4	Calcium.....	92
4.3.2.5	Magnesium.....	93
4.3.2.6	Iron.....	94
4.3.2.7	Copper.....	95
4.3.2.8	Manganese.....	96
4.3.2.9	Zinc.....	97
4.4	Yield Parameters.....	98
4.4.2	Physical Parameters.....	98
4.4.2.1	Yield Performance Index.....	100
4.4.3	Chemical Parameters.....	103
4.4.3.1	Yield Parameters.....	104
4.4.4	Overall Yield Performance Index.....	105
4.5	Movement of Nutrients.....	106
	CHAPTER FIVE.....	109
	CONCLUSION AND RECOMMENDATIONS.....	109

5.1	Conclusion	109
5.2	Recommendations.....	111
	REFERENCES	114
	APPENDICES	120
	Appendix 1: Movement of nitrogen between the soil and the plant.....	120
	Appendix 2: Movement of phosphorus between the soil and the plant.....	121
	Appendix 3: Movement of potassium between the soil and the plant.....	122
	Appendix 4: Movement of calcium between the soil and the plant.....	123
	Appendix 5: Movement of magnesium between the soil and the plant.....	124
	Appendix 6: Tuber elemental content ranking.....	125

LIST OF TABLES

- Table 3.1: Detection limits for elemental analysis
- Table 3.2: Preparation of calibration standards for nutrient analysis
- Table 4.1: Composition of soil, filter aid and filter aid wastes
- Table 4.2: Composition of organic fertilizers used for planting
- Table 4.3: Composition of soil used for planting
- Table 4.4: Post- harvest soil composition
- Table 4.5: Nitrogen content in the leaves
- Table 4.6: Phosphorous content in the leaves
- Table 4.7: Potassium content in the leaves
- Table 4.8: Calcium content in the leaves
- Table 4.9: Magnesium content in the leaves
- Table 4.10: Iron content in the leaves
- Table 4.11: Copper content in the leaves
- Table 4.12: Manganese content in the leaves
- Table 4.13: Zinc content in the leaves
- Table 4.14: Nitrogen composition of the tubers
- Table 4.15: Phosphorous composition of the tubers
- Table 4.16: Potassium composition of the tubers
- Table 4.17: Calcium composition of the tubers
- Table 4.18: Magnesium composition of the tubers
- Table 4.19: Iron composition of the tubers
- Table 4.20: Copper composition of the tubers
- Table 4.21: Manganese composition of the tubers
- Table 4.22: Zinc composition of the tubers
- Table 4.23: Physical yield parameters
- Table 4.24: Blood meal and bone meal yield performance index
- Table 4.25: Physical yield performance ranking
- Table 4.26: Chemical yield performance parameters
- Table 4.27: Cow dung and goat blend assigned percentage elemental ranking
- Table 4.28: Overall yield performance indices ranking
- Table 4.29: Ranking between the composition of nutrients in pre and post-harvest soils

LIST OF FIGURES

Figure 1.1: Alcohol Fermentation in Yeast.....	3
Figure 1.2: Beer Manufacturing Process.....	4
Figure 1.3: Sources of wastes in Beer Manufacturing	6
Figure 3.1: Sampling points within the backfilling hill.....	21
Figure 4.1: Macronutrients and Micronutrient content of leaves in plain soil bag for the 3 months.....	67
Figure 4.2 Macronutrients and Micronutrient content of leaves in diatomaceous earth bag for the 3 months.....	68
Figure 4.3: Macronutrients and Micronutrients content of leaves in cow dung bag for the 3 months.....	68
Figure 4.4: Macronutrients and Micronutrients content of leaves in cow blend bag for the 3 months	69
Figure 4.5: Macronutrients and Micronutrients content of leaves in goat droppings bag for the 3 months.....	69
Figure 4.6: Macronutrients and Micronutrients content of leaves in goat blend bag for the 3 month.....	70
Figure 4:7 Macronutrients and Micronutrients content of leaves in blood meal bag for the 3 months	70
Figure 4.8: Macronutrients and Micronutrients content of leaves in blood meal blend for the 3months.....	71
Figure 4.9: Macronutrient and Micronutrients content of leaves in bone meal bag for the 3 months.....	71
Figure 4.10: Macronutrients and Micronutrients content of leaves in bone meal blend bag for the 3 months	72
Figure 4.11: Weight of potatoes harvested	81
Figure 4.12: Number of potatoes harvested.....	81
Figure 4.13: Length of potatoes harvested.....	82
Figure 4.14: Nitrogen composition of the tubers	84
Figure 4.15: Phosphorous composition of the tubers	85
Figure 4.16: Potassium composition of the tubers.....	85
Figure 4.17: Calcium composition of the tubers	87
Figure 4.18: Magnesium composition of the tubers.....	88

Figure 4.19: Iron composition of the tubers.....	89
Figure 4.20: Copper composition of the tubers	90
Figure 4.21: Manganese composition of the tubers.....	91
Figure 4.22: Zinc composition of the tubers	92
Figure 4.23: Overall yield performance indices ranking	102

LIST OF ABBREVIATIONS

EDTA - Ethylenediaminetetra-Acetic Acid

EABL – East African Breweries Limited

NEMA – National Environmental Management Authority

CEC – Cation Exchange Capacity

SOM – Soil Organic Mater

ADP – Adenosine Diphosphate

NAD⁺ - Nicotinamide Adenine Dinucleotide

ATP - Adenosine Triphosphate

NADH – Reduced Nicotinamide Adenine Dinucleotide

LIST OF APPENDICES

Appendix 1: Movement of nitrogen between the soil and the plant

Appendix 2: Movement of phosphorus between the soil and the plant

Appendix 3: Movement of potassium between the soil and the plant

Appendix 4: Movement of calcium between the soil and the plant

Appendix 5: Movement of magnesium between the soil and the plant

Appendix 6: Tuber elemental content ranking

CHAPTER ONE

INTRODUCTION

1.1 Background of the study

The generation of wastes is inherent in any industrial process where raw materials are converted into finished products using various chemical processes. Some of the wastes generated in industrial processes are important constituent raw materials in other complementary industrial applications (Varnam & Sutherland, 1994). An example is the use of wastes from the timber processing in the paper industry and in the ply wood industry. This is one of the reasons as to why industrial areas are put up around a dominant industry so as to benefit from the resultant proximity to raw materials. The issue of managing wastes is seldom as straightforward as using them for other industrial processes (Varnam & Sutherland, 1994). In most cases the wastes that are generated end up being a challenge to the factory. Thus many industries are overwhelmed by the wastes generated and end up carelessly disposing them off (Briggs *et al.*, 2004).

The Beer industry is a practical example of merging sound waste management strategies and environmental requirements (Briggs *et al.*, 2004). In order to understand the challenges posed to environmentally sound waste management, one would need to understand the industrial processes that take place in the industry vis-à-vis the hierarchy of wastes. These are the unit operations involved in the production process from raw materials up till the final product including the by-products (Dittmer & Desmond, 2005). The hierarchy of wastes on the other hand paints a picture of step wise preferential treatment and prioritizing of wastes that is involved within the entire outlay of the production process (Bustamante *et al.*, 2005). It is also important because it aids in understanding where significant process changes can be made so as to reduce the amount of waste that is eventually generated.

The beer industry is one of the largest beverage industries in most developed countries (Dittmer & Desmond, 2005). Developing countries also have vibrant beer industries that are of similar standard as those in the developed countries. The major difference is the kind of market which they service, since developing countries have a large informal alcohol sector. This is as opposed to the developed countries where the alcohol sector is more formal and streamlined. The beer process can be divided into malting, milling, mashing, boiling and fermentation.

Malting is the first step in preparing harvested barley into a ready feedstock for the brewing process (Briggs *et al.*, 2004). Malting involves the breakdown of the carbohydrates in the barley into starches. In the first step the grain is steeped by soaking for approximately 40 hours. Soaking is done so as to induce the germination of the barley grains. This is normally enhanced in the second stage whereby the germinating grains are spread for five days in a germination room. The last stage involves the kilning of the germinating grains in a gradual increase of the grains in a kiln. This stage halts the induced germination process and completes the malting stage.

The malting process normally takes place in an external site in most brewery processes. The barley therefore normally arrives in the brewery as malt. Size reduction of the malt takes place in large crushers after the malt is received in the plant (Briggs *et al.*, 2004). The aim of the milling is to expose the barley's cotyledon by parting the enclosing kernels. The milling of the malt is normally not done to a smooth flour but rather into a mixture of both coarse and fine particles.

Mashing takes place in large mash vessels known as mash whereby the milled malt is mixed with hot water. The main purpose for the hot water mix is to activate enzymes within the grain so as to breakdown the starch into simple fermentable sugars (Varnam & Sutherland, 1994). The saccharification process leads to the hot water dissolving the simple sugars such as glucose, sucrose and fructose among others to form a sweet sugary liquid known as wort.

In the boiling stage the wort from the mashing is married together with hops in a large copper kettle whereby the mixture is boiled. The purpose of boiling is to end all enzymatic activities and to catalyze the many chemical reactions that determine the beer's characteristics for example the colour, flavour and aroma of the beer. The hops that are added assist in both adding the characteristic bitterness of the beer and to add flavor (Udeh & Kgatla, 2013). Boiling also isomerize the resins in the hops, results in protein precipitation and in sterilization of the wort.

The hot wort containing flavours from the hops is first cooled in heat exchangers before the mixture is directed into a fermentation tank. Fermentation is the actual conversion of the simple sugars within the mixture into alcohol by the use of yeast cells. After the yeast has converted the sugars into ethanol, the beer is stored into large tanks for aging and further flavour development in a process known as conditioning (Udeh & Kgatla, 2013). The fermentation cycle by the yeast on the sugars is as shown below:

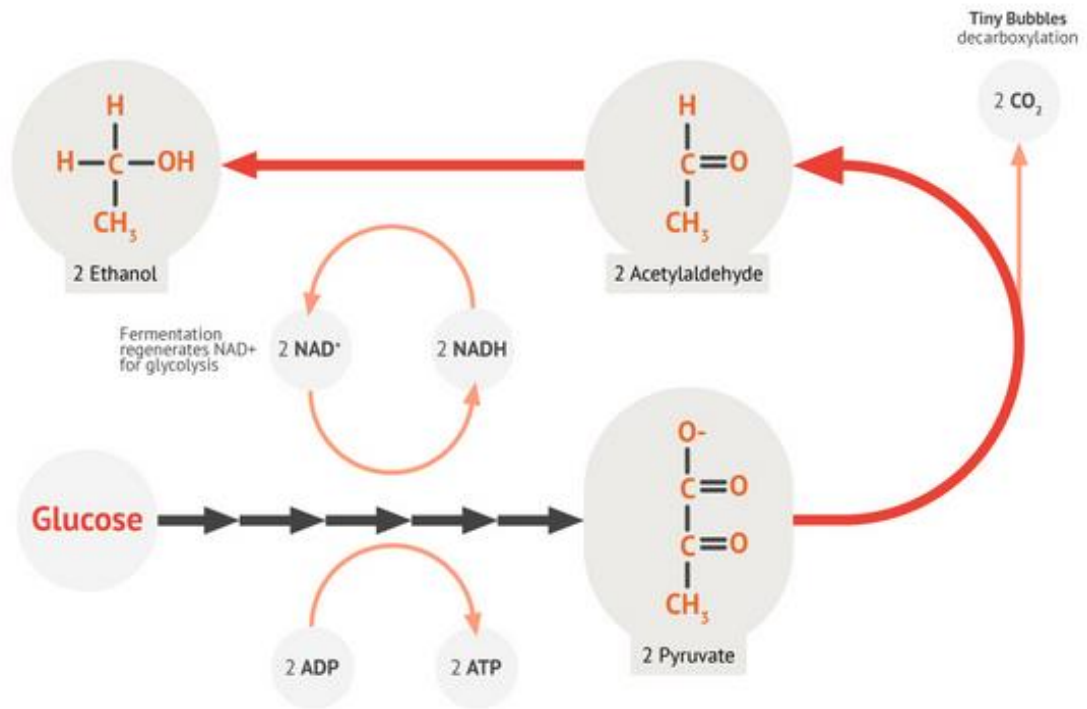


Figure 1.1: Alcohol Fermentation in Yeast

Source: Smith & Hui, 2004, Food

Processing: Principles and Applications

Breakdown of glucose into ethanol is shown in equation 1.1



The enzyme complex is known as *Zymase* and it is naturally occurring in Yeast.

Breakdown of sucrose into ethanol is shown in equation 1.2



The enzyme responsible for the breakdown of sucrose is known as *Invertase*. Sucrose is a dimer composing of one part fructose per one part glucose. The *Invertase* works by breaking the glycosidic linkages between the glucose and fructose (Stryer, 1975).

The glycosidic linkages are broken down in a process known as Glycolysis which involves the breakdown of the subsequent glucose molecules into two Pyruvate molecules (CH₃COCOO⁻). The summary of the glycolysis reaction is as shown in equation 1.3



Where **ADP** – Adenosine Diphosphate

P_i – Inorganic phosphate component

NAD⁺ - Nicotinamide Adenine Dinucleotide

ATP - Adenosine Triphosphate

NADH – Reduced Nicotinamide Adenine Dinucleotide

Once the beer has been matured to the desired feel and the flavours developed appropriately in conditioning, it is filtered. The aim of the filtration is to remove the cloudiness that characterizes beer at this stage. It is also important in the removal of suspended matter within the beer in addition to colour development. Once the filtration is done with, the beer is packaged in either kegs, bottles or cans ready for the market.

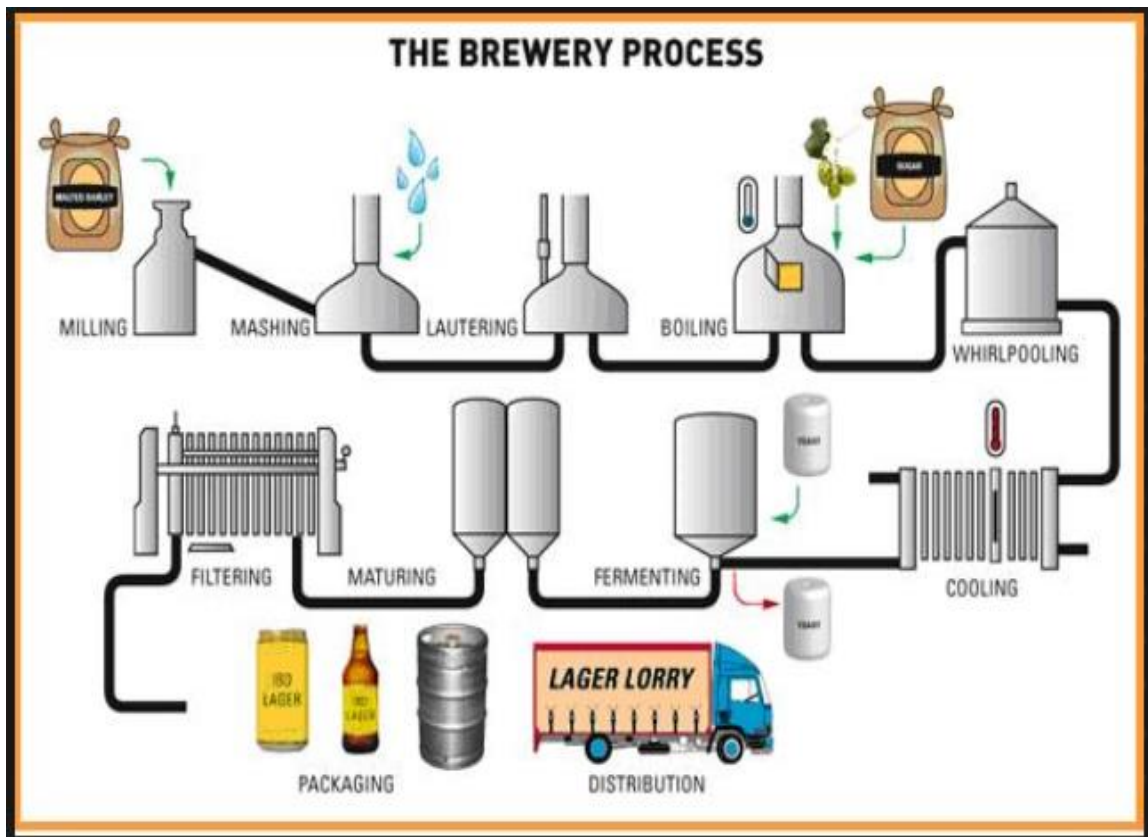


Figure 1.2: Beer Manufacturing Process

Source: Priest & Stewart, 2006,
Handbook of Brewing, 2nd Ed.

In the systematic arrangement of waste management strategies, that is the hierarchy of wastes, a production unit critically evaluates the wastes that are produced. After analyzing, the wastes produced are categorized into five actionable steps: Minimize, Re-use, Recycle, Recover and Dispose. These five steps help to minimize the amount of wastes that are ultimately released by the manufacturing process (Olajire, 2012).

The first step is to ensure that all wastes generated during the chemical processes used in the production cycle are minimized to the greatest extent possible. This is mainly achieved by optimization of the reactions that occur through increasing the conversion factor of the feed products (Stephanopoulos, 1999). Alternatively one could use cleaner technologies that assist to reduce the wastes produced as exhaust fumes in the stalks.

The second step is to re-use materials, fuel and any other useful process effluents back in the process. This step is particularly useful when the energy used in the various industrial processes is considered (DuPont, 1996). An example is when the steam generated from unit operations involving boiling is re-used in heat exchangers to heat a stream of water. Hot water from boilers or heat exchangers can be used to run through pipes and ducts in the industrial outlay that require to be maintained at a certain temperature (Stephanopoulos, 1999).

The third step which is sometimes considered the most important step in the hierarchy is recycling. This is because recycling is directly involved in minimizing the amounts of wastes generated in a process and subsequently those that are disposed. In order to effectively utilize recycling in an industry, one has to understand the chemical kinetics, reaction rates and conversion rates that are inherent in a particular process (Stephanopoulos, 1999). By understanding these chemical laws and principles an operator can, for instance, combine the recycled stream back into the system without adversely affecting the efficiency on the process (DuPont, 1996). The amounts added in the recycle stream should still have enough of the required material in an extractable quantity. This guarantees that recycling doesn't just act as an inert stream that has little in terms of product generated but also ensures that the energy cost is increased. Reaction rates are directly indicative of the feasibility of the addition of the recycle stream into the feed stream (Stephanopoulos, 1999). Once a process attains a certain conversion rate, no matter how much of the effluent is recycled into the system, the forward rates that favor more extraction of the product are overwhelmed by the back reaction rates and side reactions that end up producing minimal product or worse still, having the desired product consumed.

Step number four in the hierarchy is to recover. Recovering involves the process of removing the wastes entirely from the production system. Some wastes, for example exhaust fumes can easily be recovered from the product stream. Others however require the use of other unit operations entirely dedicated to their removal. An example is the removal of moisture which normally requires the use of dryers. At times certain wastes are physically mixed with the desired product and have to be completely recovered. Examples of these are the components

in a distillation process and those in liquid-liquid extraction (Stephanopoulos, 1999). In order to recover such wastes for re-use, the processes involved are much more technical than removal of moisture in crystallization.

The fifth step in the hierarchy is the disposal of the recovered wastes in the instances that they cannot be further recycled or recovered into the process and could be the process that has highly contributed to hazards associated with waste disposal. This is because in most cases there is seldom any economic benefit resulting from disposal apart from costs. It is precisely due to these costs that disposal, in the absence of strict environmental regulations, is done haphazardly. However, if alternative and more profitable ways of disposing wastes can be found, then industries will have an incentive to look into environmentally sound disposal techniques (Bustamante *et al.*, 2005).

In the beer industry, this hierarchy of wastes also applies. The focus of the study was solely on the fifth step of Disposal of the wastes. This is primarily because an environmentally sound industry such as EABL has in place sufficient strategies to deal with minimization, recycling and recovery of the wastes they generate. They have in place sufficient disposal strategies. The sufficient disposal strategies in place are however not sustainable in the long run because the backfilling of the filtration wastes within the brewery is hampered by minimal space and with time the wastes will prove to be a challenge due to accumulation.

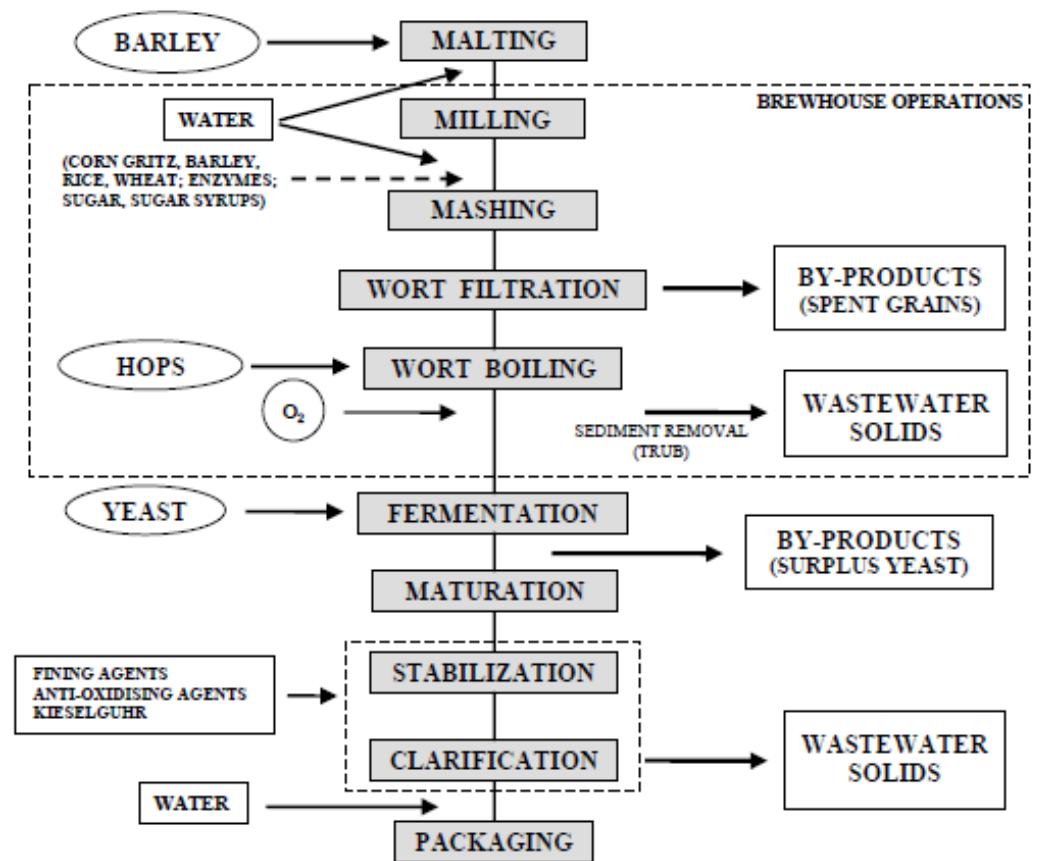


Figure 1.3: Sources of wastes in Beer Manufacturing

Source: Mathias *et al.*,2014,
Solid Wastes in Brewing Process:
A Review

1.2 Statement of the Problem

In every manufacturing process in industry there are three important materials in the process. The first is the feed constituent of the process which involves all the raw materials that flow in the chemical process together with the necessary reagents that are used to process the raw materials. The second is the product of interest that is obtained as a result of the chemical conversions that take place in the system. This second constituent happens to be what the entire process is geared towards its production. The third constituent is that made up of the process wastes that result. This third constituent generated is perhaps the most important with regard to how the manufacturing unit handles waste disposal. This derives from the fact that its composition is usually of little to no value to the manufacturers. However, strict environmental regulations that are normally in place dictate that they are handled in a way that does not pollute the environment. Therefore how to dispose of them is of paramount

importance. For this reason industries such as the beer industry would try to minimize, re-use, recycle and then dispose of them in a way that doesn't affect their bottom line (Bustamante *et al.*, 2005).

Most disposal methods that are in place focus on finding alternative use for process wastes for example selling them to farmers for use as animal feed (Bustamante *et al.*, 2005). This is normally sufficient in disposing off the wastes in an environmentally sound manner. However, due to the chemical composition of the filtration wastes, there may be an even more attractive alternative way of getting rid of the said wastes (Bustamante *et al.*, 2005). This study aimed at investigating an alternative and economically viable waste management method that is currently not being applied within the company namely, the use of the filter aid wastes as a fertilizer constituent. Fertilizers are supposed to increase soil productivity by supplying the necessary nutrients to the crops (Tan, 1998). Therefore use of the filter aid waste as fertilizers can increase food security by enhancing crop productivity.

1.3 Objectives of the study

1.3.1 General Objective

To investigate the viability of filter aid wastes for use as a fertilizer.

1.3.2 Specific Objectives

- (i) To determine the physical characteristics of filter aid wastes, soil and different organic soil supplements.
- (ii) To establish the chemical composition of macronutrients in the filter aid wastes
- (iii) To establish the chemical composition of micronutrients available in the filter aid wastes
- (iv) To carry out a field test using potatoes and compare the effect of filter aid waste as a fertilizer with that of other organic soil supplements and blends on the growth of potatoes
- (v) To measure the uptake of macro and micronutrients in the potatoes throughout the growth phase up to the harvest

1.4 Justification

The project aimed to carry out physical and chemical analysis of the filter aid waste produced by EABL. The analysis was important in order to determine their viability for use as a soil enrichment supplement (Smith & Hui, 2004). By characterizing these wastes, the beer

producing company EABL can then look at an attractive alternative method of use for the wastes that they produce.

The filter aid wastes are produced and disposed of in different physical conditions (Priest & Stewart, 2006). The physical state of the wastes is important in assigning the nature of use for the wastes and ease of use for application as a soil enrichment supplement. Whether the wastes are in the form of slurry or whether they are a solid usually end up affecting its effectiveness of enriching the soil to which it is applied. Slurry for instance could be difficult for plants to uptake mostly because of the ability of the wastes to leach and ease of uniformly spreading the organic fertilizer within a farm (Koenig & Johnson, 2011). In terms of chemical nature, an indication as to whether the wastes are basic or acidic go a long way in its suitability to adequately release its nutrients to plants growing in a specific soil type.

Food security is a major concern for a country such as Kenya and the increased use of fertilizers in farming is one way of boosting yields. The filtration wastes can only be useful as an organic fertilizer if it contains the necessary nutrients for plant growth. The macronutrients necessary for healthy plant growth not only have to be present in the fertilizer, but also have to be present in a form that is available for uptake by the plants. The macronutrients in question are Nitrogen, Phosphorus and Potassium with the primary micronutrients of Calcium and Magnesium. These nutrients are responsible for among other things conditioning the soil so as to support healthy plant development (Tan, 2005). They also aid in important plant developments such as root development, upright stems, healthy and colorful fruit development, chlorophyll content in the leaves and the avoidance of stunted growth in plants. The filter aid is made up of diatomaceous earth, which is inorganic in nature, but once it has been used for filtration it adsorbs the organic beer fermentation wastes (Priest & Stewart, 2006). Many organic materials, and chemical materials for that matter, have significant quantities of the nutrients required for plant growth (Tan, 2005). However, this in itself is not enough due to the issue of the availability of those nutrients during the growth cycle of the plant. Thus for a material to be used as a fertilizer it is usually not enough to simply characterize it by the macronutrient composition that it has (Aizaki *et al.*, 2013). The material has to be tested in the field so as to check whether the nutrients could actually be effectively up taken by the plants for which the fertilizer was intended to improve. Such a test involves the actual application of the soil supplement in a field and growing plants which are constantly checked to observe how the addition of the supplement improves and enhances the growth of the test plants (Koenig & Johnson, 2011). To this effect a test field of known soil characterization was chosen for the plants. In order to really check for effect of the

supplement, to the same field other alternatives to the supplement being used were also applied in similar test fields. The alternatives that were used were cow manure, goat droppings, blood meal, bone meal and a test field free of any addition of supplements. This was done so as to check for the range of effectiveness of the organic fertilizers both as a stand-alone supplement and as a blend with other organic fertilizers currently in use.

The environmental challenges posed by backfilling of the wastes within EABL can be significantly reduced or totally eliminated if the effectiveness of the process wastes as an organic fertilizer is established. In addition to that EABL would be offering farmers an alternative organic fertilizer option. This could be of significant importance to a country such as Kenya by minimizing the effects of food insecurity while at the same time conserving the environment by effectively recycling significant quantities of beer wastes.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

The issue of waste management in industry has been at the forefront of most industrial and academic research that has been carried out in the past few years. From the industrial stand point, tough environmental regulations by agencies such as National Environment Management Authority (NEMA) have necessitated that environmentally safe waste management strategies are adopted. A failure to comply with environmental best practices has meant tough fines, lengthy and costly litigation and legal battles and in the worst cases a complete closure of operations. In addition to these, research is normally encouraged so as to come up with not only effective waste management strategies but also economic ones that do not grossly affect the firm's turnover (Smith & Hui, 2004). Apart from the turnover, most of the strategies in place are normally integrated to run concurrently in the system. Therefore, the industrial research is also focused on the design outlay of the industrial architecture and the process control mechanisms that have been put in place. Thus better design parameters that encourage use of recycled streams and use of actuators and fast acting sensors that check for optimization are common industrial research topics.

Academic research on the other hand had been equally effective in influencing the manner in which industries deal with the waste that they generate. The one advantage that academic research has over industrial research is that academic research is usually more explicit and detailed than industrial research in terms of the extent of its coverage as opposed to industrial research which tends to be rather specific to a particular challenge (Briggs *et al.*, 2004). As a result of this, academic research would involve a number of experimental methods that industry could specifically tailor fit to cater for its specific application and process needs.

2.2 Waste from beer manufacturing

It is clear that in order to get the proposed use of beer manufacturing wastes as an organic fertilizer; one had to appreciate the various unit operations that generated the wastes. A critical examination of each process and the disposal methods employed and possibly some of the current research that was being done to come up with alternatives is important. The main focus in this project was on the wastes obtained from the mashing, boiling, fermentation and filtration processes. These wastes are collectively called wet brewery wastes and are

normally responsible for the loss of approximately 20 litres of water per every 100 litres of beer produced in the brewing process (Mathias *et al.*, 2014). The kind of wastes generated in the above four processes are normally inherent in beer production and thus their relative quantities remain the same throughout each subsequent batch in the brewery (Priest & Stewart, 2006).

The use of beer process wastes as an organic fertilizer in the early 21st century was still a novel idea whose application hadn't really taken off. This was because such wastes had other uses such as animal feed. However, the use of organic matter as a soil supplement has been on the rise in recent years mainly due to the advantages associated with the use of organic fertilizers such as soil conditioning, as opposed to the chemical fertilizers (Aizaki *et al.*, 2013). Due to such reasons, organic fertilizers which often have lower levels of active constituents than the chemical varieties are increasingly being used by farmers who are keen to go organic (Aizaki *et al.*, 2013). Studies had proved as much especially with regard to the improved soil porosity, aeration capacity and better retention of nutrients within the soil.

Another reason for preference of organic fertilizers has been the effects associated with over nutrition of soils that usually results due to continual use of chemical fertilizers (Chesworth, 2008). Over use of chemical fertilizers results to their nutrients being available in the soil in forms that cannot be taken up by plants a condition that jeopardizes the health of the plants (Aizaki *et al.*, 2013). The other reason may be that the quantities of the macronutrients available in the chemical fertilizer can be so large that they are preferentially taken up at the expense of other micronutrients that are equally important for specific growth requirements such as fruit formation (Chesworth, 2008). Due to such negative effects associated with chemical fertilizers and the positive effects associated with organic fertilizers, some farmers are steadily using organic fertilizers (Chesworth, 2008). The beer process wastes which can be used as an organic fertilizer can in principle provide the same advantages such as soil conditioning that other organic fertilizers such as manure and peat composts provide (Koenig & Johnson, 2011).

2.2.1 Mashing Wastes

In mashing, the main purpose is to mix the ground malt with hot water in mash tuns so as to produce wort. Wort is a sugary liquid containing simple sugars which are to be converted by the yeast into alcohol. A lot of research has been done so as to ensure the carbohydrates contained in the malted grain are converted to the simple sugars required for beer

manufacturing to the highest degree possible (Carvalho *et al.*, 2004). Industrial research with regard to these wastes has mostly been led by the major beer manufacturers such as Guinness of Ireland and Heineken of The Netherlands. The focus has mainly been on the minimization of the wastes produced in the mashing pits by altering the mashing process through temperature manipulation of the mash mixture (Carvalho *et al.*, 2004).

A case in hand for minimization of wastes produced during the mashing stage of beer production is in the Dutch beer manufacturer Heineken. Heineken emphasizes on temperature adjustments and rests for the hot water that is added during mashing. These temperature adjustments help to develop the character and distinctive taste of the beer. Temperatures in the first mashing vessel are adjusted from a range of between 45-55°C. In this vessel the breakdown of proteins commences via the activation of protease enzymes within the mash. The temperature is then allowed to elevate before being rested at about 60°C so as to breakdown the glucans in the mash. By the time another temperature rest takes place at just above 70°C, the starches are converted into fermentable sugars such as maltose and glucose. Although such a mashing process was common to the production of lagers by various brewers, Heineken has realized that by adjusting the temperature rests for various durations of time results in a higher conversion of the proteins and starches within the mash. The net result of such high conversions is that Heineken produces significantly less spent grain waste than the 1400-2000 kg/L which is the range that is produced by nearly all manufacturers (Carvalho *et al.*, 2004). The fact that a major manufacturer such as Heineken can manage to keep its wastes at the lower end of the average meant that the cumulative benefit is that they ended up producing a lower tonnage of spent grain wastes within the entirety of their worldwide operations (Carvalho *et al.*, 2004).

This spent grain normally contains fibers, proteins, free amino acids, ash, vitamins and phenolic compounds in various ratios depending on the starting materials and mashing process (Mathias *et al.*, 2014). The spent grain has found many uses, for example as a filter medium for the wort generated while the protein content contained in the spent grain is used to make protein concentrates for use in other industrial applications such as the manufacture of health supplements (Niemi *et al.* 2013). By fermenting the spent grain, Hashemi *et al.* (2011) obtained fermentation products such as lactic acid, gums, ethanol, enzymes and antibiotics which have significant applications in the pharmaceutical industry.

2.2.2 Boiling Wastes

Boiler wastes originate from the wort during the mashing process along with the hops that were added to the wort. The wort usually contains a lot of suspended wastes that did not undergo sedimentation or that passed through the filtration sieves between the mashing and boiling processes. After boiling the wort together with the hops, the resultant hot trub waste is quite rich in organic matter and has a high water content of between 80-90% (Priest & Stewart, 2006). An analysis of the hot trub wastes by Mathias *et al.* (2014) showed that it contained carbohydrates, proteins, ash, fatty acids and phenolic compounds. The average composition of the hot trub in dry matter was: non isomerized hops bitter substances (10-20%), Carbohydrates (containing glucans, pectin and starch) (4-8%), Proteins (50-70%), Polyphenols (5-10%), fatty acids (1-2%) and minerals (3-5%) (Mathias *et al.*, 2014).

The hot trub originates from the precipitate formed when the high nitrogen containing wort loses about 6% of its nitrogen content (Briggs *et al.*, 2014). The precipitate is formed as a result of the coagulation of the high molecular weight proteins within the wort. Coagulation on the other hand resulted when the boiling process forced the protein molecules to lose their solvation water and become denatured. This is due to the formation of complexes which affected neutralization when cations such as Ca^{2+} reacted with the negative charges within the peptide and protein structures (Briggs *et al.*, 2014). Electrostatic interaction between the lower solubilization hop compounds and insoluble proteins could also result in precipitation. The hot trub may have contained small amounts of lower molecular weight proteins which were composed of the specific amino acid group Proline (Briggs *et al.*, 2014). The Proline interacted with the condensed and oxidized polyphenols such as tannins and the carbohydrates within the medium to produce the hot trub. Research by Briggs *et al.* (2014) had shown that the interaction of the carbohydrates, polyphenols and Proline became unstable above 80°C.

The trub formation process is affected by many factors, for example the malt drying process, type of barley used, pH controls of the mashing process, type of milling, seasonal effects in the cultivation area and concentration of ions among others. The degree of solubilization of hops, the oxidation achieved during boiling and the resultant primitive wort extract in the boilers also affect the trub forming process. Coagulants and adsorbents such carrageenan gum could be added so as to enhance the trub formation (Barchet, 1993). Due to the relative difficulty in handlability, the hot trub is cooled and mixed with spent grain and other supplements for the preparation of animal feed. Its high protein composition results the trub

find application in the bio products industry as a protein concentration constituent (Priest & Stewart, 2006).

2.2.3 Fermentation Wastes

Fermentation is another part of the process that has in the past few years sparked a great deal of both academic and industrial research. From the industrial standpoint, the focus had always been in the reproducibility of the exact kind of yeast that had been used for years so as to develop and maintain the same flavor for which a particular brand was known (Boekhout & Vincent, 2003). In the main Guinness brewery in Dublin, Ireland for instance a lot of research was done in the fast multiplication of yeast cells that were to be used in the fermentation of the stout (Guinness, 2009). The need for this arose from the fact that all the yeast that was used in all the Guinness breweries across the globe came from the one main brewer in Dublin. In addition to that, the cryogenic yeast storage vats were only opened twice a year, so as to minimize the risks of contamination, so rapid multiplication of the yeast was of paramount importance (Guinness, 2009). With regard to waste management, the uniformity of the yeast used in fermentation is of ultimate importance to a brewer. This is because once a brew master notices any significant deviation from the required taste profile, the entire batch of the beer is to be discarded resulting to a substantial amount of waste. Although such a scenario rarely happens, mostly due to the strong control mechanisms in place, it did occur in the last 20 years and resulted in a waste management catastrophe due to the hundreds of thousands of liters of beer that were dumped in a safe manner (Guinness, 2009).

Waste management in the fermentation process investigated the alternative use of the fermentation broth wastes (Ha *et al.*, 2011). The unfermented sugars and proteins could be converted into other chemicals of industrial importance (Ha *et al.*, 2011). For example the broth could be converted into bio-ethanol without adding carbohydrates, microbial cells or enzymes which is not only cost effective but also effectively minimized the wastes from fermentation (Ha *et al.*, 2011). The bio-ethanol obtained could then be used as a fuel to heat the water that is added to the mash in the boiling tanks. The other advantage was that the fermentation broth wastes' stream was easily integrated into the system so as not to disrupt the normal fermentation batch rotations in the brewing process (Boekhout & Vincent, 2003).

Khattaka *et al.*, 2013 found out that conversion of the wastes into the bio-ethanol could also be increased significantly. This can be done by treating the fermentation broth from

consecutive batches at high temperature. This was found to be more effective as it did not require pauses between every batch but could be seamlessly integrated into the process to cater to various batches (Khattaka *et al.*, 2013). This resulted in a better process integration scheme in which various batches were merged so that the production of bio-ethanol in the plant would become a continuous process. Due to the high temperature through which the consecutive batches underwent simultaneous saccharification and fermentation, the bio-ethanol that was produced from one batch was used to raise the temperature for the consecutive conversion of other batches.

2.2.4 Filtration Wastes

Before the beer is taken up for filtration, conditions that favor the deposition of yeast and other haze substances in the beer such as low beer pH and cold temperature are employed in the maturation tanks (Priest & Stewart, 2006). Maturation generally exhibits a low efficiency in the elimination of turbidity; thus in as much as maturation takes care of the turbidity in the beer, it is a very slow process and even if it was left to completion it rarely achieves the desired clarity (Mathias *et al.*, 2014). The use of filters and other filter media in the beer industry is to clarify the beer and remove the cloudiness that is inherent in beer after fermentation.

Due to the better filtration results that membrane filters exhibit, many major brewers around the world have considered switching their operations to include membrane filtration (Markovic *et al.*, 2003). It has however been found that they are relatively more expensive as compared to other filter media currently in widespread use. The commonly used filter media include various powdered filter medium which include diatomaceous earth, residual yeast, activated carbon, perlite and cellulose is determined by several factors. An example is the use of the cellulose fibers' filter press which were initially in wide use but due to their high costs, efficiency notwithstanding, were replaced by perlite and diatomaceous earth (Mathias *et al.* 2014). The other types of filter media such as the cellulose fibers are relatively expensive thus powder filters are the ones used in most cases. The sort of filter media that a brewer chooses to eventually use is determined by other equally important factors such as efficiency, process integration and availability to name but a few (Markovic *et al.*, 2003). An example of powder filters which is widely used in the industry is diatomaceous earth mainly due to their low cost and availability.

Poor clarification of the beer can give rise to various interruptions with the beer quality and appearance in the post processing bit of the beer process such as transportation and storage. Changes that are caused by rough handling such as shaking, high temperatures above the ambient, and photo exposure of the beer to light results in oxidation. The net effect of the oxidation is that the beer would lose its flavor profile and become more turbid. Thus in order to attain better colloidal stability in the beer, clarification techniques is used to remove the turbid materials for example, α and β glucans, yeast, proteins, and oxidized polyphenols (Markovic *et al.*, 2003).

The amount of filtration wastes obtained is inversely proportional to the clarity of the beer that is packaged for sale. In most cases filtration encompassed use of filters in combination with other materials such as adsorbent agents so as to achieve the desired result (Russ *et al.*, 2005). It is usually a multi-step process in which each step is responsible for elimination or minimization of specific turbidity agents (Mathias *et al.*, 2014).

Diatomaceous earth is the most widely used powder filter today with a conventional filter of 1-2g diatomaceous earth per 1 litre clarified beer. It has a very high organic material retention of polyphenols, proteins and yeast. Once the filtration has ended (saturated) the filter medium cannot be recycled. Saturation is achieved when the cake mass attains in excess of three times its initial weight (Fillaudeau *et al.*, 2006). The chemical treatment of the saturated filters has been attempted before however, complete regeneration has been hard to achieve despite the use of methods such as calcination and chemical treatment (Olajire, 2012). The organic composition of the saturated filter medium is dependent on the diatomaceous earth composition and the composition of the retained particles. The retained particles on the other hand depend on the wort; type of beer and the way the raw materials are treated. The protein content in the filter waste is between 8-15% w/w (Russ *et al.*, 2005). For this reason; the disposal of this waste into the environment is difficult since the high organic load would interfere with normal disposal techniques such as the common sewer. The main alternative for disposal as a result had been landfills but landfills are expensive and not always available. Due to the high moisture content of about 70%, the filtration waste could be used as a soil enrichment component. Alternatively the waste could be added to the malt bagasse for use as an animal feed (Briggs *et al.*, 2004).

2.3 Organic Fertilizers

The use of fertilizers in agriculture is one of the most significant advancements that were made past the Agrarian Revolution. Chemical fertilizers in particular completely revolutionized agriculture in Europe and North America by the early 20th century (Chesworth, 2008). Advancements in chemistry and chemical technology resulted in significant innovations such as the Haber process in Germany. The conversion of nitrogen gas from the atmosphere by reacting with hydrogen gas to form Ammonia was one of the most important chemical discoveries of the past millennium (Koenig & Johnson, 2011). The large scale production of ammonia is seen as the precursor to the increased food production rates that were witnessed in Europe before the outbreak of the First World War (IFA, 2011).

The leap to the use of chemical fertilizers in agriculture was not a sudden event as such. It was a culmination of man's need to bolster agricultural production in a far more consistent scale than had previously been achieved using organic fertilizers (Chesworth, 2008). The use of peat, compost and livestock manure had previously characterized farming. However, their use on a large scale had proved to be challenging mainly due to the low potency of the fertilizers, fluctuations in fertilizer compositions, difficulties in handability, strong stench and bulkiness (IFA, 2011). Thus the invention of industrial processes for the manufacture of chemical fertilizers was a welcomed occurrence.

Despite chemical fertilizers dominating agriculture, scientific research would unearth major environmental challenges that the fertilizers posed to the environment (Chesworth, 2008). Surface runoff of nitrogen containing fertilizers resulted in over nitrification of rivers and streams next to agricultural fields. The effect of this is the deterioration of aquatic life due to the reduction of dissolved oxygen that aquatic life needs in order to survive in the water ways (IFA, 2011). Another major challenge associated with chemical fertilizers is that of mineral complexation within the soil (Chesworth, 2008). Here, those nutrients that are supposed to be available for the plants to uptake end up complexing with minerals in the soil with the net result being that they end up being insoluble in water. Organic fertilizers also have their environmental challenges that they impact on the environment for example organic loading which results in an increased Biological Oxygen Demand (BOD) in water ways (Viets, 1962). This is especially true for locally used organic fertilizers such as manure where the aerobic requirements it imposes on the surrounding area can be quite significant especially in sights where it is heaped.

Organic fertilizers have been found to aid in the chemical chelation of fertilizers in the soil. According to Viets (1962), the net effect of this chemical chelation is increased availability of micronutrient supply of fertilizers to the plants. Hue *et al.* (1986) further showed that organic acids contained within organic fertilizers not only aid in conditioning the soil, they also play an active role in the cation exchange involving the metallic micronutrients. Organic fertilizers have considerably less compositional nutrient content than chemical fertilizers but the relatively lower nutrients are in a more available form to the plants (Hue *et al.* 1986). The reason why chemical fertilizers have higher ratios but still tend to be less available is that the available fraction keeps diminishing as the number of seasons of continual application to the field increases (Viets, 1962). Although crop rotation and intercropping limit over-fertilization of crop fields when chemical fertilizers are used, they still do not restore the available fraction to those that the soil initially had before fertilizer application (Viets, 1962).

2.4 Soil Enrichment

The main function of fertilizers is soil enrichment. Hue *et al.* (1986) showed that over the course of a growth period, a crop extracts nutrients from the soil at a rate that is considerably higher than the rate at which the soil can self-replenish. Although crops are not the only factors that remove nutrients from the soil, since soil erosion, leaching and deforestation also contribute (Koenig & Johnson, 2011). When these factors are held constant, crop cycles drain the nutritional resources of the field diminishing yields (Smith & Hui, 2004). It is for this reason that farming has, since the Agrarian Revolution, involved the use of some form of soil enrichment supplement. These supplements are aimed to return nutrients to the soil at a rate faster than natural processes such as the decaying of plant matter would normally do.

However, the amount of fertilizer introduced to the soil is not always proportional to increase in soil fertility, but is dependent on other factors, for example the type of release of a soil enrichment supplement (Tan, 1998). The difference in release between chemical and organic fertilizers is therefore a very significant difference when it comes to the choice of fertilizer. Chemical fertilizers generally tend to be fast release in terms of availing the nutrients to the crop during a particular growth cycle. It is for this reason that chemical fertilizers are often used for targeted growth such as is the case for top dressing during the flowering of a crop. By top dressing the farmer can robustly boost flowering of the crops by supplying the required nutrients and in a timely manner. Organic fertilizers on the other hand are generally slow release and are therefore may not be ideal for targeted growth (Smith & Hui, 2004). Hue *et al.* 1986 have shown that the fact that organic fertilizers are slow release is of great benefit

for agricultural fields. Organic fertilizers also improve soil aeration, water permeability, water retention capacity and the cation exchange capacity of some soils among other soil conditioning benefits (Smith & Hui, 2004).

2.5 Field Test

Field testing is a method of scientifically testing the efficacy of any given product after it has undergone extensive laboratory research. By conducting a field test, a researcher is able to merge theoretical expectations to real world realities (Chesworth, 2008). It is through such real world realities that a researcher is able to correct certain shortcomings that may have been overlooked during the initial analysis. Before conducting a field test however, there are some considerations that have to be taken into account. In agricultural field tests for instance, the kind of soil that is to be used for analysis has to be one that is easy to analyze. This means that it is advisable to use virgin soil or soil that is poor in nutritional composition (IFA, 2011). By so doing, a blank test can easily be distinguished from the treatment group due to the fact that any significant changes in nutritional composition in the treatment group can solely be attributed to the additives added and nothing else. Tan (1998) has shown that such poor soils can be used for subsequent analysis of other important factors of fertilizer application such as over nutrition. This can be achieved by replicating the amounts that would be applied in the farm over several seasons so as to see at what point crop rotation, soil conditioning and change to organic fertilizers can be recommended (Rowell, 1994).

The condition under which a field test is conducted is also an important factor when it comes to checking for the efficacy of any soil enrichment additives (Aizaki, 2013). Scientific research dictates that such conditions have to be highly controlled and strictly regulated so as to minimize or all together eliminate the effect of external factors (ASA & SSSA, 2010). It is for this reason that most field tests are initially conducted in greenhouses where almost every condition is documented and accounted for. After the initial runs in the greenhouse, the next stage is normally to conduct the tests in open fields in well demarcated blocks or plots where the treatment groups and blanks are in the same field. Once this has been done, researchers select farmers and divide them into treatment groups and control groups. Such farmers are those that normally plant the same crop, are in the same region and do their farming in the same period of time during the same planting season. After such a rigorous field test, the data can then be compiled and then the fertilizer can be recommended for use to other farmers (Rowell, 1994).

Together with the condition and state of the soil; the other major component of a successful field test is the choice of plant for analysis. The choice of plant can assist in pointing out shortfalls in the performance of a fertilizer. For example, the plant has to have several points of analysis from which a researcher can easily access and these points of analysis should be easy to physically spot any signs of nutritional deficiencies. The plant should have a short growth span so as to enable the researcher to take the shortest possible time to observe such deficiencies and also have adequate time to do a planting rerun preferably within the same growing season. The Kenya Agricultural Research Institute (KARI) has shown that potatoes provide an excellent plant when it comes to nutritional analysis (Oyoo *et al.*, 2013). Potatoes have several points on analysis that can be easily sampled for analysis throughout the growth period (ASA & SSSA, 2010). These include the leaves, flowers, stem, roots and tubers. Having such diverse points of analysis is important because they can show the suitability of a fertilizer for different growth periods. For instance the macronutrient nitrogen is very important for initial growth especially in the formation of healthy and robust leaves (Bohn *et al.*, 1985). Micronutrients such as zinc, copper and iron on the other hand are very important during the setting of the tuber. Therefore a potato can provide the necessary sampling points for a researcher to check for the availability and quantities of all the necessary nutrients in a fertilizer.

2.6 Pre Planting and Post-Harvest Tests for Macro and Micronutrients

Before any field test is carried out, understanding the characterization of the soil to be used, the filter aid waste and the various organic fertilizers to be blended is an important step. The importance is because it enables the researcher to understand the various compositional levels and the deficiencies which the plant has to contend with during the growth period.

2.6.1 Soil Test

For the soil tests, sampling was done on the top, middle and bottom layers. However, since all the fertilizers that were applied during planting were done in top dressing form, the results of the top layer were the ones that were used. The post-harvest soil analysis therefore included the nutrients that were left over in the top soil after the plant that had been planted the previous growth cycle has consumed the necessary nutrients it needed during its growth (Tan, 2005). Measuring the top soil only simulates the effects of leaching, plant uptake and surface runoff of the nutrients that normally occurs in farms. Therefore, by measuring the top soil, the research gives an accurate representation of what happens in a normal agricultural

field after the application of fertilizers, which means that the top soil together with its elemental content and physiochemical properties are what should, in theory, be available in the field for the start of the next planting cycle (Bohn, McNeal & O'Connor, 1985).

One disadvantage of only measuring the top soil is that there is a possibility that the mineral content obtained in the analysis may contain the unavailable nutrient portion of the total nutrient composition (Nissar *et al.*, 2000). These unavailable nutrients are in the form of ligands, organometallic complexes, metal complexes and inorganic compounds that for all intents and purposes can only be broken down into available by laboratory processes.

2.6.1.1 pH

The proper soil pH is important for suitable plant development since it affects the availability of essential nutrients to the plant (Tan, 2005). Therefore, for plants such as potatoes that grow over a wide range of pH values, the effect of pH on yield cannot be over emphasized since the availability, uptake, leaching and eventual retention of nutrients in the soil is normally governed by the sort of chemical reactions that take place in the soil. Examples of these reactions are: the decomposition of organic matter and minerals, the exchange capacity of cations in the soil and complexation. All these processes are affected by the nature of the reactants and propagators of the reactions to completion or equilibrium. For example for two soils containing roughly the same amount of zinc, the availability of the Zn^{2+} in the lower pH soil will be slightly higher than in the soil with a pH in the neutral zone all other factors held constant (Thornton *et al.*, 2008).

2.6.2 Available Macronutrients

2.6.2.1 Nitrogen

Post-harvest elemental content of the soil is important in assessing whether a fertilizer that was applied during the growth period benefited the soil by enriching it after the crop has already been harvested (Koenig & Johnson, 2011). Since nitrogen is one of the principal nutrients that is normally consumed by plants during growth, it is important that the farmer understands about its availability in the soil and the form in which it is available in (Tan, 2005).

Total nitrogen is an important procedure when trying to gauge the general condition of the soil, however, in cases such as a post-harvest analysis, the analysis for the nitrogen in the soil ought to be that of the available portion. This is because during the growth period, the plant

that had previously been grown in the field have already consumed most of the available nitrogen and what is left is a relatively small quantity of available nitrogen and a larger percentage of the unavailable nitrogen. Pending any significant conversion processes that turn the unavailable nitrogen into available forms, a post-harvest total nitrogen content analysis ought to be used in comparison with the pre-harvest levels to just give an indication of the uptake quantities for the crop so as to estimate the amount of fertilizer that can be used in the field in the next growth cycle.

2.6.2.2 Carbon

Soil organic matter is an important aspect of soil fertility as it affects the physical and chemical properties of the soil and these in turn have a bearing on the soil productivity (Aizaki *et al.*, 2013). Soil organic matter affects the physical characteristics of a soil by affecting such important factors as leaching, porosity, aeration and water retention capacity of the agricultural field (Aizaki *et al.*, 2013). These physical parameters have a bearing on the kind of plants that can be planted and their performance courtesy of how they affect the distribution and supply of nutrients in the soil. The chemical characteristics are affected by the nature of the products of decomposition that normally results after microorganisms work on the organic matter. Acidic or basic products are released depending on the starting materials in the organic matter. Chemical characteristics are also affected by the ability of the organic matter to distribute or release metallic cations in the soil (Bohn, McNeal & O'Connor, 1985). This release of cations is due to the cation exchange capacity (CEC) of the soils. It is through the CEC that important elements such as calcium and magnesium among other important micronutrients are made available to plants.

2.6.2.3 Phosphorus

Phosphorus does not easily leach from the soil and is therefore one of those elements whose addition to the soil during or before planting can last throughout an entire growth cycle (Bohn, McNeal & O'Connor, 1985). Despite the fact that the phosphorus content in a soil may be high, in most cases it is available in forms that the plant can not readily uptake. It is for this precise reason that Phosphorus is considered a limiting nutrient and why for this project it was the limiting nutrient of choice. The phosphorus is mainly up took in the form of orthophosphates (H_2PO_4^- and HPO_4^{2-}) which is obtained from a paltry amount of about 20% of the added nutrient (Bohn, McNeal & O'Connor, 1985). Anywhere between 20-80% of the phosphorus that remains in the soil and is not up took by the plants is in an organic form, most abundantly *Inositol Hexaphosphate* (Phytic Acid) (Richardson, 1994). Of the close to

20% of phosphorus that is not in organic form, the P is available in an inorganic fraction of about 170 different forms of minerals (Holford, 1997).

2.6.2.4 Potassium

Although K is normally available in most soils in large enough quantities to sufficiently meet the needs of the plant during the entire growth period, its availability to the plants is subject to several factors. One of the factors is the quantity of available K in the soil which is the sum of the water soluble K and the exchangeable K in the soil (Aizaki *et al.*, 2013). Another is the fixation capacity of that soil which fixes the K by extracting it from the fertilizer and limiting its availability to the crops. The ability of a soil to hold on to K and other cations also determines its availability to the plant. High soil organic matter content (percent carbon) translates into a greater storage capacity for K and by extension its availability to the crop (Bohn, McNeal & O'Connor, 1985).

2.6.2.5 Calcium

For calcium to be made available to plants it needs to be applied constantly due to the fact that it is not very mobile in the soil (Chesworth, 2008). This means that even if a field has significant amounts of calcium, a farmer will still be required to apply it so as to increase its availability to the plant. The amount of calcium in a soil is normally correlates to the pH of that particular soil. A high calcium content normally indicates alkaline conditions in the soil (Bohn, McNeal & O'Connor, 1985). Boosting the levels of Ca in the soil can be important if the crop to be planted requires basic conditions. However, it's worth noting that most of the problems that are associated with excess Ca in the soil are the secondary effects of high alkalinity in soils. The importance of calcium to a farmer comes about in its ability to maintain a chemical balance in the soil and as a result also reducing soil salinity (Tan, 2005). This is important especially in field where crop rotation isn't done and a singular crop is grown continuously. In order to keep the nutritional requirements and fertilizer application rates fairly constant, soil conditioning using lime is normally done.

2.6.2.6 Magnesium

Depending on the plant that is to be planted on the field, the amount of magnesium isn't of too much particular interest such as is the case with the macronutrients. Magnesium nonetheless plays an important role in the general growth process (Bohn, McNeal & O'Connor, 1985). Magnesium along with calcium is those elements whose availability to the plant is governed by the exchange capacity of the soil. Plants normally uptake magnesium in

its ionic form (Mg^{2+}) and a high content of Mg in the soil need not necessarily mean that the crops that are to be planted will have that amount of Mg available to them during the growth period (Bohn, McNeal & O'Connor, 1985). Magnesium is normally present in the soil in three principle forms: soil solution, exchangeable and non-exchangeable form. First is the magnesium that is found in soil solution. This form is readily available to the plants and is normally found in equilibrium with the exchangeable magnesium in the soil (Rowell, 1994). The second form is the exchangeable magnesium. This form happens to be the most important fraction as it is the one that actually determines the amount of magnesium in the soil that is available for the plant to use. It is this particular portion that is normally held by the soil organic matter and therefore the one that is released through the CEC mechanism of the soil (Rowell, 1994). The third non-exchangeable form consists of the magnesium that is in mineral form within the soil. Due to its complex constitution in mineral structures, the breakdown of this particular form in the soil is very slow and is thus not available to the plants (Rowell, 1994).

2.6.3 Available Micronutrients

2.6.3.1 Manganese

Manganese is a very important micronutrient in the soil whose role in plant development is especially important in the initial growth phase. At this stage, the manganese is a very essential element in the leaf cells that aid in photosynthesis (Chesworth, 2008). The total amounts of manganese that are obtained in a soil test do not necessarily indicate the amounts that are available for uptake by the plant. This is mainly due to the nature of the manganese and the complex reactions that it undergoes in the soil (Bohn, McNeal & O'Connor, 1985). Manganese biogeochemistry's complexity arises due to the fact that the element is present in a number of oxidation states (0, II, III, IV, VI and VII). However, for biological systems it is available in the states II, III and IV. Of all the biologically available forms, the divalent Mn^{2+} is the most soluble and thus available form whereas the trivalent and tetravalent manganese have very low solubility and thus are available in very minute quantities (Guest *et al.*, 2002). The availability of the divalent manganese is influenced by both the redox conditions and pH conditions (Ducic & Polle, 2005). In acidic soils, for instance, an increased redox potential can result in oxides being reduced thereby increasing the availability of Mn II. Whereas in alkaline soils, the auto-oxidation of Mn^{2+} over that of MnO_2 , Mn_2O_3 , Mn_3O_4 and Mn_2O_7 (Ducic & Polle, 2005).

2.6.3.2 Copper

An essential element in plant growth, copper is naturally found in most top soils in several forms with the amounts ranging from within 2 ppm to 100 ppm. The average however stands at about 30 ppm (Chesworth, 2008). For this particular soil, that is, the one that was used for the field test, it wasn't the top soil as it was obtained from a construction site after it had been dug from several feet below the surface. This was purposefully done so as to make the soil naturally deficient in several elements and therefore any growth attributed to nutritional was to be supplied by the addition of the filter aid waste, its various blends and other fertilizers. Thus a majority of the post-harvest copper content that is observed for the several bags can mainly be attributed to the effect of the added soil conditioning regiments. Soil copper content is mainly affected by the organic matter content and the pH of the soil (Bohn, McNeal & O'Connor, 1985). In terms of organic matter content, a high level inhibits the availability of copper by limiting the leaching and mineral fixation processes (Chesworth, 2008). However, on decomposition of the organic matter, an adequate amount of the Copper can then be released and made available for the uptake by plants (Bohn, McNeal & O'Connor, 1985). The effect of pH is such that soils within the acidic range are mostly deficient in copper whereas those with high alkalinity, above 7.5, and those that the pH is increased normally have a low copper availability.

2.6.3.3 Iron

The levels of iron that are obtained after a basic elemental soil test are not necessarily reliable enough to base an entire crop cycle on. This is mainly because although iron is found abundantly within the top soil, it is mainly found in unavailable forms. This iron is found in the form of hydroxides, silicate minerals and iron oxides (Chesworth, 2008). There is a correlation between the amount of soil organic matter and the availability of iron in forms that the plant can readily uptake. The organic matter reduces the precipitation of iron as ferric hydroxide and chemical fixation of the iron by combining with the iron in the soil (Bohn, McNeal & O'Connor, 1985). Iron salts are not very soluble in water and are thus mostly available in small quantities for the use by plants during growth (Rowell, 1994). Due to this low solubility, the quantities of iron present in the soil between the pre-harvest and post-harvest period do not vary too much. The fact that iron is not very soluble does not necessarily negate its importance in plants. It is a major constituent of chlorophyll and thus very important in the initial growth phase where a robust leave system is paramount in the growth of a healthy crop (Chesworth, 2008).

2.6.3.4 Zinc

Zinc is one of those nutrients that are generally used in very minute quantities. However, unlike other micronutrients such as calcium and magnesium the exact role of zinc in the soil and its importance isn't exactly known (Chesworth, 2008). What is known is that it is an important nutrient in the enzymatic processes that normally take place during the development stage. The levels of zinc in the soil are subject to interference by several factors. One of those factors is the pH dependence of the concentration of available Zinc ions (Zn^{2+}). As the pH levels shift from the acidic range through to the neutral range (6.5-7.5) the ability of the crop to uptake zinc reduces remarkably (Bohn, McNeal & O'Connor, 1985). The second factor is the relationship between phosphorus and zinc and the effect that excess phosphorus concentration has on the availability of zinc in the soil. This is especially true in cases where excess phosphorus is supplied through manure. It is however important to know that the manure fertilizer also has significant amounts of zinc that it supplies to the soil (Bohn, McNeal & O'Connor, 1985). Therefore, in cases where organic fertilizers such as manures are used in soil conditioning, a post-harvest soil test might indicate significantly high quantities of zinc which might not in practice be available to the next crop that is to be planted in the field in the following growth cycle.

2.6.4 Nutrient Uptake Trends During the Grow Period

The analysis of how nutrients make their way from the soil to the rest of the plant throughout the entire growth cycle of the plant is in itself the best indicator of the performance of a fertilizer (IFA, 2011). Waiting for the eventual harvest after crop maturation isn't an advisable gauging technique for checking for the performance of a fertilizer. A regular check during the growth cycle is the most advisable analysis technique due to the fact that by so doing, a scientist can correctly isolate the type of deficiency that a crop is experiencing and at what particular stage of growth that deficiency manifests.

Nutritional deficiencies normally manifest themselves at different stages of growth. In the case of potatoes for instance, phosphorus stimulates early root development while increasing the water usage efficiency for the growing plant. Therefore, if a farmer notices that the young potato plant is drying up and he uproots and checks a sample and notices that the seedling has a poorly developed root system, then that is a quick indication that the soil may be highly deficient in phosphorus among other nutrients. With such an observation, a timely intervention of adding fertilizers to that field can result in the crop being saved from utter destruction (IFA, 2011). Such a scenario is normally an extreme case of deficiency but is

nonetheless a case study that shows the importance of regular analysis to check for fertilizer performance in a plant.

In potatoes, checking for nutrient uptake can be done in any of several ways. The first method can be to check for the development and uptake in the roots. The other method is checking for the transportation of the nutrients through the stem. Lastly one could alternatively choose to check for uptake by gauging the levels of the nutrients in the leaves. This particular project chose to focus the nutrient uptake analysis on monthly tests of the leaves. This was arrived at due to a combination of many factors chief among which was the fact that the leaves are very good indicators of nutrient deficiencies due to their sensitivity to both over nutrition and under nutrition. It is however important to note that the availability of nutrients in the leaves is subject to different processes that take place in the plant and the interaction of the roots (or any other receptor part) to the source of the nutrient which in this case is the soil. Such processes are responsible for the contact with the nutrient source, absorption of the nutrients and the eventual transport of the nutrients to the rest of the plant.

2.6.4.1 Biological Absorption Coefficient (BAC)

The Biological Absorption Coefficient (BAC) is referred to as the ability of a plant to uptake elements or nutrients from the growth media. BAC is also referred to as the Index of Bio-Accumulation (IBA) or the Transfer Factor (TF). This ability of the plant is an important parameter through which a scientist can predict the possibility of deficiencies of certain elements in a crop that is under scientific observation. The BAC is useful in giving a ratio between the rate of elemental concentration changes in plant areas such as the leaves and the elemental concentration in the growth media (soil). From several studies such as those conducted by Alexander *et al.* (2006) show that different soil-plant systems have different reactions to both excesses and deficiencies of micronutrients such as the transitional elements of zinc, iron, manganese and copper among others. The above micronutrients have generalized Transfer Factor (TF) values for different soil-plant systems which were used in predicting deficiencies of these micronutrients in combination to the monthly uptake analysis levels. Cu and Zn have a TF of 10^{-1} while Mn has a TF of 10^{-2} while Fe has a TF of 10^{-3} .

2.6.5 Plant Processes

2.6.5.1 Root Uptake

The growth and development of the roots is the most important precursor to the proper utilization of a fertilizer that is applied for the benefit of the plant (Tan, 2005). This is

because, despite the fact that there are several means through which plants can uptake nutrients such as through the leaves for instance, the most potent means of nutritional uptake by plants is through the root system. In addition to it being the most potent route, during the initial stages of development it is normally the only means that is available especially for plants that start their growth as seed in the soil. In such instances other avenues of nutrient uptake aren't developed or operational enough for the plant to rely on for its nutritional needs.

Thus a robust and healthy development of the roots ensure that the plants kick start their growth by accessing those nutrients that are beneficial for their growth. It also ensures that the plant can realistically access the nutrients from the growth media (Kabata-Pendias, 2011). This is an important aspect as it correlates to the nutritional amounts that end up in plant extremities such as the leaves due to the fact that elemental concentrations are intrinsically linked to the chemical composition found in the growth media. The most crucial mechanism in the uptake of nutrients by the roots is the route through which elements and nutrients pass through in the intercellular spaces and cell walls of the cortex. The basics of root uptake aside, the nutrients in the soil are available for uptake by the roots in several means. The uptake can either be passively (non-metabolically), actively (metabolically) or through a combination of both processes. Both active and passive uptake methods depend on processes of uptake mechanisms in root surfaces such as rhizosphere effects, chelation influenced transportation inside the cells and the cation exchange capacity (CEC) the roots (Kabata-Pendias, 2011).

Passive uptake involves the diffusion of ions from the soil solution at the exterior of the root to the root endodermis. The passive uptake is normally related to those nutrients that are normally in plenty within the soil and easily go into solution. Elements such as Potassium, which are highly soluble and readily enter into solution within the soil, are passively up taken. Active uptake is determinant on the presence of metabolic energy so as to force the nutrients to leave the soil solution and get to the cell walls and intercellular voids of the root. Energy is normally required because there is a chemical gradient of the nutrients between the growth media and the root. Research findings from several investigations have shown that at the concentrations of micronutrients that are normally found in most soil solutions, their absorptions in the roots are metabolically controlled. There is also the ion activity within the soil solution which is one of the most significant factors that normally the plant uptake of other ions. Therefore the kind of ion activity that occurs in the soil influences the uptake of a

particular element and is most important for the case of active uptake as opposed to passive uptake.

Findings by Morel (1997) have shown that external cation concentrations within the soil solution that are lower than $0.5\mu\text{M}$ normally favor the active uptake of nutrients. On the other hand higher concentrations of above 0.1mM tend to passive uptake. The depletion of some micronutrients such as Mn, Zn and Fe from the interface of the soil and root however have been shown to reflect a higher mechanism of root uptake than can normally be associated with the mass uptake mechanisms or diffusion processes in the soil (Hinsinger *et al.*, 2006).

2.6.5.2 Absorption

Absorption happens to be one of the main sources for macronutrients and the source for micronutrients that are trace elements within the soil. The mechanisms of absorption for trace element micronutrients are mainly affected by the ability of the transitional element to bind to the soil constituent. Generally, plants uptake minerals from the soil in solution form (Tan, 2005). The nature of the nutrients that are found in solution can either be in chelated, ionic or complex forms. The absorption for macro and micronutrients differ significantly in the sense that the abundance of macronutrients in the soil means that they normally form relatively significantly higher concentrations in the soil solution. This is especially true for nutrients such as Potassium which readily enters into solution.

Micronutrients on the other hand owing to their relatively lower abundance in the soil and difficulties in some of them such as iron to enter into solution, normally form very low concentrations in the soil solution. The absorption for both these forms of nutrients occurs at the root surface from the soil solutions that they form. What this means is that it is the concentration of a particular nutrient in solution that determines its availability to the plant as opposed to the overall amounts within the growth media (Chesworth, 2008).

Due to the fact that the solution in which this nutrients are found in are with water in the growth media, the absorption of the nutrients is strongly dependent on the occurrence of H^+ and other ions that are also in solution with the moisture in the soil. It is worth noting that the absorption of nutrients by the plants isn't solely a function of their abundance in the soil solution. The process of absorption is sensitive and subject to various parameters both within the soil environment and the plant in itself. With regard to the soil environment, it is subject to properties such as the cation exchange capacity (CEC), aeration factor of the soil, the temperature of the soil solution, the pH and the soil organic matter (SOM) content.

Absorbance rates with respect to the plant are dependent on accumulation of different ions within the soil-plant interface. Such an accumulation leads to the selective and preferential uptake of other nutrients at the expense of others despite their abundance in the soil solution. An example is the effect of excess accumulation of K within the root and the effect it has on the absorption of the Ca and Mg cations. Preferential absorbance aside, absorbance in the plant is also dependent on the concentration gradient of an element that occurs at the soil-plant interface.

The intensity of absorbance differs for all the nutrients depending on the stage of growth and development of the crop. In potatoes, there are certain nutrients that are more intensively used during the initial growth phase such as nitrogen while others such as manganese are required in larger quantities by the plant during the later stages of maturity. Therefore for these two elements a look at their uptake values as shown by monthly leaf analysis shows a corresponding accumulation in the leaves during the growth cycle of the potatoes. The absorption rates are also influenced by the accumulation and immobilization of the nutrients in the root structure. This is especially in the case of sufficiently high supplies whereby the transportation of cations to the leaves seems to be controlled by the exclusion mechanism (Zhao *et al.*, 2001).

2.6.5.3 Translocation

After the roots have provided the appropriate sites for absorption and then plant processes have chosen the nutrients that are to be absorbed, those nutrients have to be transported throughout the entirety of the potato crop. The translocation of these nutrients within the plant involves several processes such as xylem transport, phloem transport and the immobilization, storage and accumulation of the nutrients within the plant.

For the case of cation translocation within the plant, the chelating ligands happen to be among the most important in the control of the transport of these metal ions. It is however not only the chelating ligands that determine the cation translocation in the plant, factors such as the redox state, pH, polymerization, hydrolysis; the complexation of the cations with organic compounds such as zinc and manganese (which is partially complexed) and formation of insoluble salts also determine translocation. An example is the formation of insoluble phosphate salts that limit the availability of cations in the leaves in cases where there is an over nutrition of phosphates within the potato plant.

Metal immobilization within the cells of the root have been found to hugely impact on the amounts of the corresponding cations that are transported to the plants extremities such as the leaves (Kabata-Pendias, 2011). Translocation of nutrients is also governed by the electrochemical variables in the plant cells as a result of the different elements. These electrochemical variables determine the ease of transportation of various ions based on the strength at which these ions are bound. Easily bound nutrients such as K and Na are very easily transported while moderately bound elements such as Mn and Zn are transported without so much difficulty while the strongly bound nutrients such as Cu and Fe provide more difficulty in transportation

2.6.6 Effects of Nutrients on the Leaves

Deficiencies and excesses of various nutrients that eventually show on the leaves are subject to several mechanisms that either work to inhibit their availability in cases of excesses or preferential uptake in cases of deficiencies. However, the close interdependence of micronutrients especially on the availability of macronutrients means that their inadequacies happen to be more pronounced (Peris *et al.*, 2007). But in cases of excess micronutrients in the soil, plants normally adopt through processes such as immobilization of excess nutrients, preferential up taking and root surface action.

In the immobilization of the excess nutrients in various organs such as the leaves of the plant, the nutrients are stored as immobile compounds such as minerals. The excess micronutrients can also be reduced after they have accumulated in the leaves by defoliation in which case the excess micronutrients find their way back to the soil. The roots can also play a major role by the selective/preferential uptake of only those nutrients that are not in excess in the plant. By the roots preferentially up taking only those nutrients that are not in excess, then those nutrients that are in excess end up complexing and chelating in the exterior of the plant (roots) within the growth media. The plant surface cells also play an important role in getting rid of excess nutrients by binding the excess ions in the cell walls after which a restructured influx of those ions occur through the cell's plasma membrane.

2.6.7 General Nutrient Trends in the Monthly Leaf Uptake Analysis

2.6.7.1 Nitrogen

Among the most important nutrient, nitrogen is highly useful for the growth and development of the potatoes. Next to the water that is consumed by the plant, nitrogen is the most consumed additive that is consumed and is passively up taken by the potatoes. Due to its

abundance and importance to the plant throughout the growth cycle, nitrogen is consumed throughout the entire growing period (Barker & Pilbeam, 2007). Nitrogen is important in the robust growth of leaves and is an important component of the chlorophyll molecule and is thus important in photosynthesis. It is also an important constituent of nucleic acids, proteins and nitrogen is readily available from the rapid growth phase to the end of growth where its availability to the plant is made available to younger tissues from the older tissues. The trend is such that the levels start very high in the first month but gradually drop by the third month.

2.6.7.2 Phosphorus

Next to Nitrogen, Phosphorus is the most heavily consumed nutrient by the plant. It is a very important constituent of the energy molecule ATP and in general constitutes about 0.2% of the plants dry matter (Morel, 1997). The uptake of phosphorus by the plant is influenced by the availability of magnesium which normally determines the uptake of Pi (available form of P in the soil) from the soil and thus the availability of P in the leaves. The Pi is actively absorbed by the plant due to the fact that its concentration in the soil rarely exceeds 10 ppm with the active uptake necessarily so as to raise the concentration of the Pi in the plant by up to 1000 times than in the soil (Morel, 1997).

2.6.7.3 Potassium

A sufficient quantity of potassium in the soil normally translates into sufficient levels of the K in the plants as can be observed in the leaves. Plant cells normally accumulate potassium from relatively dilute soil solutions. The availability of the K occurs passively via a discrete high and low affinity mechanism at the plasma membrane of the roots. Potassium is used in many vital processes one of which involves the regulation of the opening and closing of the stomata which is a rate determining step in photosynthesis (Maathius & Sanders, 1996).

2.6.7.4 Calcium

The presence of calcium in solution normally enhances the selectivity in the uptake of metabolically important elements preferentially against unwanted ones. To this effect the availability of the cations of potassium and magnesium affect the levels of calcium that are detected in the leaves (Cotrufo *et al.*, 1963). Calcium is important in the structural composition of plant cells such as the leaf cells where sufficient levels of Ca enables the proper functioning of stomata cells and the overall performance of the photosynthesis process.

2.6.7.5 Magnesium

Magnesium is the main constituent of the chlorophyll molecule which is very important in the photosynthesis process. An acute deficiency of magnesium normally results in poor chlorophyll formation and performance hence affecting the plants ability to properly grow (Barker & Pilbeam, 2007). As a very important element in photosynthesis, Mg from the growth media is normally preferentially up taken by the roots through passive by diffusion and is then goes through mass transport so as to reach the leaves.

The portion of the Magnesium that is normally up taken by the plants is usually in exchangeable form and whose availability is highly dependent on the levels of other cations namely potassium and calcium within the soil. This means that the levels of Mg that are eventually detected at the monthly leaf uptake analysis are also subject to the availability of the other cations within the very leaves.

This trend is to be expected considering the important role that Mg plays in stomata formation and photosynthesis; thus during the 1st and 2nd month during which time the potatoes are undergoing robust growth and hence they are highly required (Gugala *et al.*, 2012). The case for the third month is such that the potato tubers have already grown and are only setting while the vines are beginning to die off as the leaves also dry out. At this particular stage of growth, the plant undergoes very little, if any, photosynthesis and therefore nutrients that are highly utilized for this process are in very small concentration at the leaves.

2.6.7.6 Iron

The amounts of iron that are available within the plant are governed by the nature of uptake that it undergoes from the roots. The difficulties in the uptake of Fe mean that the amounts of the element that end up in the plants extremities are in small amounts. Before the Fe travels up the roots through the stem, a plaque accumulation first occurs which is a gradual process and what this means is that the levels of iron in the leaves start up low in the first month as they gradually increase by the third month. Thus at intensive growth rates at the beginning the levels are low in the young leaves but the eventual build up means that the older leaves tend to have more concentration of the element (Kabata-Pendias, 2011).

2.6.7.7 Copper

Copper is an important element in the functioning of the plant due to its significant role in plant respiration and photosynthesis. Although the Cu is strongly bound to the root surface, it is normally made available to the plant with relative ease from the onset of growth up to

maturity (Kabata-Pendias, 2011). This explains the trend of availability of copper to the plant through its composition in the leaves.

2.6.7.8 Manganese

During the intensive growth period, there is an accumulation of Mn at the root surface which is gradually released and translocated to the leaves and other plant organs as the plant continues to mature (Cotrufo *et al.*, 1963). Manganese is always up taken by the plant when in partially complexed form. What this means is that the form in which it is complexed normally determine its availability to the plant.

2.6.7.9 Zinc

Zinc is an essential element in the several plant processes among them being the formation of carbohydrates and chlorophyll. It is relatively mobile in the plant and its movement from the roots to organs such as the leaves is subject to the movement of the complex in which it is bound to within the plant. Zinc is normally bound to organic compounds in its complexed form and thus its availability is wholly dependent on the plants selectivity towards the absorbance and translocation of the organic compounds.

2.7 Tuber Development

Tubers first start to appear in the potato plant once the crop attains a height of between 15cm and 20 cm. At these heights, the crop has already established numerous leaves and the stem has sufficient strength to support the growth of more leaves. The formation of tubers typically appears once the plant has been growing for between 5-7 weeks. At this stage, the plant that eventually develops tubers has enough nutrients to get through the initial stages of crop growth and propagation (NPCS Board of Consultants & Engineers, 2007). It should however be noted that the fact that tubers start to appear does not mean that the plant has sufficient nutrients to last the entire growth cycle.

Although tubers can be harvested while the vines are still green, for the purposes of analysis in the project, the tubers were left to develop to maturity for 100 days to a point where the vines and leaves had dried up. Mature tubers have been found to have a higher dry matter content thus making them better for use in processing and for scientific analysis purposes. Mature tubers also have tougher skins which happen to be much more resistant to bruising and skinning during harvesting. The skinning and damage of tubers can cause stress which leads to physiological ageing of the tubers. Skinning and bruising often reduce the aesthetic

value of the potatoes which may negatively affect the income of a farmer. Skinning and bruising are the most responsible effects for potato damage. It is therefore more prudent to let potatoes achieve full maturity because at full maturity the effects of skinning can be minimized. This is especially true for the case of seed potatoes whereby the skin is set before harvesting so as to reduce the impact of skinning and give the seeds longer storage life.

2.7.1 Factors Affecting Tuber Development

The development of tubers is linked to several factors in the growing field which include:-

2.7.1.1 Soil

Potatoes generally require viable, deep and well drained soils. Such soils ensure that the tubers can form without any physical hindrance from the soil. The soil that was used for this project was well drained and the amounts put in the planting bags ensured that the potatoes had a deep soil for proper root and tuber development. A soil high in organic matter content also favor the development of healthy viable tubers especially in cases where they are properly drained. Drainage of a soil is directly linked to its aeration due to the fact that the voids to be used as pathways by the water are normally the same that are used for aeration. The organic fertilizers that were used had high organic matter content and the blending with the filter aid waste significantly improved aeration in the top soil.

The depth at which the potato seed is planted at also affects the eventual development of the tubers. The tubers in the project were planted at a depth of about 10 cm which was sufficient enough because by planting in a bag the effects of erosion on minimizing the depth at which the seed is planted is eliminated. Shallow planting normally results in the depletion of early season moisture and eventually to lower marketability of the tuber due to small sized, green and tubers that have been exposed to the surface during the growth period. Deeper planting though isn't the automatic solution to challenges posed by shallow planting. There should be an average depth at which once the tubers are planted they do not end up exposed to the surface. The disadvantages of deeper planting include: poor crop development, delayed emergence of the shoot, a higher soil lift and an eventual reduction in yield.

2.7.1.2 Size of the seed

The size of the seed normally affects the kind of planter operations that can be applied in a field. Planter operations such as weeding may be affected if the tubers are planted in such a way that they hinder proper weeding especially in cases where small tubers are all over the hill. For higher yields, larger tubers are preferred because they can be planted at significantly

deeper depths than smaller tubers and still emerge. The size of the seeds that were used for this project measured between 3.5cm and 5cm in diameter. In addition to that, hilling normally aids the larger tubers as heaping the soil normally provides the best environment for big tuber seeds.

Big tubers aren't necessarily the answer to best yields though; this is especially true for excessively large tuber seeds (NPCS Board of Consultants & Engineers, 2007). Such tubers produce too many shoots during growth within the hill thus increasing the tuber set significantly. The net effect of this is that the tubers that are eventually harvested, although many in number, have small tuber sizes.

2.7.1.3 Fertilizer

Fertilizers provide the necessary nutrients for a plant to develop properly. But for a plant to develop properly it requires only the necessary nutritional supply that results in the best yield. To this point tuber development may be adversely affected by over fertilization of the soil. The fact that all the fertilizers that were applied to all bags had been standardized to the recommended application rates by KARI using phosphorus as the limiting nutrient meant that cases of over-fertilization of the field had been eliminated.

2.7.2 Effects of Various Nutrients on the Tuber

2.7.2.1 Nitrogen

Too much Nitrogen nutritional content in the tubers results in the potatoes having a watery texture and having low cooking quality. An excess of nitrogen in the soil normally results in delayed tuberization, create an environment that promotes infection by certain pathogens and results in slow tuber skin development during maturity (Stark *et al.*, 2008). A growth fluctuation can result in cases where top dressing during the growth period is used. This is due to the fact that fluctuating levels of nitrogen for instance results in a hollow heart, misshapen tubers and a brown center. The addition of nitrogen fertilizer has an effect on the tuber yields up to a certain point. However, higher applications have been found to delay tuber development (Stark *et al.*, 2008). Over application on the other hand delay the potato set, maturity of the tubers and leave the leaves susceptible to blight.

2.7.2.2 Phosphorus

Phosphorus deficiencies result in storage problems, black spot bruise and brown centers in the potatoes. On the other hand, sufficient P concentrations result in early rooting in the plant.

It also encourages later maturity in the potatoes whilst giving the potatoes harder skins (Kirkby & Pilbeam, 1984). Sufficient amounts also increase the dry matter content of the potatoes while increasing the dry matter content of the potatoes.

2.7.2.3 Potassium

Sufficient quantities of potassium normally results in increased tuber sizes. As opposed to the muriate of potash, the sulphate of potash normally increases the tuber dry matter (Kirkby & Pilbeam, 1984). However, an excess amount of K for example in the form of sulphate of potash may affect the dry matter content by slightly reducing its quantities. Amount of the potassium aside, the form in which the K ions are made available to the plant also affect the uptake of potassium. For instance the rate at which one plant uptakes K ions from the muriate of potash differs significantly to how another does. This is because while in solution the muriate contains both K^+ and Cl^- ions and therefore the kind of hindrance that the chloride ions offer to the uptake will depend on the plant's need for the chloride ions and whether it can readily get them from another source.

2.7.2.4 Calcium

The deficiency of calcium in the growth environment results in development of an internal brown spot in the tubers. The deficiency of calcium in tubers is normally as a result of the poor uptake of the element by the plant. In addition to the poor uptake, there also tends to be problems that result due to the distribution of the calcium in the plant. Potatoes normally have very limited ability to regulate the distribution of calcium between the low transpiring organs (tubers) and the quick growing tissues (leaves) (Kirkby & Pilbeam, 1984). Despite these challenges associated with the uptake and eventual distribution of calcium in the tubers, it is only extreme cases of deficiencies that can manifest into physically observable parameters.

2.7.2.5 Magnesium

Sufficient levels of magnesium in the soil normally results in larger tuber sizes. Severe Mg deficiencies can result in a yield reduction of about 15%, while a regular use of Mg has been shown to increase potato yields by between 1% and 10% in trials (YARA, 2015). Magnesium is required by the plant in adequate levels so as to aid during the tuber bulking stage. Proper irrigation is required so as to keep the moisture levels in the soil high enough in order to prevent the restrictive effect of dry soils on Mg uptake.

2.7.2.6 Iron

The levels of potassium in the soil negatively correlate to that of Iron in the tuber whereby higher K content results in lower Fe content in a tuber. A study showed that the application of higher K doses resulted in a decrease of up to 32% of Fe in the tuber dry content composition compared to soils where only recommended levels of K were applied (Panique *et al.*, 1997). Therefore, a deficiency of iron such as that occasioned by excess K levels in the soil normally result in the tubers having less nutritional value. This might not be very apparent by just looking at the potatoes however chemical analysis of the nutritional content of the tuber can point out to the Fe deficiency.

2.7.2.7 Copper

An increased level of potassium in the soil normally affects the copper content that the tubers eventually attain (Stark *et al.*, 2008). Too much P levels normally decreases the copper content in the tuber by decreasing the dry matter content of the potato.

2.7.2.8 Manganese

Manganese is an important element especially in the tuber development stage. Its main effect is in the skin finishing phase of tuber development whereby sufficient levels of manganese in the soil results in a proper skin finish for the tubers (Mohamadi, 2012).

2.7.2.9 Zinc

Zinc is a very important element in the metabolism of carbohydrates, synthesis of proteins and enzyme activation such that its uptake in sufficient quantities results better quantitative and qualitative performance of tubers (Mohamadi, 2012). Zinc has been found to have a positive impact on the quality of tubers by increasing the tuber yield and mean weight of the tuber (Alloway, 2004). An excess of zinc in the tubers can be indicated by its effect on enzymatic reactions that the potato undergoes once the raw potatoes have been peeled. For instance the phenolic compounds and tyrosine compounds within the tuber undergo enzymatic discoloration faster due to the oxidation of these compounds resulting in the formation of ferric dihydric phenolic complexes after cooking (NPCS Board of Consultants & Engineers, 2007).

2.7.3 Effects of Various Factors on Tuber Quality

Over fertilization isn't the only effect of poor fertilizer application practices that affect tuber development.

2.7.3.1 Cultivation

Cultivation is an important practice that aids in increasing the water flow rate and aeration within the soil and killing of weeds that would have otherwise competed with the principal crop for nutrients in the field. It also ensures that the hill is properly shaped so as to ensure maximum tuber growth. In the project cultivation was done before planting so as to ensure that the soil was properly aerated and that it mixed properly with the fertilizers that were applied.

Multiple cultivations are however not encouraged due to the adverse effects it may have on the plant's growth (NPCS Board of Consultants & Engineers, 2007). These cultivations have been known to cause compaction of the soil which eventually ends up reducing aeration and the growth of the tubers. The net effect is that the potatoes can end up being bruised during harvesting due to the production of clods. Another negative effect of cultivation is that it may end up setting some of the tubers higher within the hill. Such tubers are eventually left exposed to the sunlight thus resulting in greening and poor tuber development.

2.7.3.2 Defoliation

Defoliation is the practice of cutting down excess leaves from a growing plant. In this project defoliation was practiced but not in the traditional sense of the practice. Young, healthy and green leaves were not cut from the potato crops. Instead those leaves that had matured and started to dry out were the ones that were pruned out from the plant and deposited on the growing surface (Stark *et al.*, 2008). Weeds that had also grown on the planting surface were also pruned and deposited on the surface of the planting bags.

This foliage has been found to aid in the maturity of the tubers by helping to set the tuber skins. In addition to this, defoliation is normally done to minimize the potential of viral infections and diseases. Generally it is more desirable to have the plant dried up for the purposes of foliage. This is because by cutting green leaves, one may interfere with important plant functions such as photosynthesis and end up negatively affecting the yields of the plant (Love *et al.*, 2001). This is especially true for tubers that are to be used for seeds and have to be stored for significant periods of time. Defoliation does not necessarily result in an increase in tuber quality, it however aids in the achievement of a desired skin set which may eventually assist in increasing the storage tolerance of the potatoes by minimizing the effects of bruising. Under certain conditions, such as the production of potato seeds, defoliation may be necessary so as to control the size of the tuber.

2.8 Tuber Characterization

A tuber characterization is the surest way to gauge the yield of the potato plant. This is because it is only via such characterization that the potency of a particular fertilizer can be gauged. Characterization also helps in ascertaining the general health of the harvest. Infections on the potato during the growth period normally have an adverse effect on the yield and quality of harvest. This is especially true for infections that aren't particularly visible on the vines and whose effects are only eventually noticeable once the farmer harvests his crop.

The potato tuber analysis was done in two ways. The first was the physical analysis and the second was the chemical analysis.

2.8.1 Physical Characterization

The physical analysis was done so as to serve as an indicator of the quality of the yield. This analysis, though not a scientific parameter for determining yield quality, was done mainly due to the fact that significant deficiencies and infections to the potatoes are easily observable. Physical characterization is also important due to the correlation to which farmers attach between the appearance and quantity of the harvest to the quality of the yield.

The physical parameters that were considered included:

2.8.1.1 Potato Colour

The colour of the potato tubers relate directly to the planting conditions and how the hill was set (Stark *et al.*, 2008). The planting conditions such as the depth of planting have an impact on the eventual colour of the tubers. For those tubers that were planted at shallow depths, over the course of growth the tubers become exposed to the sunlight thus ending up with a greenish colour.

2.8.1.2 Brown and Black Spot

The occurrence of a brown spot within the flesh of the tubers indicates a deficiency of certain nutrients that are essential for the development of a healthy viable tuber. The deficiency of calcium in the soil normally results in a brown spot developing inside the tuber. The size of the brown spot and the intensity of the brown colour depend on the extent of the deficiency that the potato crop had. A black spot bruise results as a result of significant deficiencies of Phosphorus in the soil (NPCS Board of Consultants & Engineers, 2007). In addition to the

black spot bruising the potatoes growing in such a phosphorus deficient environment also have a darkened colour.

2.8.1.3 Potato Skin and Bruising

The potato skin appearance is normally an indication of the maturity levels of the potatoes with those tubers that have completely matured having a set skin. The bruising of tubers is closely linked to the potato skin due to the fact that potatoes whose skins haven't set properly tend to bruise more easily (NPCS Board of Consultants & Engineers, 2007). Bruising is also affected by the planting operations that a farmer undertakes both during the planting period and the harvesting time. Cultivation may result in some tubers being bruised while in harvesting care should be taken when digging up the tubers so as not to damage them. Bruising normally affects the storage time of tubers and also gives access points for infection.

2.8.1.4 Potato Weight and Size

On the face of it the weight or size of potatoes doesn't necessarily translate to a better yield. This is because perhaps a different number of seed was planted in each field and therefore different quantities and dimensions of harvest are to be expected. Also the size of the seed dictates the number of shoots that eventually emerge from the soil and eventually grow into vines and develop tubers (Stark *et al.*, 2008). This means that the harvest quantity cannot wholly be dependent upon as an indicator of yield comparison especially in the phase of such unique variables.

2.8.2 Chemical Characterization

The chemical analysis is the scientific basis through which yield quality can be determined. This is due to the fact that through a chemical analysis, the nutritional value of the tuber can be determined and the health benefits accrued such as energy content, food group content and the recommended dietary allowance once consumed (NPCS Board of Consultants & Engineers, 2007). A chemical analysis further serves to give the extent of the deficiencies that the potatoes harvested have. This in essence qualifies the observable deficiencies that are noted during the initial screening and physical characterization (Holford, 1997).

There is a direct correlation between the soil mineral content and the potato tuber mineral. This is due to the fact that in the lack of any other external source of nutrients, all the nutrients that end up in the growth and development of the potato tubers are as a result of the mineral composition within the bag. The minerals amounts obtained from tuber analysis

normally differ in the same soil conditions depending on the variety of potato that has been grown.

Soil characteristics also influence the nutrients that are eventually measured in the tuber analysis (Love *et al.*, 2001). However, for this particular project a single variety of potatoes was used coupled with uniform soil dug up from the same site. By keeping these two particular variables constant, the elemental compositions that are eventually obtained during tuber analysis are due to the variable of the type of fertilizer that was used in each bag. Potato nutrition therefore has an effect on the overall yield of the potato crop; the size of the tubers harvested which includes the dimensions and weight of the potatoes (Love *et al.*, 2001). It also has an effect on the overall quality of the harvest such as the tuber skin set, nutritional value and health of the potato.

2.9 Yield Performance

There are several techniques that can be used in order to determine whether a potato harvest gave out the best possible yield (Kleinschmidt, 1984). In order to understand how such parameters are important and their usefulness, the definition of yield has to be brought into play.

According to Webster's dictionary (2013), Yield, as pertaining to agriculture, is defined as: To give forth by a natural process and especially by cultivation a productive natural product. Scientists also agree on this definition by go a step further by setting out the various parameters which can be used to classify yield (Kleinschmidt, 1984). Thus in a scientific sense, the productivity of a yield is not just the exemplary performance of one parameter, but it is rather a function of many parameters that come together seamlessly to give a greater classification of a produce.

With regard to the farming of potatoes, some of the parameters that are considered as being important towards the determination of a good yield include but are not limited to the physical characteristics of the potato harvest (Agriculture and Food Development Authority, 2013). Such characteristics include: weight of the potato harvest per hectare, size of the potatoes harvested, average weight of the potatoes harvested and colour of the tuber flesh.

These physical qualities are the ones that farmers happen to lay the greatest emphasis on due to the fact that they are easily identifiable and universally accepted as great indicators of yield (Love *et al.*, 1998). From a scientific point of view, researchers and nutritionists agree that chemical characterization plays a far greater role in determining the quality of the yield especially in cases where a comparison of different fields has to be done. In instances where

the physical attributes of different harvests both indicate that there was a proper yield in terms of the weight of harvest for two or more field for instance, a more detailed parameter may be required to distinguish the yield quality. This is where the chemical characterization comes in.

There are several techniques that are available for use in determining the yield via chemical characterization and these techniques are all dependent on the parameter of interest or objectives of the test. A nutritionist or dietician may focus their chemical analysis on the nutritional content of the potatoes in terms of carbohydrate, protein, vitamin and fat percentages (Davies *et al.*, 2004). A scientific researcher may limit their research on the elemental analysis of the potato tuber. This project chose to focus on the later due to the fact that the main objective of the project was to look at the use of beer filtration waste as a fertilizer. The most potent way of analyzing the performance of a fertilizer, especially when doing a comparative study, is to do an elemental analysis of the end product of plant growth. An elemental analysis also enables a researcher to track the flow of nutrients from the growth media to the extremities of the plant all the way to the final growth product (Chesworth, 2008). By doing such a test, the researcher, such as is the case in this project, can correlate the fertilizers applied to each field to the elemental composition in the final product for each field and compare the quality of the yield.

For a comparison of the yield quality of various fields to be considered as being a true representation of what a good yield is, there are certain basic parameters that have to be established (Davies *et al.*, 2004). Such parameters include that the potatoes should not have suffered and disease or fungal infection and the tubers should not have any significant observable physical blemishes. In addition to these two, the flesh of the tuber should not have observable deformities such as a brown spot that clearly indicate a significant elemental deficiency (Stark *et al.*, 2008).

For the case of this project, all the potatoes that were harvested did not show any deficiency in nutrients throughout the growth period. This was confirmed by the physical and chemical analysis that was done in the tuber analysis stage. As such a comparative yield performance index could be done due to the fact that a healthy harvest that, for all intents and purposes, had undergone the same growing conditions was being compared so as to gauge the best performing fertilizer. Due to the difficulties of establishing the yield performance, this project chose the use of measurable parameters for both the physical and chemical analysis tests that were done.

Based on the 5 physical parameters that were classified in this project the yield interpretation as to the bag with the greatest/best yield varies.

2.9.1 Yield Performance Index - Physical Parameters

The performance of potatoes from each planting bag was ranked from 1 – 10 with the best performing potatoes given a rank of 1 and the worst performing potatoes a rank of 10 with the other potatoes ranked in an ascending manner in terms of performance in between.

In cases where some potatoes from different bags had the same values, they were ranked using the same number and then the next value given the immediate following number.

After ranking the parameters from 1 – 10, these ranking numbers were assigned percentage values with the highest ranked number 1 given a 100% value while the lowest ranked number 10 was given a 10% value. From these assigned percentage values, a yield performance index was obtained by adding up all the assigned percentages for all the parameters from one bag and then divided by the number of parameters so as to get the yield performance index.

The same mathematical application was applied to all the bags and an overall yield ranking obtained that were then used to calculate the best yield based on the physical characterization as far as the five parameters are concerned.

2.9.2 Yield Performance Index - Chemical Parameters

The chemical parameters of a harvest give a more detailed representation as to the quality as opposed to the quantity of the yield (Davies *et al.*, 2004). In as much as it is the physical parameters that are most easily noticeable and relatable to the ranking of a yield as being either good or bad, the quality of the yield happens to be a more significant indicator of yield. The most desirable harvest is that which the physical and chemical parameters of the yield are in agreement. This means that a huge potato harvest should also have the optimum chemical characteristics for the potatoes (King *et al.*, 2011).

Chemical parameters for yield determination are especially important when it comes to scientific research as it helps the researcher to track the movement of nutrients during the growth period from the growth media all the way to the harvest product (Stark *et al.*, 2008).

CHAPTER THREE

METHODOLOGY

3.1 Sampling

The procedure that was to be employed in sampling determined the results of this study (Tan, 2005). The sampling had to be as representative of the study as possible such that successive runs of the same study could give reproducible results under the same conditions and analysis procedures.

3.1.1 Sampling Area

The sampling area was within the Tusker Brewery of the EABL. Dry samples of the used filter aid were taken from the back-filling site at various points of the waste heap as shown in Figure 3.1 below.

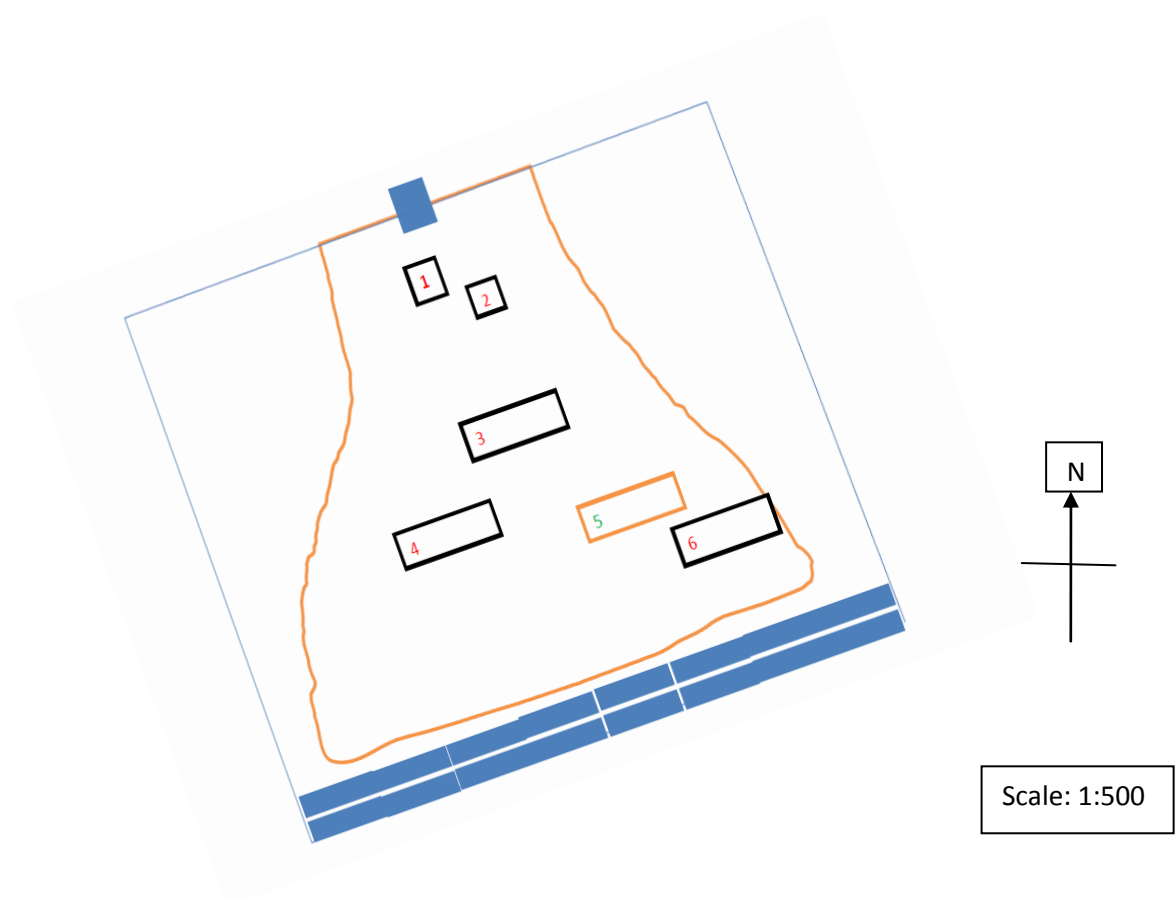


Figure 3.1: Sampling points within the backfilling hill

Key:

- 1: Approximately 3 weeks old
- 2: Approximately 6 weeks old
- 3: 4-5 months old
- 4: 7-9 months old
- 5: Over 1 year old
- 6: 9-10 months old

In addition to the six sites within the back-filled site, two other wet sampling points were included. The first was a slurry sample from the Filter aid exit site. A sludge sample from a tractor bed from which the filter aid is first left to settle before back-filling was also extracted. All the samples were taken in triplicate from a distance of 0.5m apart at each sampling point for the dry samples.

3.1.2 Sample Collection Procedure

The wet samples were taken after between a few hours of release for the slurry and about two days of being deposited for the sludge sample. The dry samples were taken from various points of the heap at the back-filling site. The samples ranged from between 3 weeks after deposit and slightly over a year of deposit. For sample points 3, 4, 5 & 6, the sampling had to be done at a depth of between 15-30 cm because the heap at these points was covered with vegetation and to avoid effects of runoff interference. The wastes were fetched and placed into carefully labeled sample bottles for the wet samples and polyethylene bags for the dry samples (Tan, 1998).

3.1.3 Sample Treatment

The samples were stored in a cool and dry place where they were left in the open for aeration (ASA & SSSA, 2010). Subsequent sample treatment was done before any chemical analysis was done. For the slurry sample, sieving was done so as to get rid of any suspended materials and insects that were in the slurry. After being left to settle for about five days, the slurry separated into a liquid and a fine powdery deposit at the bottom. The liquid was ejected and the powdery deposit filtered under vacuum in a buchner funnel so as to obtain a light brown powder for chemical characterization. The sludge paste was spread over a polythene sheet on

top of a lab bench and left to air dry. After seven days, the cake had dried up and formed a light brown powder which at that point was ready to undergo characterization.

The dry samples also underwent some basic preparation such as drying so as to be ready for chemical analysis. Samples from points 3 to 6 in the heap had to be air dried in order to bring the moisture content to below 10%. The samples were then sieved so as to get rid of roots, broken glass and other plant materials.

3.2 Experimental Procedures

3.2.1 Determination of pH

The measurement of pH, a widely used electrical method of analysis, was done on each sample. A pH meter model IQ150 was used to determine the pH values of the samples. A 2g sample was weighed and dissolved in deionized water in a small 50 ml plastic bottle. Deionized water was then added until an approximate volume of 25 ml. The bottle was then shaken well so as to ensure that the sample was dissolved. The pH probe was then immersed into the bottle and the pH reading noted. This procedure was then repeated for each sample and the reading noted.

3.2.2 Analysis of Nitrogen

The Kjeldahl method was used in determination of the total nitrogen content in a sample. In the wet digestion method, the sample (in triplicate) was digested for five hours using concentrated sulphuric acid so as to convert all the nitrogen present in the sample into ammonium (Bohn *et al.*, 1985). The Kjeldahl method was preferred due to its relative simplicity and its efficiency in terms of completeness and speed of the conversion of the nitrogen into ammonium. In order to raise the efficiency of the digestion of the sample, salts and a selenium catalyst were added. The salts were useful in raising the temperature at which the digestion took place while the selenium catalyst promoted the oxidation of the organic matter in the sample (Rowell, 1994). The standard Kjeldahl method used was thus a two-step analysis process the first being the digestion of the sample so as to convert nitrogen into ammonium and secondly the determination of the amount of ammonium in the digest. Exactly 10g of air dry sample that had been ground to pass through a 0.5mm sieve was weighed out before being carefully transferred to a 500ml Kjeldahl flask. 10.0g of mixed catalyst was then added and washed into the flask with 5-7ml of distilled water. 20ml of concentrated 36N H₂SO₄ from a graduated cylinder was then added. The acid and sample

were then mixed by gently shaking and then allowed to stand for 20 minutes. The flask was then heated gently and cautiously in a fume cupboard. When digestion was completed, the flask was allowed to cool. On cooling, 100ml of distilled water was added and shaken to mix. The mixture was then transferred to a 250ml volumetric flask and made up to the mark.

3.2.3 Determination of Ammonium (NH₄) in the digest by distillation

This step involved the determination of the ammonium present in the digest by distillation with an alkali and the subsequent titration of the distillation product. 50.0ml of the digest was pipetted into a 500ml Kjeldahl flask and to it 200-250ml of distilled water and two glass beads were then added. The distillation apparatus was then set up in such a way that the lower end of the Liebig condenser led into a 500ml conical flask that contained 50ml of 2% boric acid solution and a few drops of mixed indicator. The Kjeldahl flask was held at about 45° and 25ml of the 10N NaOH gently poured down the neck of the flask and then immediately connected to the distillation apparatus. The flask was then swirled to mix the contents and commence distillation. The flame was regulated so that the distillate was not too hot above 35°C. The distillation continued until close to half of the liquid in the Kjeldahl flask had been distilled. The receiver flask was lowered so that the end of the condenser was out of the liquid before the distillation was stopped so as to prevent sucking back action. The amount of Ammonium in the distillate was then determined by titration with 0.01N HCl. The colour changed at the end point green to grey to pink. The following correlation was used so as to calculate the percentage of nitrogen in the sample:-

- 1 ml of 0.01N HCl in the titration is equivalent to 0.14mg Ammonium.
- If a 10.0g sample was to be used to give 250ml of digest from which a 50ml aliquot was distilled, then the % N in the sample was:

$$\frac{\text{ml acid} \times 5 \times 0.14}{\text{wt of soil (mg)}} \times 100 = \text{mg of N}$$

Assuming a reading of 30 ml of 0.01N acid and 10.0g of soil, then the calculation is

$$\frac{\text{mg N}}{\text{mg Sample}} = \frac{30 \times 5 \times 0.14}{10000} = 0.21$$

3.2.4 Determination of Phosphorus

Phosphorus analysis was done using the calorimetric method of analysis due to the simplicity and reproducibility of the method (Pierzynski, 2000). This calorimetric method is also referred to as the double acid extraction method and it involves the use of a Spectrophotometer to get an absorbance versus concentration plot from which the Phosphorus in the sample can be extrapolated. The double acid extractant used was composed of 0.95N HCl in 0.025N H₂SO₄ (involving ascorbic acid). A reagent that was named Reagent A was then prepared by dissolving 12g of ammonium molybdate [(NH₄)₆Mo₇O₂₄], 0.29089g of potassium antimony tartarate and 5N H₂SO₄ into a 2.0l volumetric flask. A second reagent named Reagent B was prepared by dissolving 1.056g of ascorbic acid for every 200ml of Reagent A.

A standard P stock solution containing exactly 0.1mg P/ml which is equal to 100ppm or 100µg to be used in the spectrometer was prepared by dissolving 9.4393g of monobasic Potassium Phosphate (KH₂PO₄) in a one liter volumetric flask and to it 5 drops of toluene added so as to kill any microbes. A secondary P standard solution containing 5ppm P or 5µg P/ml was then prepared from the 100ppm stock solution by pipetting 5ml into a 100ml volumetric flask.

5g of the sample was weighed in duplicate into a 100ml extracting tube. To the extracting tube, 50ml of the double acid reagent was then added after it was accurately measured by pipetting. The extracting tubes were then stoppered tightly and placed horizontally on a mechanical reciprocating shaker. The extracting tubes were then shaken for 30 minutes. The samples were then filtered through a Whitman No. 44 filter paper. The filtrate was then collected in specimen bottles.

A set of standard P solutions were prepared by pipetting 0, 1, 2, 3, 4 and 5ml of the 5ppm secondary standard. The pipetted solutions were then put into 50ml volumetric flasks. To each of the flasks, 5ml of double acid was then added followed by 20ml of distilled water. 8ml of Reagent B was then added to each flask and immediately made to volume with distilled water while being mixed thoroughly. It was important to make sure that the mixing was done thoroughly immediately after the distilled water was added to the mark. The mixture was allowed to stand for 15 minutes before the absorbance readings were taken with the spectrophotometer. The data obtained was used to plot an absorbance versus P concentration calibration curve from which absorbance was determined.

A suitable aliquot of the sample extractant was pipetted into a 50 ml volumetric flask. To the flask approximately 25ml of distilled water was added. 8ml of Reagent B was added to the flask followed by distilled water to the mark. The contents were thoroughly mixed. The mixture was then allowed to stand for 25 minutes. The sample was then run through a spectrophotometer to obtain its absorbance reading. The point in the calibration curve at which the absorbance of the sample intersected the calibration curve was the corresponding concentration of P in the sample.

3.2.5 Analysis of Potassium

The exchangeable potassium present in the sample was determined from the ammonium ethanoate leachate using a flame photometer. The procedure description was as follows (IFA, 2011). A standard $1\text{mg K}^+ \text{ml}^{-1}$ was made from dry potassium nitrate KNO_3 at 105°C for 1 hour before it was cooled in a desiccator. From the $1\text{mg K}^+ \text{ml}^{-1}$ volumetric standard, standard Potassium solutions of $0\text{-}10 \mu\text{g K}^+ \text{ml}^{-1}$ were prepared.

5g of $<2\text{mm}$ air-dry sample was weighed into a 100ml beaker. To the beaker 20ml of 1M Ammonium Ethanoate solution was added and stirred before it was allowed to stand overnight. The suspension that resulted was then transferred to a filter funnel fitted with a Whitman No. 44 filter paper that was standing over a 250ml volumetric flask. The beaker was then thoroughly washed with the 1M ammonium ethanoate, the same as with the funnel. The sample was then leached with successive 25ml volumes of 1M ammonium ethanoate while the funnel was allowed to drain between each addition. This was done until 250ml of the filtrate was collected. This filtrate was the extract that was used to determine the amount calcium and magnesium present in the sample.

The funnel was then placed in a rack over a 250ml beaker. The interior was then washed with the 25ml volumes of the ammonia while the funnel was allowed to drain between the washings. After it had drained, the funnel was next placed in a 100ml volumetric flask. It was then leached with successive 25ml volumes of KCl solution while the funnel was being allowed to drain between each addition. This was continued until nearly 100ml had been collected. 1.293g of KNO_3 was weighed into a 100ml beaker. To the beaker 1ml of HCl (approximately 36% m/m HCl) was then added: This was as a preservative for the solution because it had to be stored for a few days. The contents were then transferred with washings into a 500ml volumetric flask. The flask was then topped up to the mark. 10ml of the solution from the volumetric flask was pipetted into a 100ml flask and topped up to the mark with

Ammonium Ethanoate solution: This contained $100\mu\text{g K}^+ \text{ ml}^{-1}$. From this 100ml flask 0, 2, 4, 6, 8 and 10ml of this solution was pipetted into 100ml flasks and then each made to the mark with Ammonium Ethanoate solution. These flasks contained 0, 2, 4, 6, 8 and $10\mu\text{g K}^+ \text{ ml}^{-1}$ respectively.

The solution that contained the K^+ was to be sprayed into a gas-air mixture. The amount of light emitted was dependent on the flame conditions and on the rate at which K^+ entered the flame. Following the manufacturer's instructions and with a K^+ filter in place, the millimeter was set to read zero to correspond with the zero K^+ standard. The same was done on the full scale deflection to correspond with the $10\mu\text{g K}^+ \text{ ml}^{-1}$ standard. The stability of the instrument was then checked by spraying the zero and maximum standards again. A calibration curve for the photometer was plotted of the reading versus potassium concentration. It was a straight line connecting all the points of the standards. The sample was then sprayed on the photometer and reading taken. From the calibration curve, the corresponding potassium concentration was obtained by checking against the photometer reading.

3.2.6 Determination of Calcium and Magnesium

Calcium and magnesium could be determined together by a titration method. The titration method involved chelation of the cations with ethylenediaminetetra-acetic acid (EDTA). The procedure was to determine the Ca^{2+} and Mg^{2+} together by the use of solochrome black indicator. The principle behind this method was based on the fact that in an alkaline solution, the solochrome black formed a red complex with Ca^{2+} and Mg^{2+} . EDTA however had a stronger complexing power for both the magnesium and calcium ions and thus took them away from the indicator. After all the Ca^{2+} and Mg^{2+} had been removed, the solochrome black would revert to its normal colour (Rayment & Lyons, 2011).

0.05M ethylenediaminetetra-acetic acid (EDTA) disodium salt was prepared along with a buffer solution that was made by mixing 17.5g of ammonium chloride (NH_4Cl) and 143ml of ammonia solution (approximately 35% NH_3 m/m) in a 250ml volumetric flask. A solochrome black indicator was then prepared by dissolving 0.25g of solochrome black in 190ml of triethanolamine and 63 ml of ethanol. A Calcium solution containing $250\mu\text{g Ca}^{2+} \text{ ml}^{-1}$ was then made from a volumetric standard containing Ca^{2+} from 2.05g anhydrous calcium nitrate ($\text{Ca}(\text{NO}_3)_2$) that was dissolved in water in a 500ml volumetric flask for 1 hour at 105°C and to it 1ml of HCl (approximately 36% m/m HCl) added as a preservative.

25ml of the calcium solution was pipetted into a 250ml conical flask then 2ml of the buffer solution and a few drops of solochrome black indicator added. The contents of the conical flask were titrated using 0.005M EDTA until the colour changed from purple-red to a pale, slightly greenish blue colour. The end-point was achieved when the last trace of pink disappeared from the blue colour at 15.6ml. 25ml of the extract was pipetted into a conical flask then 2 ml of the buffer solution and a few drops of solochrome black added. The contents of the conical flask were titrated using 0.005M EDTA until the colour changed from purple-red to a pale, slightly greenish blue colour. The end-point was when the last trace of pink disappeared from the blue colour.

3.3 Field Test

A field test was required so as to check for the viability of the process wastes as an organic fertilizer. The soil was first characterized by analysis of the organic matter and macronutrient content (ASA & SSSA, 2010). Similar characterization tests were performed on other commonly used organic fertilizers which would be blended with the brewery wastes in the formulation of the organic fertilizers. The organic fertilizers investigated included cow manure, goat droppings, blood meal and bone meal. The characterization tests carried out were similar to those performed on the brewery wastes, the nutrients of interest in the tests being N, P, K, Ca and Mg.

The small scale nature of the project coupled with the strict experimental parameters that were envisioned for the project discouraged an open plantation. A controlled growth environment was preferred in which destructive interactions such as surface runoff interactions would be eliminated. To this effect the project settled to do the planting of the test crops in large high density polyethylene (HDPE) bags. The location of these bags was a rooftop 'Garden' atop the Department of Chemistry at the Chiromo Campus of the University of Nairobi. 10 bags were chosen and filled slightly above halfway with between 25-30Kg of soil. The bags were arranged in two rows of five bags 1 meter apart with a distance of 1 meter between each bag.

The project settled on potatoes as the plant of choice to test for the efficacy of the beer wastes as an organic fertilizer. However, in order to get the best possible comparative analysis parameters, the potatoes that were to be planted had to be a pure variety. The *Asante* potato variety was chosen and was obtained at the National Potato Research Center at Tigoni, Limuru after consultations with the experts therein.

3.3.1 Field Arrangement

The area chosen for the placement of the growing polyethylene bags was 10m by 4m in dimensions. This area was chosen because the conditions such as sunlight exposure time were uniform for each bag. This was because the arrangement of the bags was in north-south direction and without a shade cast on any bag which meant that all the plants were exposed to sunlight for the same duration from dawn to dusk.

3.3.2 Blending with Organic Fertilizers

The aim of blending was to arrive at a superior organic soil nutrient enrichment supplement. However, the blending had to be done in a standardized manner in which each blend would have approximately the same amount of the limiting nutrient. Appropriate calculations were performed with phosphorus as the limiting nutrient based on the recommended fertilizer application of DAP. The surface area of each bag was calculated so as to enable a mathematically scaled down application of the nutrient Phosphorus from the recommended application ratio.

3.3.3 Planting Procedure

Six wheelbarrows full heaps of soil weighing about 320Kg were collected from a construction site within Chiromo campus and packed into 10 Large High Density polyethylene bags. The soil was filled to about two-thirds which translated to a weight of between 25-30Kg after stones, sticks and other plant materials were removed. A blank, the filter aid (brewery) wastes and the 4 organic fertilizers of cow manure, goat droppings, blood meal and bone meal together with their respective blends were then added to each of the 10 bags after appropriate blend ratios and amounts of each additive were calculated based on the KALRO recommended Di-Ammonium Phosphate (DAP) application weight of 500Kg per hectare. After the bags were filled with the soil, three potato tubers (*Asante* variety) which had been obtained from the National Potato Research Center in Tigoni, Limuru were then planted in each bag

Based on the recommended DAP application rates of 500Kg per hectare, the composition of the DAP [(NH₄)₂HPO₄] was characterized and for the purposes of blending phosphorus pentoxide (P₂O₅) was identified as the limiting component. DAP is composed of the NPK ratio 18:46:0 (18% N, 46% P₂O₅, 0% K₂O). From the phosphorus pentoxide (P₂O₅) phosphorus was chosen as the limiting macronutrient such that:-

0.46 x 500 kg DAP = 230 kg P₂O₅ per hectare

But P₂O₅ is composed of 2 parts P for 5 parts O

Therefore 2/7 x 230 kg P₂O₅ per hectare = 90 kg P per hectare

Thus, in order to scale down on the nutrients that were added to the potatoes grown in the bags, the ratios for the filtration wastes, organic fertilizers and organic fertilizer blends were calculated using the limiting macronutrient of phosphorus (90kg P per hectare) from the KALRO recommended DAP application ratio.

The arrangement of the bags was such that the front left row contained the blank (plain soil) in the first column and pure organic fertilizers: cow manure, goat dropping, blood meal and bone meal respectively. The second row contained the plain brewery wastes in the first column and brewery wastes' blends of cow manure, goat dropping, blood meal and bone meal respectively. After planting the potatoes were watered after between two and four days from the planting day up to the two and a half month period. 1-3 litres of water were poured in each bag depending on the weather conditions throughout this period. Leaf samples were obtained after every month of growth for a monthly nutrient uptake analysis. At the third month, harvesting was done and a post-harvest analysis of the potato tubers done. A post-harvest analysis of the soil in each bag was thereafter done.

3.3.4 Plant Tissue Analysis

The method that was used was the wet acid digestion using sulphuric acid (H₂SO₄), salicylic acid, hydrogen peroxide (H₂O₂) and selenium catalyst method. This method was used for plant tissue analysis covered both the monthly nutrient uptake analysis carried out on the leaves and the post-harvest tuber analysis that was carried out after three months of growth. The wet acid digestion method was chosen because it was particularly suited for work on a large variety of plant material samples. It normally gives precise and reproducible results for the analysis of NPK, Ca, Mg, Cu, Fe, Zn and Mn among other nutrients in plant tissues.

In the method, about 30% of the organic matter is oxidized by the hydrogen peroxide (H₂O₂) at a relatively low temperature of about 100°C. After the excess H₂O₂ has decomposed and the water evaporated, the digestion is then completed by the use of sulphuric acid (H₂SO₄) at relatively high temperatures of 330°C with the aid of the selenium catalyst.

For the analysis of the various nutrients, the following equipment was used:-

1. Atomic Absorption Spectrophotometer (AAS): PerkinELMer, USA AAnalyst 100
2. UV/VIS Spectrophotometer: Analytik Jena, Germany SPEKOL 1500
3. Flame Photometer: Corning 400, UK M400

The following reagents were used for the analysis: a 100 μ g P/ml phosphorus stock solution, a 1000 μ g K/ml potassium stock solution, a 100 μ g Ca/ml calcium stock solution, a 1000 μ g Cu/ml copper stock solution, a 100 μ g Fe/ml iron stock solution, a 100 μ g Mg/ml magnesium stock solution, a 50 μ g Mn/ml manganese stock solution and a 500 μ g Zn/ml zinc stock solution.

3.3.4.1 Sample Preparation

The leaf samples were cleaned thoroughly using deionized water while care was taken to ensure that the sample integrity was maintained. This was done so as to get rid of dust particles that would affect spectroscopic readings during elemental analysis. For the potato tubers, they were first washed with regular tap water so as to get rid of the mud and other impurities from the soil. The potatoes were then air dried for about an hour before being washed with deionized water and then left to air dry for another hour immediately afterwards to stabilize the tissue and stop enzymatic reactions. The potato tubers were analyzed without peeling off the skin since the mineral concentrations in the tubers can vary from the distal end to the stem end with minerals such Cu, Mg, Mn, Zn, Fe, Ca and K found in higher concentration on the potato skin relative to the tuber flesh (Subramanian *et al.*, 2011). Thus the whole unpeeled potatoes were sliced and then oven dried at 105°C until there was no more observable weight loss.

3.4 Monthly Nutrient Uptake Analysis

The Kjeldahl method of nitrogen analysis was used to determine the amount of nitrogen in the plant tissues. The procedure for the Kjeldahl method was as described in Section 3.2.2 and Section 3.2.3.

The procedure used for the analysis of phosphorus in the plant tissues was the double acid method which composed of 0.95N HCl in 0.025N H₂SO₄ (involving ascorbic acid). This procedure was the same as that described in Section 3.2.4.

The exchangeable potassium present in the sample was determined from the ammonium ethanoate leachate using a flame photometer. The procedure description was the same as that described in Section 3.2.5.

3.4.1 Elemental analysis

Elemental analysis of calcium, magnesium, iron, manganese, sodium, copper and zinc was done using AAS and Flame Photometer. For the experiment 100 ml of the final volume was necessary for the provision of concentrations that were above the detection limits. For the elements Mn, Fe, Cu and Zn, volumes of between 10 and 50 ml were required to give concentrations that were within detection limits (Kalra, 1998).

Table 3.1 Detection limits for elemental analysis

Element	Wavelength (nm)	Conc. range in Detection solution ($\mu\text{g/mL}$)	limit ($\mu\text{g/mL}$)
Calcium (Ca)	422.6	1-10	0.002
Copper (Cu)	324.7	2-20	0.005
Iron (Fe)	248.3	2-20	0.005
Magnesium (Mg)	285.2	0.1-0.2	0.0003
Sodium (Na)	589.0	0.3-3	0.002
Zinc (Zn)	213.8	0.2-3	0.002

1g of the sample was placed in a small beaker and to the sample; 10ml of concentrated nitric acid was added and allowed to stand overnight. The mixture was then carefully heated in a hot plate until the production of red nitrous dioxide (NO_2) fumes had ceased. The beaker was then cooled and to it 4 ml of 70% HClO_4 added. The mixture was then subsequently heated and allowed to evaporate to a small volume. This sample was then transferred to a 50 ml flask and then topped up to the mark with deionized water. In order to prevent an explosive reaction, HNO_3 was first added to the plant sample and allowed to mix and digest before HClO_4 was added. The sample was then sprayed in the Flame Photometer for the determination of Na, Ca and Mg.

For the determination of Cu, Fe, Mn and Zn, the sample was sprayed in an AAS and from the stock solutions of Ca and Mg, standards of 0, 2, 4, 6, 8 and 10µg/ml were prepared. From the stock solutions of Cu, Zn and Mn, standards of 0, 2, 5, 10ppm were prepared. For Fe, the stock produced standards of 0, 10, 25, 50ppm. The standards for each element were then sprayed to the AAS and the absorbance wavelength corresponding to each respective concentration noted. A calibration curve for absorbance versus concentration was plotted for each element. After the sample had been sprayed to the AAS, the readings were plotted in the respective calibration curves. From the respective calibration curves, the respective concentrations of the elements were extrapolated based on the absorbance reading that each sample gave.

3.5 Post-Harvest Tuber Analysis

3.5.1 Physical Characterization

Although the physical appearance of a harvest might not necessarily be a good pointer of scientific distinction in terms of yield, it is nonetheless a useful physical parameter. Its use comes from the fact that it can still be used to indicate a stack difference between a quality harvest and a poor harvest (Kalra, 1998). For example, a poor harvest will have very low quality tubers with some tubers having a rough skin as opposed to the smooth skin that characterizes potatoes. A post-harvest physical analysis that was therefore carried out on the tubers involving various physical indicators of good yield for example size, length, weight of the tubers, tuber skin and tuber flesh.

3.5.2 Chemical Characterization

The potatoes were washed in tap water so as to get rid of the soil and mud. The potatoes were then left to air dry on the lab bench for about 3 hours. Before analysis commenced, the tubers were rinsed with deionized water and then air dried. The potatoes were then sliced from one end to the other without peeling. The sliced tubers were then oven dried at 105°C until there was no further loss in weight.

3.6 Post-Harvest Soil Analysis

Post-harvest soil analyses tests were similar to those for the process wastes as described in Section 3.2.1 through to 3.2.6 and Section 3.4.1.

3.6.1 Determination of Total Organic Carbon

The method used was the Walkley–Black Method as described in Bohn *et al.* (1985). In the method, 1g of the sample was weighed in duplicate and transferred to a 300ml Erlenmeyer flask after it had been ground to pass through a 0.5mm sieve. 10ml of 1N $K_2Cr_2O_7$ solution was then accurately weighed and put in the flask where it was gently swirled so as to disperse the soil and come into contact with the whole sample. Caution was taken to avoid the soil sticking to the side of the flask where it would be out of contact with the reagent. 20ml of conc. 36N H_2SO_4 was then rapidly added using a measuring cylinder while steam was being directed into the mixture. The flask was then immediately gently swirled until the soil and reagents had mixed. The mixture was then swirled more vigorously for one minute. The flask was then rotated and allowed to cool on an asbestos sheet for 30 minutes. 100ml of distilled water and 5.0 ml concentrated orthophosphoric acid (H_3PO_4) was then added in order to obtain a clear end point during filtration.

4 drops of diphenylamine indicator was then added and titrated with a 0.5N ferrous sulphate solution. As the end point approached, the turbid dark blue colour became greenish and eventually changed to a clear pale green quite sharply at the end point. A blank titrate was made in the same manner without the soil so as to standardize the potassium dichromate (1N $K_2Cr_2O_7$). The results obtained were calculated according to the following formula:-

$$\% \text{ organic C in soil} = (Me K_2Cr_2O_7 - Me FeSO_4) \times 0.3 / g \text{ of air dry soil}$$

$$Me = \text{Normality of solution} \times ml \text{ of solution used.}$$

$$1 \text{ ml of 1N } K_2Cr_2O_7 \text{ oxidizes 3 mg of carbon (So } 0.003 \times 100 = 0.3).$$

In order to correctly determine the amount of organic Carbon, the figure that was obtained experimentally gave the actual amount of carbon oxidized by the dichromate which is at times uncorrected referred to as Walkley-Black value, since it does not take into account the fact that the average recovery is about 77%. Using the 1.33 conventional factor for the Walkley–Black method, the result obtained from the above formula was then multiplied by 1.33 (100/75) so as to get the actual value. Alternatively, the 0.3 used in the formula could be changed to 0.399 i.e. $1.33 \times 0.3 = 0.399$

3.6.2 Total Nitrogen

The Kjeldahl method of nitrogen was used to determine the amount of nitrogen in the soil sample. The procedure for the Kjeldahl method was as described in Section 3.2.2 and Section 3.2.3.

3.6.3 Phosphorus Determination

The Olsen Method of analysis by UV/VIS Spectrophotometer was used as described in Section 3.2.4.

3.6.4 Determination of available nutrient elements

The Mehlich double acid method was used to test for potassium, sodium, calcium, magnesium, manganese, iron, zinc and copper. The necessary reagents and extractants for the various elements were prepared together with the calibration standards to be used in the various instruments of analysis. They were prepared as follows:-

1. **Extracting Solution A** (0.05N HCl and 0.025N H₂SO₄): Prepared by diluting 4ml of concentrated HCl and 0.7ml of concentrated H₂SO₄ in a 1.0l flask and topping to the mark with deionized water.
2. **Extracting Solution B** (0.05N HCl and 0.025N H₂SO₄)
3. **Reagent A**: Prepared by dissolving 12g of ammonium molybdate [(NH₄)₆Mo₇O₂₄ · 4H₂O] in 250ml of deionized water. 0.2908g of antimony potassium tartrate [K(SbO)·C₄H₄O₆ · ½ H₂O] was then dissolved in 100 mL deionized water. The two mixtures were then added to 1.0l of 2.5 M Sulphuric acid, mixed thoroughly and then topped up to the mark in a 2.0l flask.
4. **Reagent B**: Prepared by dissolving 1.056g ascorbic acid (C₆H₄O₆) in 200 ml of Reagent A and thoroughly mixed.
5. **Calibration Standards**: These were prepared from the stock solution containing 1000 mg/l of the analytes. From the Extracting solution (0.05N HCl and 0.025N H₂SO₄), 1.0l of standards were prepared for those containing the highest concentration of each of the desired elements. Subsequent dilutions of the standards were done while adhering to the recommended range of calibration:-

Table 3.2 Preparation of calibration standards for nutrient analysis

K (ppm)	Ca (ppm)	Mg (ppm)	Na (ppm)	Fe (ppm)	Mn (ppm)	Cu (ppm)	Zn (ppm)
0	0	0	0	0	0	0	0
10	50	10	10	10	2	2	2
25	100	50	50	25	5	5	5
50	500	100	100	50	10	10	10

3.6.4.1 Atomic Absorption Spectrophotometer (AAS)

The AAS analysis was used to determine the content of iron, zinc and copper in the sample. The analysis involved extraction using 0.1M HCl from oven-dried soil samples that were extracted in the ratio 1:10 (w/v) with the 0.1M HCl. In the procedure, 5g of air dried soil sample that had passed through a 2.0mm mesh sieve was accurately weighed and put in a 50 ml Erlenmeyer flask. To the flask, 25.0ml of extracting solution B was added. The same was repeated for a blank. The flask with the extraction solutions and sample/ blank was placed for 5 minutes in a reciprocating mechanical shaker. After which the suspension was filtered into 25ml plastic vials. These plastic vials contained the sample filtrate, the blank and the standards.

The vials for the standards were as follows:-

- 0, 10, 25, 50ppm for Fe.
- 0, 2, 5, 10ppm for Zn
- 0, 2, 5, 10ppm for Cu

The absorbance of the blank, standards and sample for each of the three elements was then determined in the AAS. This was done by inserting the vials into the analysis chamber from which light from the monochromator was diffracted into rainbow colours and split into beams. The light from the resultant beams of the sample and reference are then compared from the readings obtained from the photodetector device so as to obtain the relative intensity. The absorbance readings for the standards corresponding to the particular concentration of each standard's vial were then used to plot a calibration curve from which

the concentration of each sample corresponding to the sample's absorbance was extrapolated to give the concentration.

3.6.4.2 UV/VIS Spectrophotometer

The UV/VIS Spectrophotometer was used to determine magnesium and manganese via extraction using 0.1N HCl and 0.025N H₂SO₄ from oven-dried soil samples extracted in the ratio 1:5 (w/v) with the extractant. 5g of air dried soil sample that had passed through a 2.0mm mesh sieve was accurately weighed and put in a 50ml Erlenmeyer flask. To the flask, 25.0ml of extracting solution A was added. The same was also done for a blank. The flasks with the extraction solutions and sample/ blank were placed for 5 minutes in a reciprocating mechanical shaker. The suspension was then filtered into 25ml plastic vials. These plastic vials contained the sample filtrate, the blank and the standards.

The vials for the standards were as follows:-

- 0, 10, 50, 100ppm for Mg
- 0, 2, 5, 10ppm for Mn

The absorbance of the blank, standards and sample for each of the three elements was then determined in the UV/VIS Spectrophotometer. The samples in a cuvette are placed into the analysis chamber at which point a light beam in the visible and UV region is separated by a diffraction graft into single wavelength beams. One monochromatic beam is then split into equal intensity such that one is shone on the sample cuvette and the other on the reference. The intensities of the light beams are then measured and compared by electronic detectors. The absorbance readings for the standards corresponding to the particular concentration of each standard's vial were used to plot a calibration curve from which the concentration of each sample corresponding to the sample's absorbance was extrapolated to give the concentration.

3.6.4.3 Flame Photometer

The Flame Photometer was used to determine sodium, potassium and calcium via extraction using 0.1N HCl and 0.025N H₂SO₄ from oven-dried soil samples extracted in the ratio 1:5 (w/v) with the extractant. 5g of air dried soil sample that had passed through a 2.0mm mesh sieve was accurately weighed and put in a 50 ml erlenmeyer flask. To the flask, 25.0ml of extracting solution A was added. The same was also done for a blank. The flasks with the extraction solutions and sample/ blank were placed for 5 minutes in a reciprocating

mechanical shaker. The suspension was then filtered into 25ml plastic vials. These plastic vials contained the sample filtrate, the blank and the standards.

The vials for the standards were as follows:-

- 0, 10, 25, 50ppm for K
- 0, 50, 100, 500ppm for Ca
- 0, 10, 50, 100ppm for Na

The absorbance of the blank, standards and sample for each of the three elements was then determined in the Flame Photometer. The samples were sprayed into the analysis chamber at which point the heat from the flame separates the sample into its constituent molecules and atoms. The detector then analyzes the colours that results from the energy that the atoms release when they absorb and release energy. The absorbance readings for the standards corresponding to the particular concentration of each standard's vial were used to plot a calibration curve from which the concentration of each sample corresponding to the sample's absorbance was extrapolated to give the concentration.

CHAPTER FOUR

RESULTS AND DISCUSION

4.1 Pre Planting Analysis

Before planting was done the soil to be used underwent physical and chemical characterization so as to ensure that the soil used was of uniform composition. The filter aid waste was also characterized so as to ensure at which stage of deposition the waste was to be used as a fertilizer. It was decided that the waste that had composted over a period of over one year was to be used due to the compositional stability that it exhibited in terms of smell, pH and macro and micronutrient composition. The results of these pre planting tests are shown in Table 4.1

Table 4.1: Composition of soil, filter aid and filter aid wastes

	N (ppm)	P (ppm)	K (ppm)	C (ppm)	Ca (ppm)	Mg (ppm)	pH
Soil	1100	3.10	565.5	6600	669.2	135.5	8.60
Unused Filter Aid	1200	596	1740	2500	420	560	5.95
Slurry	5000	320	1418	16200	91.23	94.15	3.50
Sludge	6000	400	1404	14500	109.20	100.5	8.50
3 Weeks	5900	419.21	1454	13900	93.13	86.23	8.40
6 Weeks	5200	381.52	1476	13300	98.83	89.24	7.30
4-5 Months	5600	392.67	1486	12600	107.85	95.21	5.00
7-9 Months	5100	406.73	1495	11800	90.28	93.22	8.80
9-10 Months	5800	403.09	1522	11100	92.31	87.18	5.85
Over 1 Year	5300	390	1540	10300	89.10	85.10	4.90

The four organic fertilizers that were to be used as blends and comparative soil enrichment nutrients were cow dung, goat droppings, bone meal and blood meal. The cow dung and goat droppings fertilizers were first sundried over a period of seven days before they were taken to the lab and subsequently used to plant potatoes. This was because had they been taken and applied in their fresh phase the combination of urine and fresh animal waste would have burned the potatoes. The results of the analysis for the organic fertilizers used are shown in Table 4.2

Table 4.2: Composition of organic fertilizers used for planting

	N (ppm)	P (ppm)	K (ppm)	Ca (ppm)	Mg (ppm)	pH
Cow Manure	15200	1100	140	1100	750	10.4
Goat Droppings	16000	2685	203	1800	920	10.1
Bone Meal	49700	85000	1520	178200	7200	5.8
Blood Meal	109000	960	2600	2300	1500	4.3

4.1.1 Soil Analysis

The soils used in this study were analyzed in accordance with the procedures given in chapter three. The analyses were carried out before planting and after harvesting. The results of the pre-harvest soil analyses are given in Table 4.3

Table 4.3: Composition of soil used for planting

Element	N (ppm)	P (ppm)	K (ppm)	C (%)	Ca (ppm)	Mg (ppm)
Recommended	1500-2000	>2200	>200	>20000	>600	>300
Amount Found	1100	3.10	565.5	6600	669.2	135.5
Description	Low content and thus not enough	Deficient for growth of potatoes	Adequate amounts for potato growth	Moderate amounts however more has to be added	Has a high content which is sufficient enough	High enough content

As shown in Table 4.3, the soil contained low yet sufficient quantities of Nitrogen, Phosphorus, Potassium, Calcium and Magnesium. The recommended levels shown are in accordance with (Love, 1986). A fast growing and nutrient sensitive crop was the most preferred kind of plant to be grown and therefore potatoes were chosen as explained in the literature review. Based on the soil analysis, a scale down calculation of the amount of fertilizer to be applied was done based on the Kenya Agricultural Research Institute (KARI) recommended application for potatoes of 500Kg DAP/ha.

After the crops had been harvested, the soils were analyzed and the results of the analysis are presented in Table 4.4

Table 4.4: Post- harvest soil composition

Bag/Test	pH	N ppm	C ppm	P ppm	K ppm	Ca ppm	Mg ppm	Mn ppm	Cu ppm	Fe ppm	Zn ppm
Soil	8.95	1800	17800	9.60	55.13	362.72	511.45	12.08	1.58	134	13.6
Diatomaceous Earth	8.80	2000	20800	1.20	52.79	358.72	497.89	22.65	1.77	132	13.0
Cow Dung	8.83	2200	22400	27.4	62.95	334.67	497.89	15.10	1.69	60.9	19.0
Cow Blend	8.85	2200	22300	48.8	69.21	394.79	504.05	24.92	1.52	111	15.3
Goat Droppings	9.14	1100	10400	21.1	47.31	274.55	290.85	15.10	3.36	52.1	8.08
Goat Blend	8.79	1400	13600	22.0	50.44	270.54	332.75	11.33	1.55	18.1	5.56
Blood Meal	8.96	500	4000	4.00	46.14	320.64	294.54	18.12	0.84	68.6	11.6
Blood Blend	8.48	1000	9800	16.9	32.84	194.39	255.11	31.71	1.61	106	12.4
Bone Meal	9.30	700	6100	109000	32.84	97000	257.57	14.35	1.65	17.6	20.6
Bone Blend	8.82	800	7600	109000	33.63	150000	288.38	23.41	1.92	34.1	19.8

4.1.1.1 pH

As shown from Table 4.4, all the bags had mild alkaline pH values with that of blood meal blend having the lowest value of 8.48 and bone meal having the highest alkaline content of 9.30.

4.1.1.2 Nitrogen

In the post-harvest soil analysis, except for the cow dung and cow blend bags which had an adequate amount of nitrogen for the growth of potatoes at 2200ppm N content, the other 8 bags had low values of nitrogen with bone meal having the lowest composition at 700ppm as shown in Table 4.4. The explanation for why N levels vary from pre-harvest to post-harvest levels in farm soils is mainly as a result of surface runoff, leaching and de nitrification (Aizaki *et al.*, 2013). In the project setup, loss by surface runoff was the least impactful mainly due to the fact that the potatoes were grown on plastic bags.

4.1.1.3 Total Carbon

From Table 4.4, the cow manure and the cow dung blend had the highest content of organic Carbon at 22400ppm and 22300ppm respectively while the blood meal bag had the lowest amount at 4000 ppm in post-harvest analysis as shown in Table 4.4. A higher amount of organic carbon indicates that the soil has a higher amount of organic matter content.

4.1.1.4 Phosphorus

From Table 4.4, the Bone meal and bone meal blend had the highest amount of P at 109000ppm while the filter aid waste bag had the lowest amount of P at 1.20ppm. This is indicated by the higher composition of the bone meal fertilizer as shown in Table 4.2

4.1.1.5 Potassium

Cow blend had the 69.21ppm K which was the highest value while blood meal blend and bone meal had 32.84ppm which was the lowest K value from the figures shown in Table 4.2.

4.1.1.6 Calcium

As shown in Table 4.2 cow blend had the highest Ca content at 394.79ppm, while blood blend bag had the lowest content at 194.39ppm.

4.1.1.7 Magnesium

The plain soil bag had the highest amount of Mg at 511.45ppm for pre-harvest soil analysis as shown in Table 4.1 while that containing blood meal blend had the lowest at 255.11ppm during post-harvest as shown in Table 4.2.

4.1.1.8 Manganese

From Table 4.2, the lowest value of Mn was 11.33ppm for the goat blend bag while the highest content was in the blood meal blend bag at 31.71ppm.

4.1.1.9 Copper

The goat droppings bag had 3.36ppm which was the highest while at 0.84ppm; blood meal had the lowest concentration as shown in Table 4.2.

4.1.1.10 Iron

The plain soil bag had 134 ppm which was the highest while goat blend had 17.6ppm which was the least among all bags as shown in Table 4.2.

4.1.1.11 Zinc

From Table 4.2, the bone meal bag had the highest concentration of Zn at 20.6ppm and goat blend had 5.56ppm which was the lowest.

4.2 Monthly Leaf Uptake Analysis

The nutrient level of the potato leaves for each bag was determined monthly (different development stages) and the results are shown in Tables 4.5 to Table 4.13. Through such an analysis, a scientist can accurately gauge the performance of the plant due to the intervention of the soil enrichment supplement that has been added either during planting, during growth or both during planting and growth.

The fact that the potatoes were grown on polythene bags meant that the sample size was relatively small and therefore a less destructive method of sampling that wouldn't end up killing the plant was chosen. Making graphical comparisons on the monthly leaf nutrient characterization gave out more details when the comparison was done per nutrient as done in Section 2.6.7. However, in order to get a comparison based on the planting bag, a graphical representation was done as shown in Figure 4.1 to Figure 4.10 below. The graphs add weight to the discussions on the nutrient levels in the leaves throughout the growth period of potatoes and are useful in showing the trends that are expected for the various nutrients from growth to harvest for any growth environment that has sufficient nutrients for potato growth. Any deviations from the expected trends can easily be interpreted from the graphs more clearly than from the tables.

4.2.1 General Nutrient Trends in the Monthly Leaf Uptake Analysis

4.2.1.1 Nitrogen

Table 4.5: Nitrogen content in the leaves

Bag/Composition	1st Month ppm	2nd Month ppm	3rd Month ppm
Soil	31500	29200	24500
Diatomaceous Earth	38500	22800	17500
Cow Dung	28000	19500	14000
Cow Blend	28000	25900	21000
Goat Droppings	24500	24500	24500
Goat Blend	35000	27200	21000
Blood Meal	45500	38900	24500
Blood Blend	49000	37200	35000
Bone Meal	52500	43900	24500
Bone Blend	70000	61800	14000

From table 4.5 the bag with the highest concentration of nitrogen at the first month of analysis was the bone meal blend bag at 70000ppm. The lowest concentration of N was on the other hand found in the goat droppings bag at a value of 24500ppm which was only marginally high than the values of both the cow dung and cow blend bag which stood at 28000ppm. In the second month of analysis, the highest N concentration was found in the bone meal blend bag at 61800ppm with the cow dung bag having the lowest concentration of Nitrogen at 19500ppm. The blood meal blend had the highest levels of nitrogen at the 3rd month of analysis at 35000ppm with the bone meal blend bag having the lowest nitrogen concentration at a paltry 14000ppm.

Taking a closer look at the trend of nitrogen in the plain soil bag as shown in Figure 4.1, it can be seen that the levels of N kept dropping from the 1st month through to the 3rd. This is the expected trend for these nutrients (Kabata-Pendias, 2011). The reason for this is due to the roles that nitrogen plays in the growth and development of the potatoes as explained in

Section 2.6.7.1. In essence nitrogen is the most consumed additive that is consumed and is passively up taken by the potatoes. Due to its abundance and importance to the plant throughout the growth cycle. Although nitrogen is consumed throughout the entire growing period, its role in the robust growth of leaves and it being an important component of the chlorophyll molecule makes it important in photosynthesis (Barker & Pilbeam, 2007).

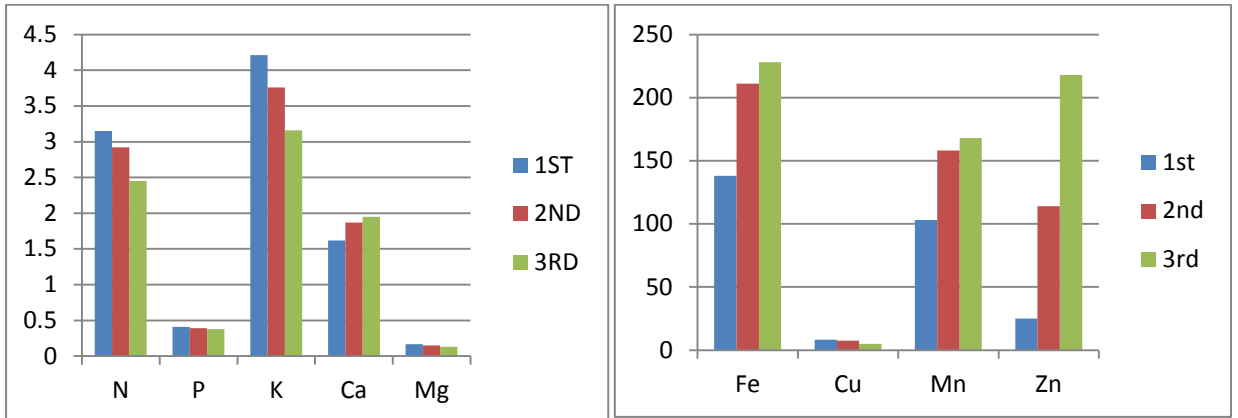


Figure 4.1 Macronutrients and Micronutrient content of leaves in plain soil bag for the 3 months

4.2.2.2 Phosphorus

The levels that are transported to the leaves don't differ too much throughout the three months due to the importance and continued use of phosphorus during the entire growth cycle of the potatoes.

Table 4.6: Phosphorous content in the leaves

Bag/Composition	1st Month ppm	2nd Month ppm	3rd Month ppm
Soil	4100	3900	3900
Diatomaceous Earth	4100	3700	3500
Cow Dung	4100	3600	3800
Cow Blend	4500	4200	4500
Goat Droppings	4400	4800	5000
Goat Blend	4200	5000	5200
Blood Meal	3400	3100	2300
Blood Blend	3200	3300	3500
Bone Meal	4300	4100	3500
Bone Blend	3200	3400	3500

From table 4.6 the levels of phosphorus were fairly constant within the first month of growth with the highest composition belonging to the cow blend bag which stood at 4500ppm with the lowest composition for the month being the 3200ppm of the bone meal blend bag. In the second month, the levels of P remained fairly constant with the highest levels of P concentration observed in the goat blend bag at 5000ppm which was closely followed by the goat droppings bag at 4800ppm. The lowest levels were observed in the blood meal bag which was closely followed by the blood meal blend bag at 3100ppm and 3300ppm respectively. For the third month of growth, the bag with the highest concentration of Phosphorus was the goat blend at 5200ppm which was closely followed by the goat droppings bag at 5000ppm. The lowest levels were observed in the blood meal bag at 2300ppm. The reasons for this observed trend for phosphorus is that it is a very important constituent of the energy molecule ATP and in general constitutes about 0.2% of the plants dry matter (Morel, 1997).

From Figure 4.2 the trend for phosphorus consumption is illustrated in the diatomaceous earth/ filter aid waste bag whereby the levels can be seen to be dropping towards the third

month due to the potatoes having actively up taken the nutrient during the robust growth phase period as noted in Section 2.6.7.2

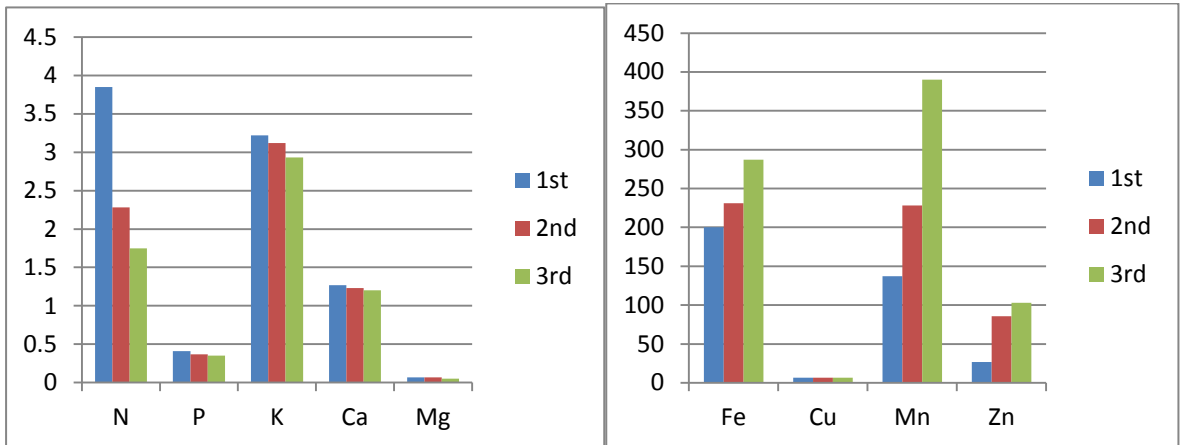


Figure 4.2 Macronutrients and Micronutrient content of leaves in diatomaceous earth bag for the 3 months

4.2.2.3 Potassium

The levels of K in the leaves start low in the first month and increases gradually up to the third month. The increase is not very sharp due to the fact that the levels of K that are used by the potatoes throughout the growth period do not vary as it is used in almost constant amounts.

Table 4.7: Potassium content in the leaves

Bag/Composition	1st Month ppm	2nd Month ppm	3rd Month ppm
Soil	42100	37600	31600
Diatomaceous Earth	32200	31200	29300
Cow Dung	39700	32800	26300
Cow Blend	37500	25800	16900
Goat Droppings	32200	29500	27300
Goat Blend	39600	36300	33000
Blood Meal	41500	37700	28600
Blood Blend	45500	41100	30300
Bone Meal	41400	27500	17200
Bone Blend	43400	28700	14900

As shown in Table 4.7, with a composition of 45500ppm, the blood meal blend bag had the highest composition of potassium in the first month as the 32200ppm of the filter aid waste and goat droppings bag stood as the joint lowest composition of the k in the month. 41100ppm was the peak composition of potassium in the second month and was found in the blood meal blend bag with the 25800ppm of the cow blend being the lowest composition of K for the month. In the third month, the highest values of potassium were observed in the goat blend bag at 33000ppm. Meanwhile, the lowest concentration was in the bone meal blend bag at 14900ppm.

Unlike other nitrogen and phosphorus, potassium is used by the plant in near equal amounts throughout the entire growth period as explained in Section 2.6.7.3. Plant cells normally accumulate potassium from relatively dilute soil solutions and thus manage to have the levels of the nutrient in relatively higher than that of N and P by the 3rd month. This trend can be illustrated in the cow manure bag as presented in Figure 4.3. Potassium's role is important in regulation of the opening and closing of the stomata which is a rate determining step in photosynthesis (Maathius & Sanders, 1996).

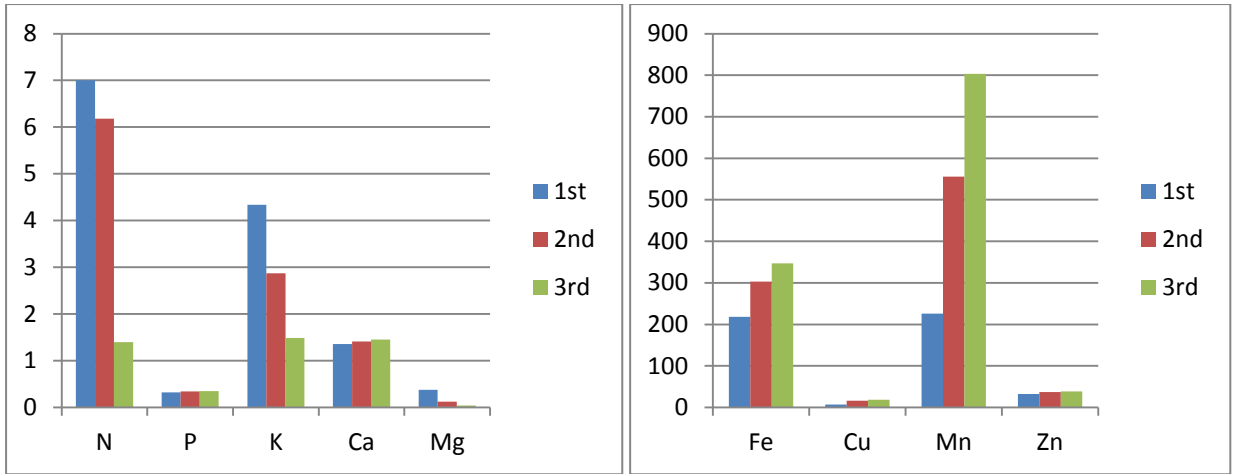


Figure 4.3: Macronutrients and Micronutrients content of leaves in cow dung bag for the 3 months

4.2.2.4 Calcium

Except for the filter aid waste bag where the levels of calcium dropped from the first month to the third month due to deficiency, all the rest of the bags, which had sufficient levels of Ca, had the levels of increase from the first to the third month.

Table 4.8: Calcium content in the leaves

Bag/Composition	1st Month ppm	2nd Month ppm	3rd Month ppm
Soil	16200	18700	19500
Diatomaceous Earth	12700	12300	12000
Cow Dung	23600	17300	14800
Cow Blend	22400	16800	15300
Goat Droppings	20100	20200	20500
Goat Blend	14300	22200	24500
Blood Meal	18800	24500	26900
Blood Blend	14800	19900	26800
Bone Meal	6800	13900	17500
Bone Blend	13600	14100	14500

From table 4.8 at the first month analysis the cow dung bag had the highest levels of Ca at 23600ppm with the lowest concentration being the bone meal bag with a concentration of 6800ppm. During the second month testing, the highest Ca concentration was found in blood meal bag which had a composition of 24500ppm while the lowest composition was found in the filter aid waste bag which had a concentration at 12300ppm. The third month of analysis had the highest levels of Ca being detected in the leaves from the blood meal and blood meal blend bags at 26900ppm and 26800ppm respectively while the filter aid waste had the lowest concentration of Ca at 12000ppm followed closely behind by the bone meal blend and cow dung bags at 14500ppm and 14800ppm respectively. The levels of calcium increase gradually and pick at the 3rd month this trend can be illustrated in the cow blend bag are presented in Figure 4.4.

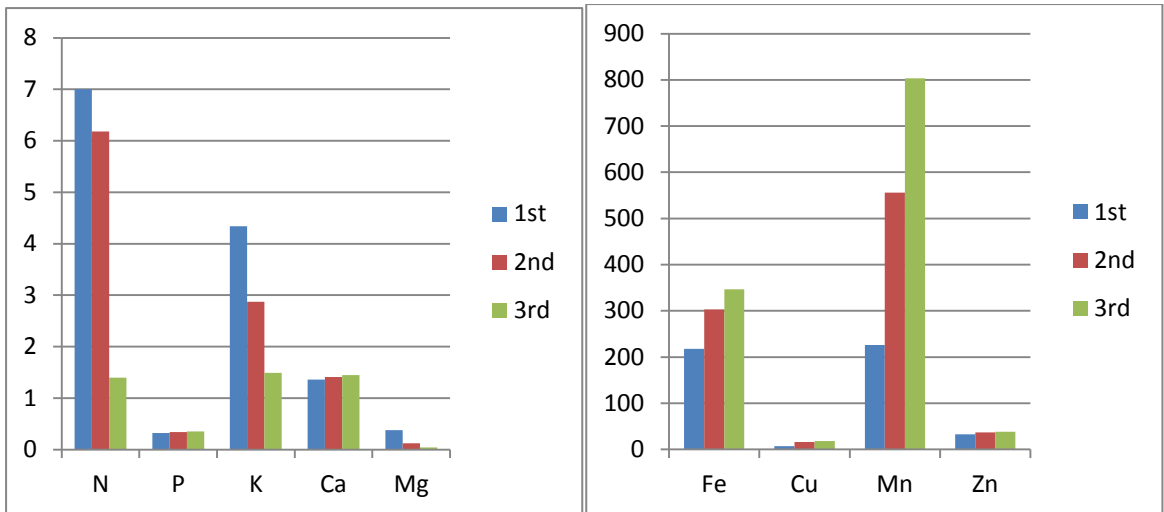


Figure 4.4: Macronutrients and Micronutrients content of leaves in cow blend bag for the 3 months

This trend is also observable in the goat droppings bag as presented in Figure 4.5. Calcium is important in the structural composition of plant cells such as the leaf cells where sufficient levels of Ca enables the proper functioning of stomata cells and the overall performance of the photosynthesis process (Cotrufo *et al.*, 1963) as explained in Section 2.6.7.4

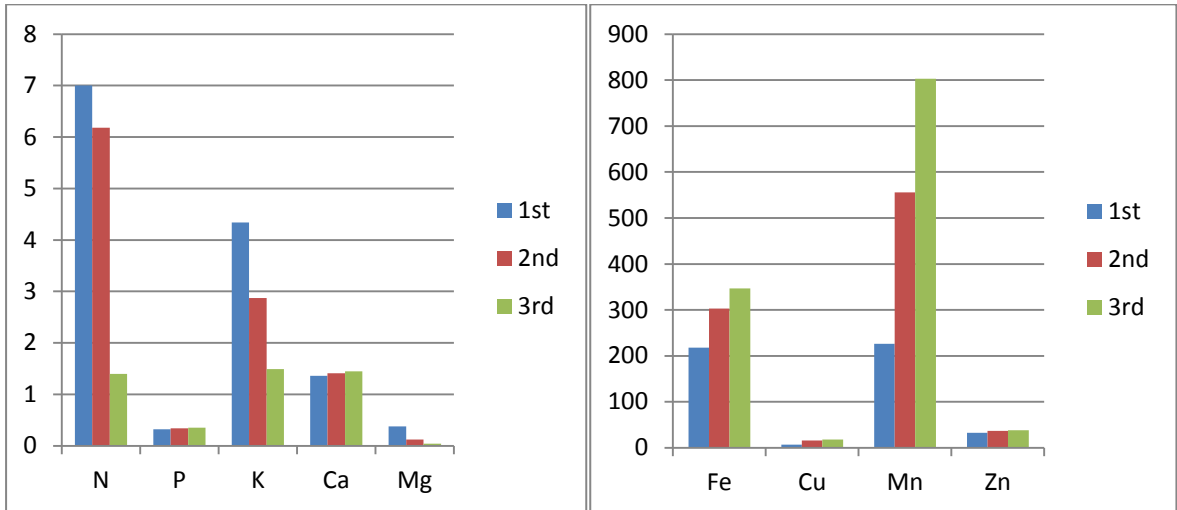


Figure 4.5: Macronutrients and Micronutrients content of leaves in goat droppings bag for the 3 months

4.2.2.5 Magnesium

With regard to the magnesium fluctuating compositional levels in the leaves, the levels detected across all bags started off very high at the first month juncture, the levels remained fairly constant for the second month and then sharply dropped during the third month.

Table 4.9: Magnesium content in the leaves

Bag/Composition	1st Month ppm	2nd Month ppm	3rd Month ppm
Soil	1700	1500	1300
Diatomaceous Earth	700	700	500
Cow Dung	1800	1100	800
Cow Blend	2700	2200	1100
Goat Droppings	3300	1700	900
Goat Blend	3300	2600	1100
Blood Meal	1300	1300	1300
Blood Blend	3700	2400	800
Bone Meal	3400	2900	600
Bone Blend	3800	1200	400

Results shown in table 4.9 Show that during the first month analysis the bone meal blend bag had the highest levels of Mg at 3800ppm while the lowest concentration was at the Filter Aid Waste bag which had a concentration of 700ppm. At the second month testing stage, the highest Mg concentration was found in bone meal bag at 2900ppm with the filter aid waste bag once again having the lowest concentration at 700ppm. In the final month of analysis, the highest levels of Mg were detected in leaves from the blood meal and plain soil bags at 1300ppm while the Bone Meal Blend bag had the lowest at 400ppm

The levels of magnesium eventually drop from a high in the first month and are at their lowest in the 3rd month as shown in the goat blend bag presented in Figure 4.6. As a very important element in photosynthesis, Mg from the growth media is normally preferentially up

taken by the roots through passive diffusion and it then goes through mass transport so as to reach the leaves as explained in Section 2.6.7.5

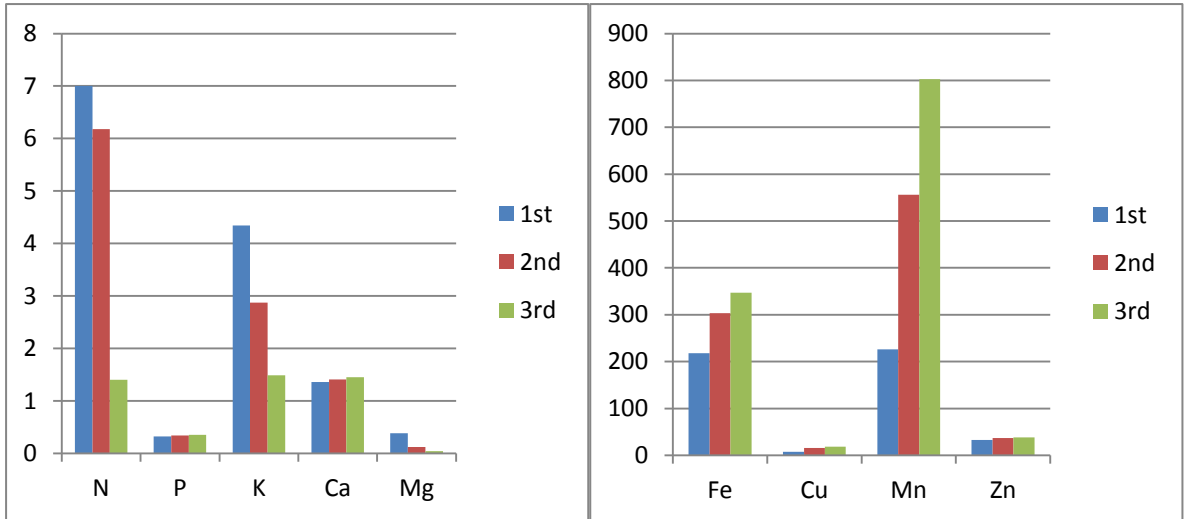


Figure 4.6: Macronutrients and Micronutrients content of leaves in goat blend bag for the 3 month

4.2.2.6 Iron

From table 4.10, 299ppm was the value of the concentration of the Iron composition of the highest bag in the first month which belonged to the blood meal blend bag. The cow dung bag had the lowest concentration of 118ppm.

Table 4.10: Iron content in the leaves

Bag/Composition	1st Month ppm	2nd Month ppm	3rd Month ppm
Soil	138	211	228
Diatomaceous Earth	200	231	287
Cow Dung	118	126	140
Cow Blend	177	109	102
Goat Droppings	275	270	263
Goat Blend	280	260	255
Blood Meal	132	201	249
Blood Blend	299	339	410
Bone Meal	239	248	272
Bone Blend	218	303	347

With a concentration of 109ppm, the cow blend bag had the lowest value of Fe concentration in the second month with the highest composition values for the month belonging to the blood meal blend bag at 339ppm. The 3rd month values for Fe concentration were such that the highest value was the blood meal blend at 410ppm as the cow blend bag stood at 102ppm which was the lowest composition for the month.

Iron levels are low during the intensive growth rates at the beginning in the young leaves but they eventual build up by the 3rd month. This trend can be seen in the blood meal bag as shown in Figure 4.7. What this means, as explained in Section 2.6.7.6, is that the older leaves tend to have more concentration of the element due to accumulation of the nutrient (Kabata-Pendias, 2011).

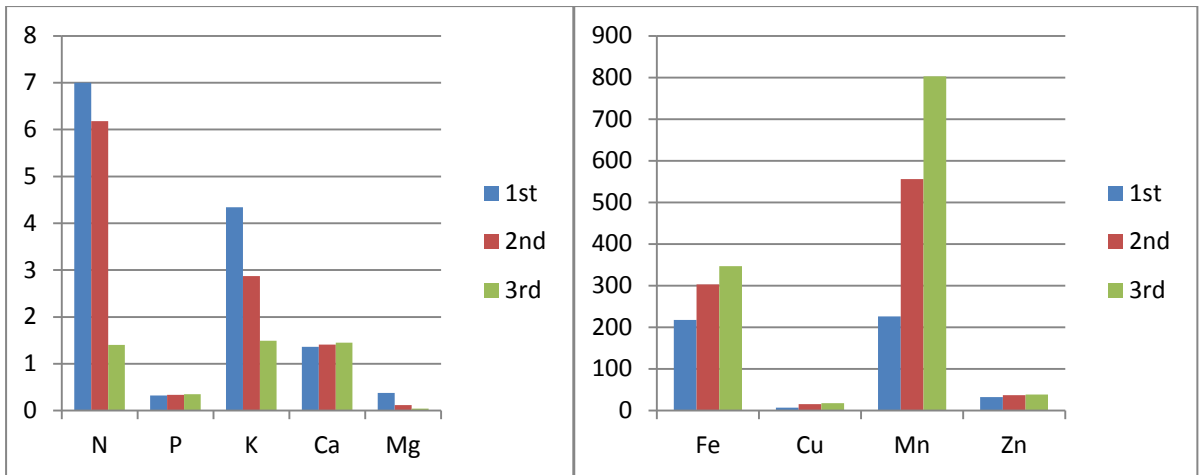


Figure 4.7: Macronutrients and Micronutrients content of leaves in blood meal bag for the 3 months

4.2.2.7 Copper

The levels of copper in the plant start at relatively low compositions for the first month and end up just slightly higher at the third month juncture. This is true for all the bags except for the plain soil bag which had a reverse trend which started high but eventually dipped while filter aid waste had a trend whereby it remained relatively the same throughout.

Table 4.11: Copper content in the leaves

Bag/Composition	1st Month ppm	2nd Month ppm	3rd Month ppm
Soil	8.33	7.43	5.00
Diatomaceous Earth	6.66	6.66	6.67
Cow Dung	6.66	4.42	1.67
Cow Blend	6.66	6.66	6.67
Goat Droppings	10.0	12.6	15.0
Goat Blend	8.33	9.93	16.7
Blood Meal	5.00	17.5	19.66
Blood Blend	5.83	13.6	26.7
Bone Meal	7.50	11.3	11.7
Bone Blend	7.30	15.8	18.3

From table 4.11 the 10.0ppm Cu composition of the 1st month happened to be the highest composition for the month as the lowest composition stood at 5.00ppm which was the composition of copper in the leaves found in the blood meal bag. The 17.5ppm Cu composition for the second month found in the blood meal bag was the highest composition while the lowest second month composition levels were the 4.42ppm found in the cow dung bag. 26.7ppm composition of copper found in the leaves of the blood meal blend bag was the highest value for the month as the 1.67ppm of the cow dung bag was noted as the lowest.

As explained in Section 2.6.7.7, copper is an important element in the functioning of the plant due to its significant role in plant respiration and photosynthesis (Kabata-Pendias, 2011). Once Cu has accumulated in the root surface during the initial growth phase, it is easily released to the potatoes as it attains maturity. This trend can be illustrated in the blood blend bag are presented in Figure 4.8.

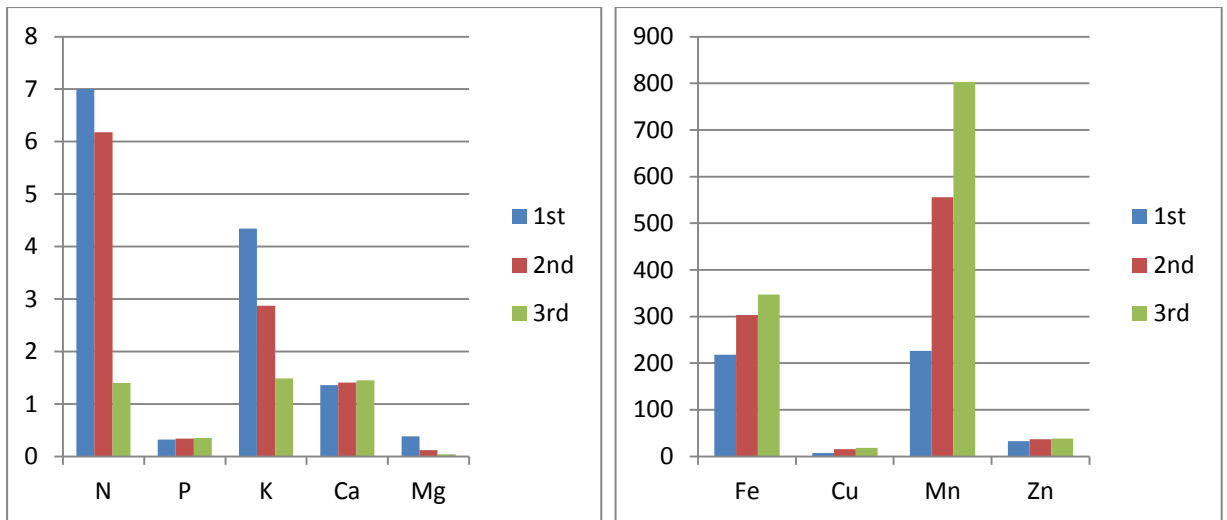


Figure 4.8: Macronutrients and Micronutrients content of leaves in blood meal blend for the 3 months

4.2.2.8 Manganese

The overall levels of Mn in all bags start out when low during the intensive growth phase of the potatoes but gradually increase as the tubers continue to mature with them attaining the highest level during the third month.

Table 4.12: Manganese content in the leaves

Bag/Composition	1st Month ppm	2nd Month ppm	3rd Month ppm
Soil	103	158	168
Diatomaceous Earth	137	228	390
Cow Dung	115	177	195
Cow Blend	120	131	152
Goat Droppings	130	149	172
Goat Blend	120	162	218
Blood Meal	155	172	180
Blood Blend	183	387	405
Bone Meal	168	194	322
Bone Blend	226	556	803

From table 4.12 the bag with the highest concentration of manganese at the first month of analysis was the bone meal blend bag at 226ppm. The lowest concentration of Mn was on the other hand found in the plain soil bag at a value of 103ppm. In the second month of analysis, the highest manganese concentration was found in the bone meal blend bag at 556ppm with the cow dung blend bag having the lowest concentration of Mn at 131ppm. The cow blend had the lowest levels of Mn at the 3rd month of analysis at 152ppm with the bone meal blend bag having the highest manganese concentration at 803ppm.

The levels for manganese that were observed were as explained in Section 2.6.7.8. During the intensive growth period, there is an accumulation of Mn at the root surface which is gradually released and translocated to the leaves and other plant organs as the plant continues to mature (Cotrufo *et al.*, 1963). The trend for the manganese can be illustrated in the blood blend bag as presented in Figure 4.9.

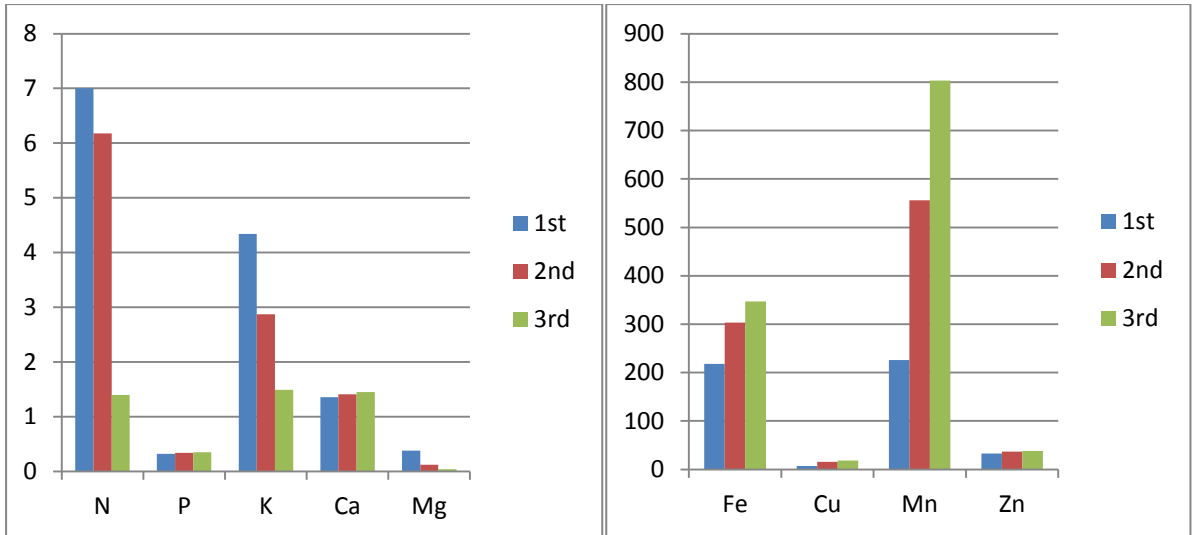


Figure 4.9: Macronutrient and Micronutrients content of leaves in bone meal bag for the 3 months

4.2.2.9 Zinc

There is no big variation of the uptake of Zn between the 1st and 3rd month in some of the bags such as the cow, goat, blood meal and bone meal and blends bags as shown by the leaf uptake analysis.

Table 4.13: Zinc content in the leaves

Bag/Composition	1st Month ppm	2nd Month ppm	3rd Month ppm
Soil	25.0	114	218
Diatomaceous Earth	26.7	85.7	103
Cow Dung	25.0	64.8	137
Cow Blend	28.3	32.4	40.0
Goat Droppings	25.0	23.1	20.0
Goat Blend	26.7	21.9	18.3
Blood Meal	43.3	33.8	27.3
Blood Blend	41.2	49.2	56.7
Bone Meal	37.0	26.4	20.0
Bone Blend	32.3	37.0	38.3

As seen from table 4.13 during the first month analysis the blood meal bag had the highest levels of zinc at 43.3ppm while the lowest concentrations were in the cow dung, plain soil and goat droppings bag which had a concentration of 25.0ppm. At the second month testing stage, the highest Zn concentration was found in plain soil bag at 114ppm with the goat blend bag having the lowest concentration at 21.9ppm. In the final month of analysis, the highest levels of zinc were detected in leaves from the plain soil bag at 218ppm. The lowest composition was in the goat blend bag at 18.3ppm while the bone meal and goat droppings bags followed close by at 20.0ppm.

The levels of zinc start out low and eventually peak in the 3rd month as illustrated in the bone blend bag are presented in Figure 4.10. From Section 2.6.7.9, the explanation for this is due to deficiencies in other micronutrients such as iron and copper in bags such as in the plain soil, filter aid waste and bone blend bags which necessitate the increase in the uptake Zn during the growth period of the potatoes (Kabata-Pendias, 2011).

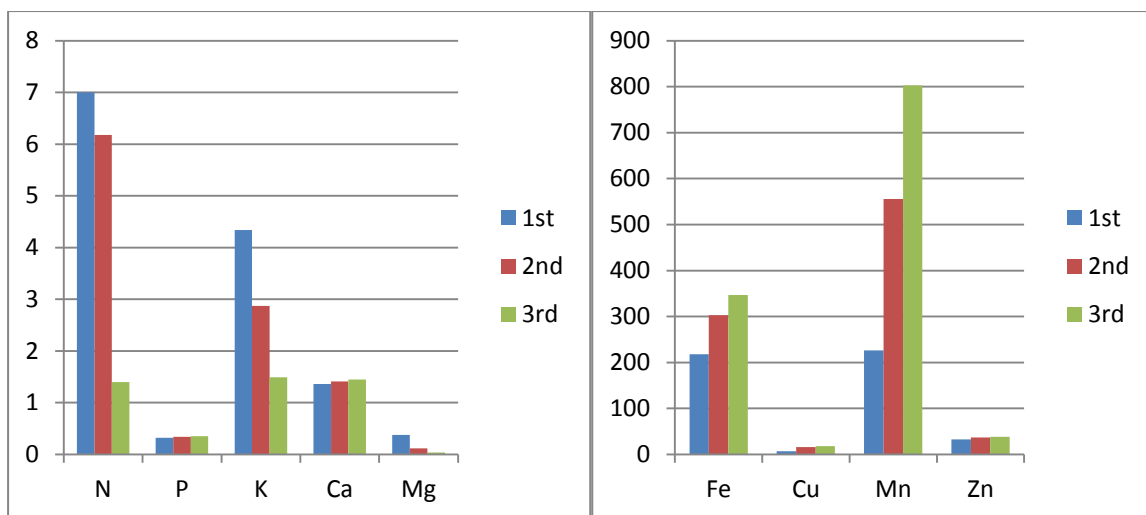


Figure 4.10: Macronutrients and Micronutrients content of leaves in bone meal blend bag for the 3 months

4.3 Tuber Analysis

4.3.1 Physical Characterization

The physical analysis was done so as to serve as an indicator of the quality of the yield. The physical parameters that were considered included:

4.3.1.1 Potato Colour

All the potatoes that were planted in this project developed within the hill and therefore none of the tubers had a greenish colour.

4.3.1.2 Brown and Black Spot

None of the potatoes in the project had any brown spot or black spot bruising thus a quick sampling observation of the potatoes showed that all the potatoes that were harvested grew in environments with no major deficiencies of both phosphorus and calcium at the very least.

4.3.1.3 Potato Skin and Bruising

The skin appearance for all the potato tubers indicated a mature harvest due to the fact that defoliation was done and all the plants were left to grow to a point whereby all the vines and leaves had dried up before being harvested. Bruising was eliminated in the project because care was taken not to harm the potatoes during cultivation and especially during harvesting.

4.3.1.4 Potato Weight and Size

However, for the case of this project, we went out of our way to try and standardize the seed and growth conditions. The seeds for instance were as close to being of similar size of

between 3.5cm and 5 cm while the growth conditions such as irrigation rate and number of seed, three per bag, was similar for all bags. Therefore, to a large extent the size and amount of the tubers harvested per bag are mainly as a result of the performance of the fertilizer that was applied in each bag.

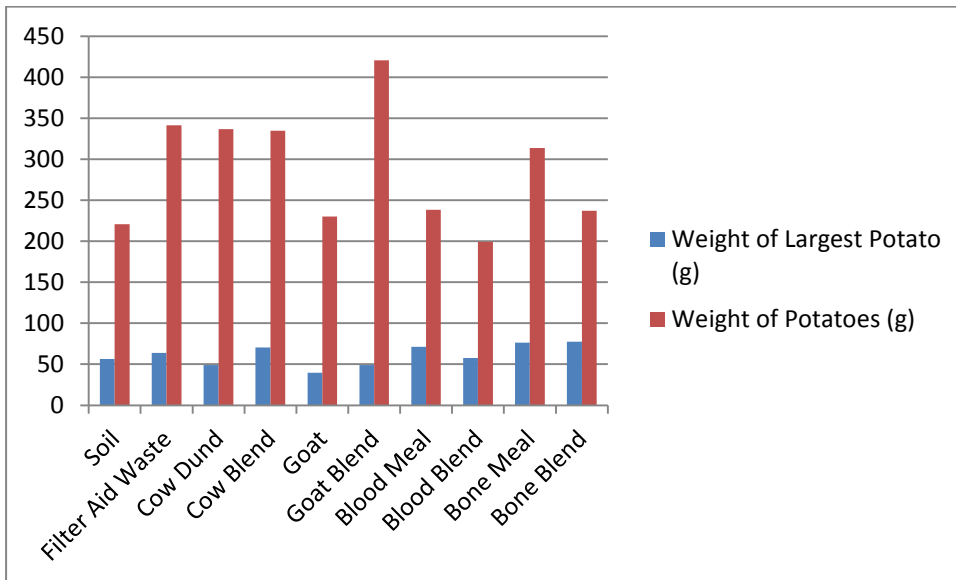


Figure 4.11: Weight of potatoes harvested

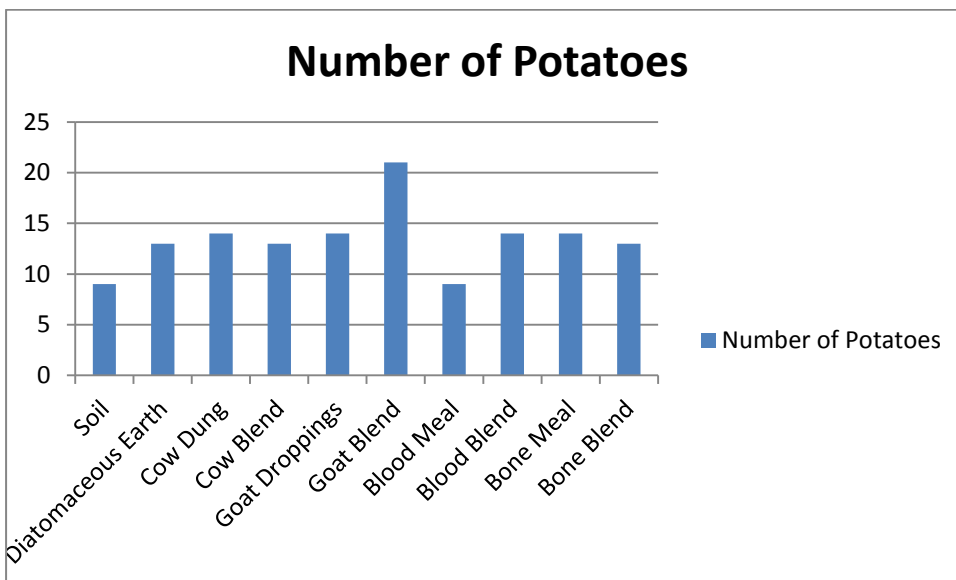


Figure 4.12: Number of potatoes harvested

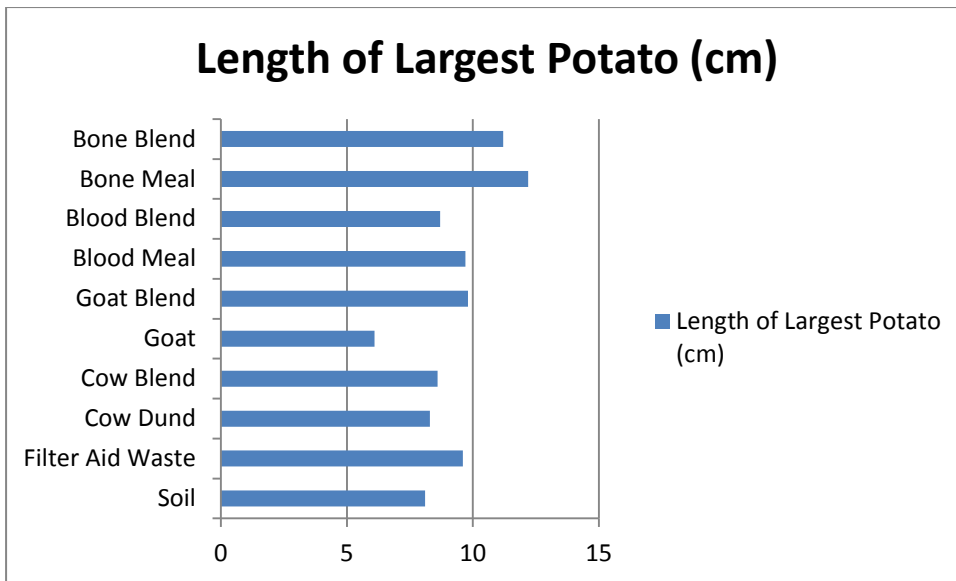


Figure 4.13: Length of potatoes harvested

4.3.2 Chemical Characterization

Potato tuber minerals significantly differ according to the field/bag in which the crop was grown in. The fertilizer that is applied to each bag influences the performance of the crops planted. The potato harvest is the eventual manifestation of the performance of the fertilizer. For the case of this research, a uniform variety was used for different bags each with different nutrient composition. The reasoning behind this is that a specific variety has a uniform way in which it responds to different levels of nutrients that it is supplied with. For instance, a deficiency in say nitrogen for a particular variety of potato will result in the same symptoms being exhibited no matter whether the source of the deficient nutrient was filter aid waste of cow manure.

4.3.2.1 Nitrogen

The tubers from the blood meal and blood blend bags had the highest content of nitrogen at 35000ppm while that of cow dung and goat blend had the joint lowest content of 14000ppm. The other bags had values that were within this range with cow blend for instance having a value of 24500ppm and bone meal at 21000ppm as shown in Table 4.14 below.

Table 4.14: Nitrogen composition of the tubers

Bag	Soil	Filter Waste	Cow	Cow Blend	Goat	Goat Blend	Blood	Blood Blend	Bone	Bone Blend
Amount (ppm)	17500	17500	14000	24500	31500	14000	35000	35000	21000	21000

The blood meal and blood meal blend fertilizers happened to have the highest concentration of nitrogen at about 109000ppm which translated to the soils of those bags also containing a high nitrogen content. The cow dung and goat blend fertilizers did not have the lowest composition of nitrogen, at 15200ppm and 16000ppm respectively. However, the percentage availability of the lowest 1100ppm N composition of the plain soil meant that the eventual tuber content for nitrogen for the plain soil stood at 17500ppm. This thus shows that the overall starting composition of a nutrient isn't necessarily the only determinant as to which bag will give the highest composition of that nutrient in the tuber analysis.

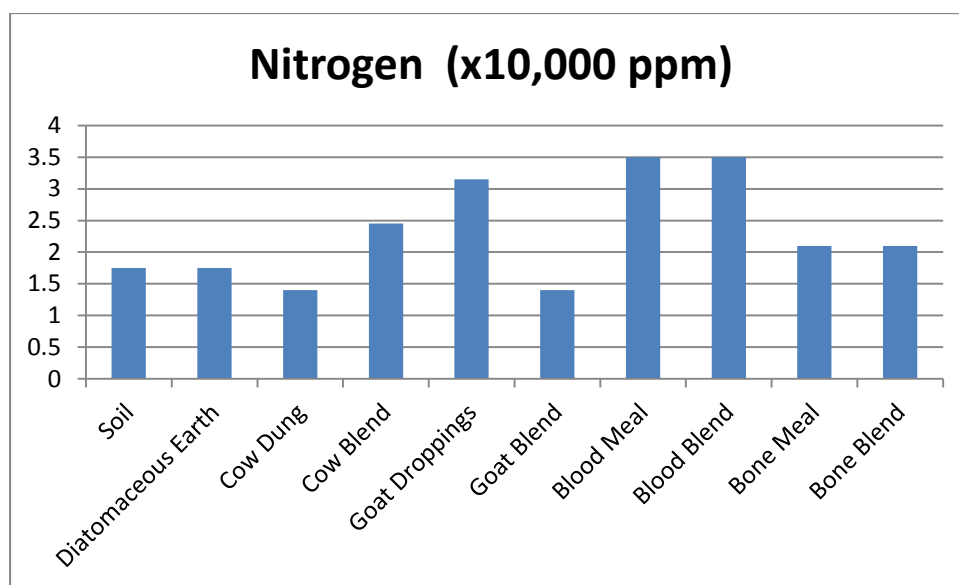


Figure 4.14: Nitrogen composition of the tubers

4.3.2.2 Phosphorus

The potatoes with the highest phosphorus composition were the bone meal bag at 5100ppm while that with the lowest was the blood meal bag at 3500ppm as shown in Table 4.15 below.

Table 4.15: Phosphorous composition of the tubers

Bag	Soil	Filter Waste	Cow	Cow Blend	Goat	Goat Blend	Blood	Blood Blend	Bone	Bone Blend
Amount (ppm)	4500	4100	5200	4900	4600	4200	3500	3800	5100	4200

The starting composition of the highest phosphorus content in the bag translated to the highest composition of P in the tubers from that bag. The bone meal had the highest composition of P at 85000ppm. The lowest composition of phosphorus was the plain soil bag with about 3.1ppm but the tuber from the plain soil ended up having 4500ppm P content in the tubers harvested from it. This was slightly better than the 4200ppm for both the goat blend and bone meal blend 4100ppm for the filter aid waste

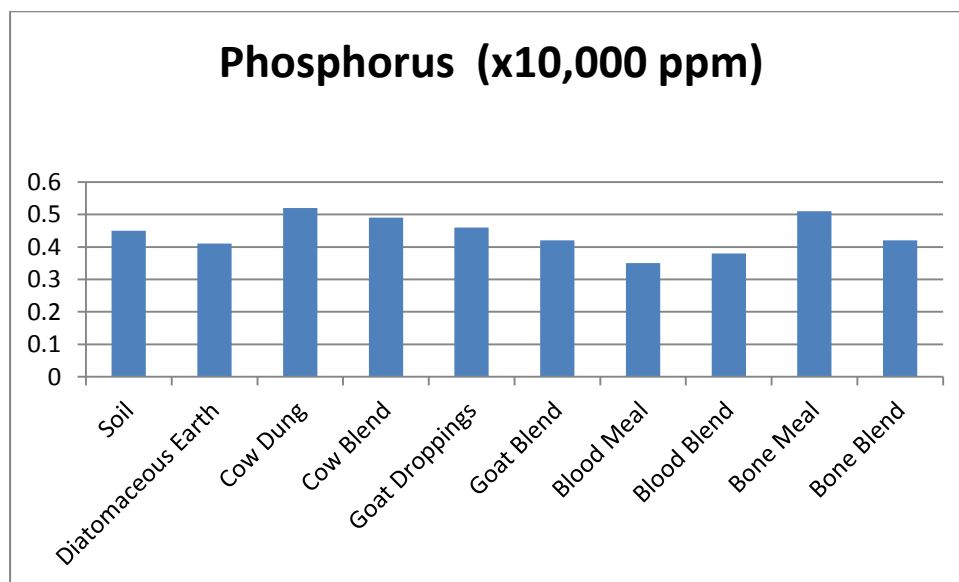


Figure 4.15: Phosphorous composition of the tubers

4.3.2.3 Potassium

The potatoes with the highest composition of K were those that were grown in the blood meal blend bag were the composition stood at 31000ppm with the second one being that of the blood meal bag at 30300ppm. The lowest composition was that in the bone meal blend at 21200ppm albeit only slightly higher than that in the plain soil and goat blend at 21600ppm as shown in Table 4.16.

Table 4.16: Potassium composition of the tubers

Bag	Soil	Filter Waste	Cow	Cow Blend	Goat	Goat Blend	Blood	Blood Blend	Bone	Bone Blend
Amount (ppm)	21600	22600	26600	25600	28600	21600	30300	31000	22200	21200

At the beginning the bags that had the highest composition of potassium was the blood meal bags which had a K content of about 2600ppm for the fertilizer added. The lowest K additive was found in the cow dung manure which had 140ppm concentration followed by the goat droppings at 203ppm.

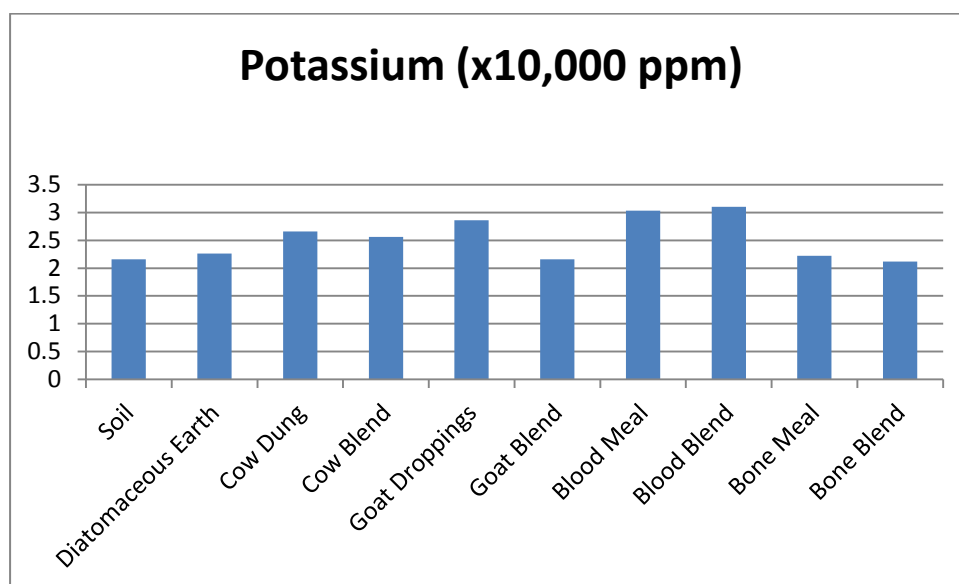


Figure 4.16: Potassium composition of the tubers

4.3.2.4 Calcium

The highest composition of calcium was observed in the potatoes that were grown in the blood meal fertilizer bag which stood at 26800ppm. The lowest content was observed in the diatomaceous earth bag which had a content of 1300ppm as shown in Table 4.17

Table 4.17: Calcium composition of the tubers

Bag	Soil	Filter Waste	Cow	Cow Blend	Goat	Goat Blend	Blood	Blood Blend	Bone	Bone Blend
Amount (ppm)	1400	1300	1400	1400	18000	17200	26800	18100	4800	10300

At the beginning before planting, the bags that had the highest Ca concentration was the bone meal and bone meal blend which had a calcium content of 178200ppm with the lowest content being that in the filter aid waste bag at 89.10ppm. Despite the fact that the bone meal fertilized bags had the highest Ca content, the potatoes from those bags did not have the corresponding highest calcium content but rather had a potato Ca content of 4800ppm and 10300ppm for the bone meal and bone meal blend respectively. The question of availability and rate of uptake by the plant more often than not are the determinants of the amounts of calcium that end up in the tuber.

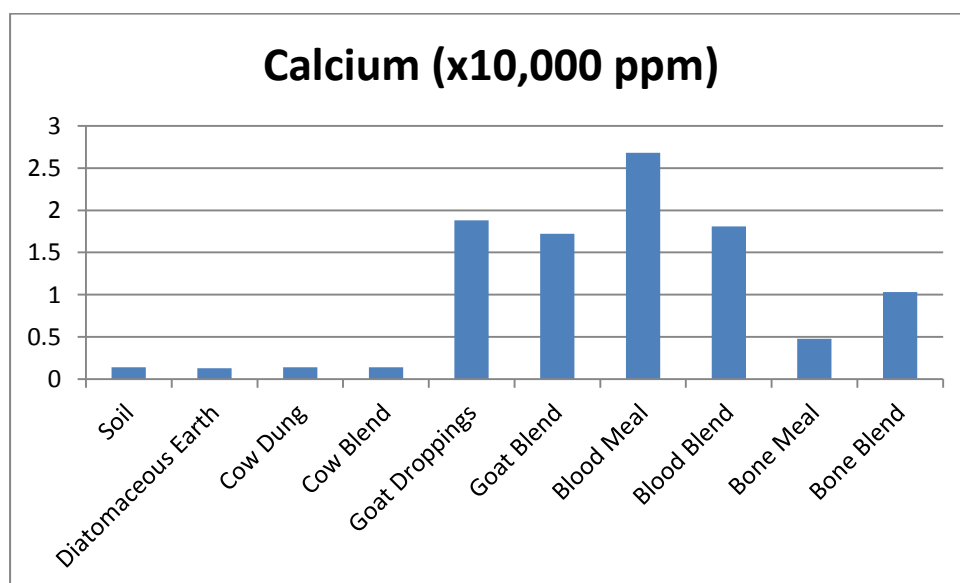


Figure 4.17: Calcium composition of the tubers

4.3.2.5 Magnesium

The content of Mg in the potatoes was not as high as the levels of the Ca, with potatoes from the blood meal bag having the highest content of 800ppm as shown in Table 4.18.

Table 4.18: Magnesium composition of the tubers

Bag	Soil	Filter Waste	Cow	Cow Blend	Goat	Goat Blend	Blood	Blood Blend	Bone	Bone Blend
Amount (ppm)	500	500	500	600	500	500	800	700	700	400

The lowest Mg content was observed in the bone meal blend bag at 400ppm. The composition for the other bags fell close to that mark with the bags of plain soil, diatomaceous earth, goat blend and cow dung all containing a content of 500 ppm. The Bone Meal fertilizer had the highest content of Mg at 7200 ppm followed by blood meal which had 1500ppm content. The relatively high blood meal content bags ended up with the highest potato Mg content while the 85.10ppm filter aid waste did not have the lowest Mg content but was still among the lowest with 500ppm.

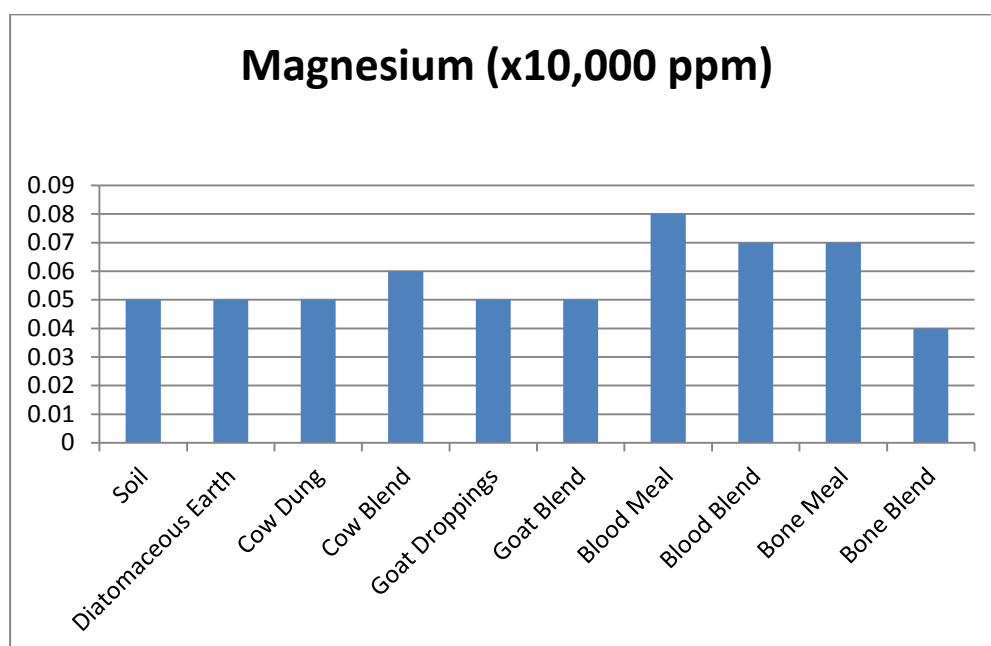


Figure 4.18: Magnesium composition of the tubers

4.3.2.6 Iron

The cow blend bag had the potatoes with the lowest Iron content standing at 95ppm while those from the blood meal bag had the highest at 410ppm as shown in Table 4.19.

Table 4.19: Iron composition of the tubers

Bag	Soil	Filter Waste	Cow	Cow Blend	Goat	Goat Blend	Blood	Blood Blend	Bone	Bone Blend
Amount (ppm)	105	100	118	95.0	233	363	410	237	358	350

Potatoes from the bone meal and bone meal blend bags also had significant quantities of Fe which stood at 358ppm and 350ppm respectively.

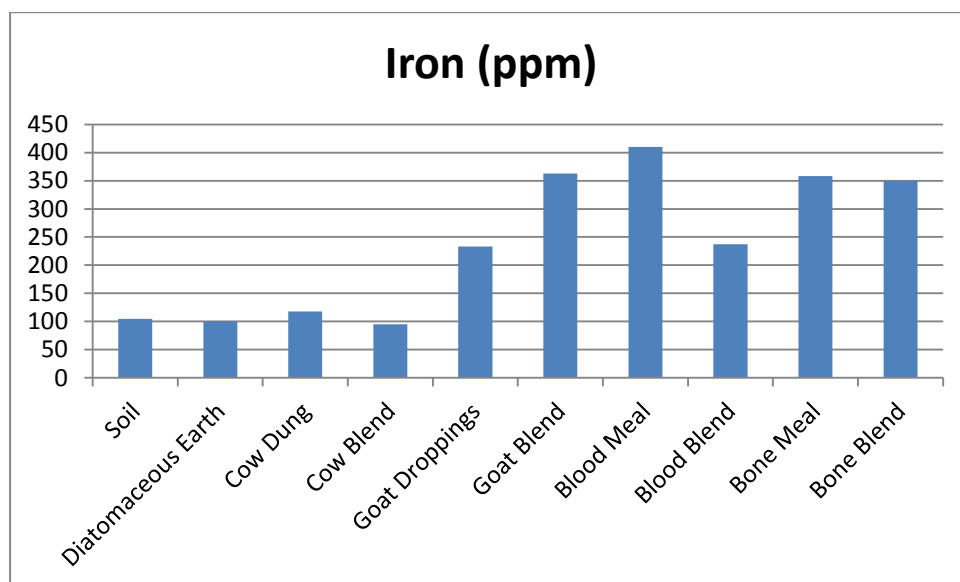


Figure 4.19: Iron composition of the tubers

4.3.2.7 Copper

Potatoes with the highest copper content were those that were grown in the blood meal bag which had contents of 26.7 ppm as shown in Table 4.20.

Table 4.20: Copper composition of the tubers

Bag	Soil	Filter Waste	Cow	Cow Blend	Goat	Goat Blend	Blood	Blood Blend	Bone	Bone Blend
Amount (ppm)	5.0	10.0	6.67	8.33	18.3	13.3	26.7	18.3	11.7	13.3

The lowest Cu content was observed in potatoes grown in the plain soil bag which stood at 5.0ppm. Other bags had potato Cu contents that stood at 10ppm for the filter aid waste bag and 13.3ppm for both the goat blend and bone blend bags

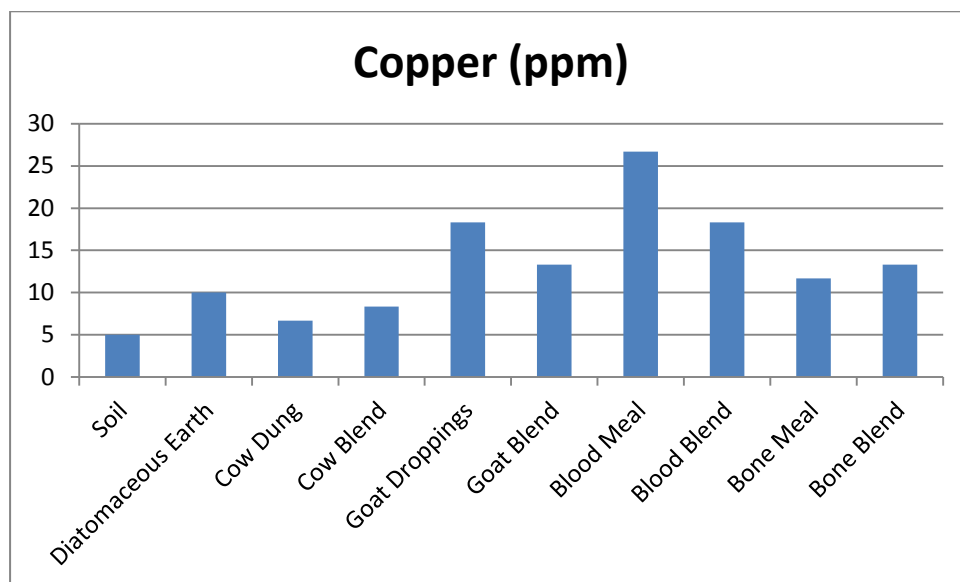


Figure 4.20: Copper composition of the tubers

4.3.2.8 Manganese

The diatomaceous earth bag had potatoes which had the lowest manganese content with a value of 18.3ppm as shown in Table 4.21.

Table 4.21: Manganese composition of the tubers

Bag	Soil	Filter Waste	Cow	Cow Blend	Goat	Goat Blend	Blood	Blood Blend	Bone	Bone Blend
Amount (ppm)	83.3	18.3	23.3	26.7	243	305	405	260	102	243

The highest content of Mn was observed in potatoes that grew in the blood meal bag which had 405ppm.

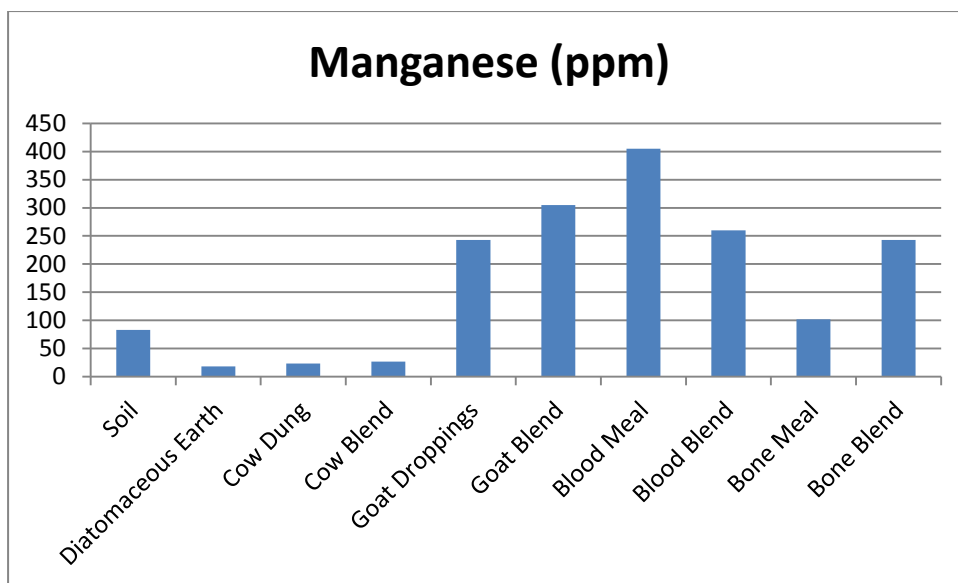


Figure 4.21: Manganese composition of the tubers

4.3.2.9 Zinc

At 56.7ppm zinc content, the blood meal bag had the highest content. The lowest content was found in potatoes that were grown in the bone meal bag at 15ppm as shown in Table 4.22.

Table 4.22: Zinc composition of the tubers

Bag	Soil	Filter Waste	Cow	Cow Blend	Goat	Goat Blend	Blood	Blood Blend	Bone	Bone Blend
Amount (ppm)	35.0	33.3	33.3	41.7	18.3	21.7	56.7	20.0	15.0	21.7

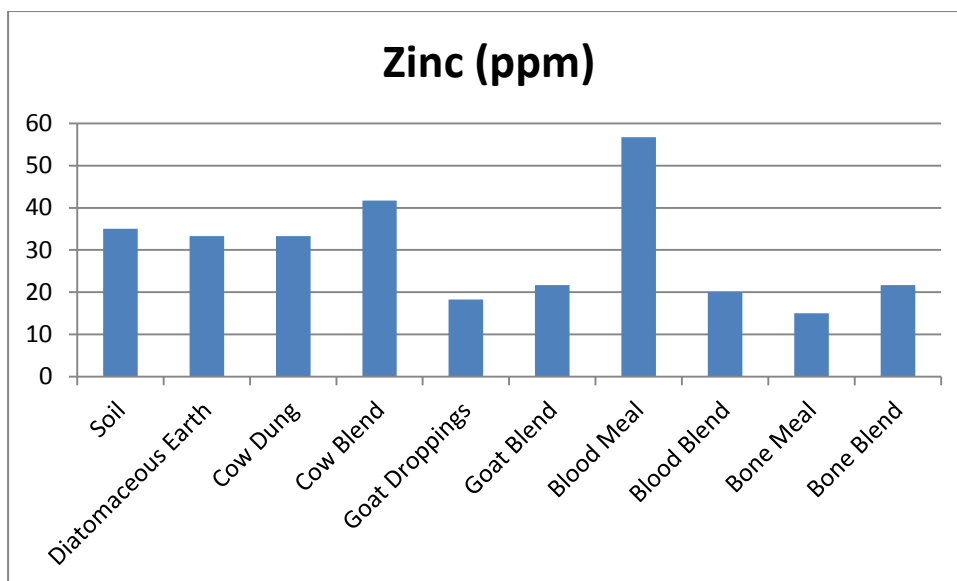


Figure 4.22: Zinc composition of the tubers

4.4 Yield Parameters

The performance of the yield was based on both physical and chemical parameters so as to better define the quality of the yield. These parameters were expressed in terms of their performance based on the analysis results.

4.4.2 Physical Parameters

The project focused on 5 physical parameters that were classified so as to give a yield interpretation for each bag. This classification gave varying results, for instance if the basis of yield is taken as the number of tubers that were harvested from each bag then the best yield was obtained from the goat droppings bag which had 21 potatoes harvested. In the same breath the worst performing yield with respect to the number of potatoes were the plain soil and blood meal bags which had 9 tubers harvested as shown in Table 4.23.

Table 4.23: Physical yield parameters

Bag	Number of Potatoes	Weight of Potatoes (g)	Average Weight of Potatoes (g)	Weight of Largest Potato (g)	Length of Largest Potato (cm)
Soil	9	220.67	24.52	56.45	8.1
Diatomaceous Earth	13	341.47	26.27	63.92	9.6
Cow Dung	14	336.60	24.04	48.84	8.3
Cow Blend	13	334.71	25.75	70.51	8.6
Goat Droppings	14	230.20	16.44	39.51	6.1
Goat Blend	21	420.52	20.02	49.16	9.8
Blood Meal	9	238.20	26.47	71.09	9.7
Blood Blend	14	199.10	14.22	57.47	8.7
Bone Meal	14	313.61	22.40	76.53	12.2
Bone Blend	13	237.27	18.25	77.59	11.2

The best yield with respect to the weight harvested per bag happened to be the goat droppings bag which had a total of 420.52g worth of tubers harvested. the worst performing yield of potatoes was observed from the blood meal blend bag which had a weight of 199.10g of potatoes harvested. The use of the average weight of potatoes harvested as a parameter for defining yield also had its own rank as to the best and worst potato yields that were obtained in the project. The best yield was obtained from the blood meal bag which had an average potato weight of 26.47g and was closely followed by the filter aid waste bag at 26.27g. The worst yield was obtained from the blood meal blend bag which had an average tuber weight value of 14.22g.

The weight of largest potato and the length of largest potato are some of the most unreliable parameters that can be used to establish the quality of the yield. This is mainly due to the fact

that the size and the length of the largest in any particular harvest are not exclusively functions of the nutritional conditions that are afforded to a crop during growth but rather freakish occurrences that scientists are yet to find a satisfactory answer to. This however does not negate the importance to which farmers attach to these two parameters vis-à-vis the correlation to which the ordinary farmers attach to their indication to yield.

With regard to the weight of the largest potato, the bone meal blend gave the greatest yield at 77.59g while the poorest yield was observed in the bag which had goat droppings at 39.51g. a look at the yield rankings based on the length of the largest potato reveals that the bag that was fertilized using the bone meal fertilizer had the highest yield with a value of 12.2cm while the bag which had the lowest yield based on the overall length of the largest potato was that which was fertilized with the goat droppings fertilizer at 6.1cm.

4.4.2.1 Yield Performance Index

Based on this criterion of classifying performance by attaching a numerical value, by using the number of potatoes ranking, the cow dung, bone meal, blood meal blend and goat blend bags had the same number of potatoes at 14 while the filter aid waste bag had 13 potatoes. All the 4 bags that had 14 potatoes harvested were given a ranking of 2 while the next highest number of potatoes was given a value of 3. Based on the physical parameters, the Blood Meal and Bone Meal Blend bag's yield performance indices were obtained as shown in Table 4.24

Table 4.24: Blood meal and bone meal Yield performance index

Blood Meal Bag	Ranking	Assigned Percentage %
Number of Potatoes	4	70
Weight of Potatoes	10	10
Average Weight of Potatoes	1	100
Weight of Largest Potato	3	80
Length of Largest Potato	4	70
		330

Bone Meal Blend Bag	Ranking	Assigned Percentage %
Number of Potatoes	3	80
Weight of Potatoes	6	50
Average Weight of Potatoes	8	30
Weight of Largest Potato	1	100
Length of Largest Potato	2	90
		350

The totals of the assigned percentages for the blood meal bag and bone meal blend bag give 330% and 350% respectively. If these total percentages are then divided by the 5 parameters that were under consideration, they give yield performance indices of 66% and 70% respectively. When these yield performance indices are compared with the other bags, they give an overall yield rank of 5 and 3 respectively.

Table 4.25: Physical yield performance ranking

Bag/Parameter	Number of Potatoes	Weight of Potatoes	RANKING				Yield Performance Index %	Overall Yield Rank
			Average Weight of Potatoes	Weight of Largest Potato	Length of Largest Potato	Yield		
Soil	4	9	4	7	9	44	8	
Diatomaceous Earth	3	2	2	5	5	76	2	
Cow Dung	2	3	5	9	8	56	6	
Cow Blend	3	4	3	4	7	68	4	
Goat Droppings	2	8	9	10	10	32	9	
Goat Blend	1	1	7	8	3	70	3	
Blood Meal	4	10	1	3	4	66	5	
Blood Blend	2	7	10	6	6	48	7	
Bone Meal	2	5	6	2	1	78	1	
Bone Blend	3	6	8	1	2	70	3	

According to the physical characterization, bone meal bag gave the best yield with a yield performance index of 78% closely followed by the filter aid waste bag which had an index of 76%. The lowest yield performance was exhibited by the goat droppings bag which had a yield performance index of 32% and was followed by the plain Soil bag which had an index of 44%.

4.4.3 Chemical Parameters

The chemical parameters that were used in the expression of yield quality were the macro and micronutrient content of the tubers.

Table 4.26: Chemical yield performance parameters

Bag/Test	N ppm	P ppm	K ppm	Ca ppm	Mg ppm	Fe ppm	Cu ppm	Mn ppm	Zn ppm
Soil	17500	4500	21600	1400	500	105	5	83.3	35
Diatomaceous Earth	17500	4100	22600	1300	500	100	10	18.3	33.3
Cow Dung	14000	5200	26600	1400	500	118	6.67	23.3	33.3
Cow Blend	24500	4900	25600	1400	600	95	8.33	26.7	41.7
Goat Droppings	31500	4600	28600	18800	500	233	18.3	243	18.3
Goat Blend	14000	4200	21600	17200	500	363	13.3	305	21.7
Blood Meal	35000	35000	30300	26800	800	410	26.7	405	56.7
Blood Blend	35000	3800	31000	18100	700	237	18.3	260	20.0
Bone Meal	21000	5100	22200	4800	700	358	11.7	102	15.0
Bone Blend	21000	4200	21200	10300	400	350	13.3	243	21.7

4.4.3.1 Yield Parameters

The elemental yield performance index for the potatoes harvested in the cow dung and goat blend bags were obtained by first assigning each element a ranking best on the comparative amount of each element found in all potatoes.

The rankings were then assigned percentages which were then added up for each bag and this summation amounted to 510% and 590% for the potatoes harvested in the cow dung and goat blend bags respectively as shown in Table 4.27.

Table 4.27: Cow dung and goat blend assigned percentage elemental ranking

Cow Dung	Ranking	Assigned Percentage %
N	6	50
P	1	100
K	4	70
Ca	7	40
Mg	4	70
Fe	7	40
Cu	7	40
Mn	8	30
Zn	4	70
		510

Goat Blend	Ranking	Assigned Percentage %
N	6	50
P	6	50
K	8	30
Ca	4	70
Mg	4	70
Fe	2	90
Cu	3	80
Mn	2	90
Zn	5	60
		590

The summation results were done for all the bags and then the value divided by the total number of variables (9) so as to obtain the yield performance indices for all the bags. The cow dung and goat blend bags gave indices of 56.67% and 65.56% respectively.

4.4.4 Overall Yield Performance Index

The yield performance indices were then ranked so as to give the overall rank. The highest overall rank was observed in the blood meal bag where the potatoes had a yield performance index of 90.00%. The cow dung bag had an overall ranking of 8 while the goat blend was ranked at 4. The lowest ranked bag an overall yield rank of 10 was the filter aid waste bag which had a yield performance index of 46.67% as shown in Table 4.28.

Table 4.28: Overall yield performance indices ranking

Bag/Parameter	RANKING									Yield Performance Index %	Overall Yield Rank
	N	P	K	Ca	Mg	Fe	Cu	Mn	Zn		
Soil	5	5	8	7	4	8	8	6	3	50.00	9
Diatomaceous Earth	5	7	6	8	4	9	5	9	4	46.67	10
Cow Dung	6	1	4	7	4	7	7	8	4	56.67	8
Cow Blend	3	3	5	7	3	10	6	7	2	58.89	7
Goat Droppings	2	4	3	2	4	6	2	4	7	72.22	3
Goat Blend	6	6	8	4	4	2	3	2	5	65.56	4
Blood Meal	1	9	2	1	1	1	1	1	1	90.00	1
Blood Blend	1	8	1	2	2	5	2	3	6	75.56	2
Bone Meal	4	2	7	2	2	3	4	5	8	64.44	5
Bone Blend	4	6	9	5	5	4	3	4	5	60.00	6

From the results are obtained from the yield performance indices, it is evident how fluid the notion of what exactly constitutes a good yield is. For instance the highest ranked yield best

on the physical parameters that were under consideration shows that potatoes from the bone meal bag gave the best yield with a performance index of 78%. However, using the elemental parameters, the yield performance index reveal that the best yield was that obtained from the blood meal bag at 90%.

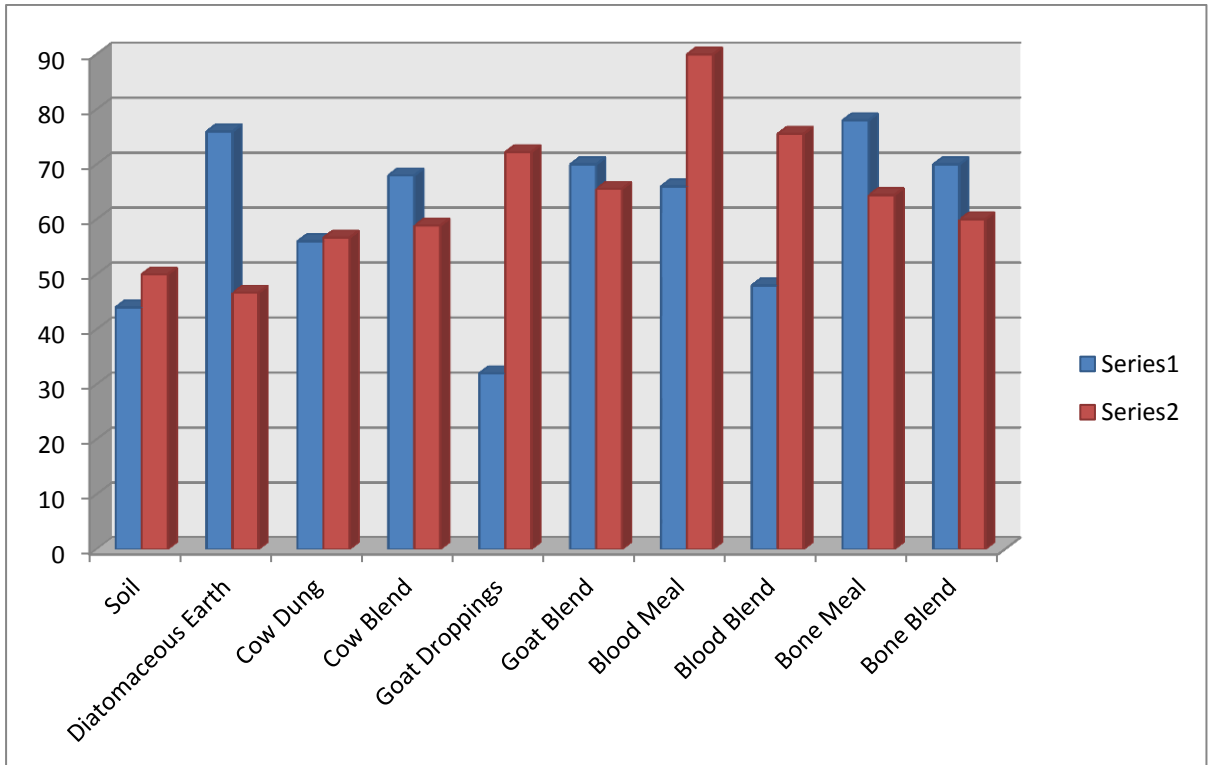


Figure 4.23: Overall yield performance indices ranking

Key

Series 1 – Yield Performance Index for physical parameters (%).

Series 2 – Yield Performance Index for chemical/elemental parameters (%).

4.5 Movement of Nutrients

The movement of the nutrients from the growth media to the plant during the growth phase was done so as to check whether the availability in the soil translated to actual available nutrients for the plant and the harvest.

Table 4.29: Ranking between the composition of nutrients in pre and post-harvest soils

Bag/Ranking	Nitrogen		Phosphorus		Potassium		Calcium		Magnesium	
	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post
Soil	10	3	10	7	8	3	9	2	9	1
Diatomaceous Earth	9	2	9	9	6	4	10	3	10	3
Cow Dung	8	1	7	2	10	2	8	4	8	3
Cow Blend	6	1	5	1	5	1	7	1	7	2
Goat Droppings	7	5	4	4	9	6	6	6	6	6
Goat Blend	5	4	3	3	4	5	5	7	5	4
Blood Meal	2	9	8	8	3	7	4	5	4	5
Blood Blend	1	6	6	6	1	9	3	8	3	9
Bone Meal	4	8	2	6	7	9	2	8	2	8
Bone Blend	3	7	1	5	2	8	1	6	1	7

Based on the pre-harvest and post-harvest soil composition analysis tests, ranked at position 10 with Nitrogen content of 1100ppm, the N levels at post-harvest for the same bag showed a composition of 1800ppm and were ranked at position 3. For phosphorus, the highest ranked bags were the bone meal and bone meal blend at pre-harvest at 85000ppm while the same bags during post-harvest testing were ranked at number 6 and 5 respectively with a content of 10900ppm and 16900ppm.

With a potassium content of 4140ppm, the blood meal blend bag had the highest content followed by bone meal blend bag at 3060ppm. But at post-harvest the cow blend bag had the highest value at 17700ppm. The highest content of calcium at the pre-harvest testing stage was observed in bone meal and bone meal blend bags at 178200ppm. However, at post-harvest, the cow blend bag was ranked highest with 19700ppm. For magnesium, the level for the lowest ranked bag was for the filter aid waste bag at 89.10ppm. But with a content of 40400ppm at the post-harvest stage, the soil in the filter aid waste bag was ranked at number 3.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

The diatomaceous filter aid waste was analyzed during this thesis project from the time it was deposited as a liquid to when it was backfilled. The analysis of this waste at different time periods of deposition revealed that the 1 year sample could be used as an organic fertilizer. Physical characterization showed that in addition to being easier to handle than the liquid and sludge samples at the initial period of waste deposition. The 1 year sample also had the advantage of not having the strong foul and pungent smell due to the composting it had undergone.

A chemical characterization of the different waste samples was also done so as to identify which sample was ideal for use as a soil enrichment supplement. The results of the chemical analysis were very erratic due to the fact that the wastes were still decomposing and thus changing characteristics. This was especially evident in the pH values obtained that ranged from a high of 8.8 for the 7-9 month sample to a low of 3.5 for the slurry. The 1 year sample had a value of 4.9 with pH being a very important parameter when it comes to fertilizers. This was concluded to be as a result of the high yeast, protein, starch and beer content among other turbidity components. From the characterization tests carried out on all the filter aid waste samples, the sample that was obtained from the pile that had stayed for over one year was chosen due to its composition stability. That sample had a pH of 4.9, N of 5300ppm, P of 390ppm, K of 1540ppm, Ca of 89.10ppm, Mg of 85.10ppm and a percent Carbon concentration of 1.03% (10300ppm).

The results of chemical analysis revealed that the filter aid waste did not have the relatively high macronutrient and primary micronutrient content of commonly used organic fertilizers. The results showed that those composition levels were still useful for the purposes of use as an organic fertilizer. However, due to the low compositional levels, the filter aid waste was to be blended with cow dung, goat manure, blood meal and bone meal organic fertilizers. These four were not only chosen due to their popular use as organic fertilizers but also due to their composition levels of the NPK, Ca and Mg nutrients. Blood meal was chosen due to its high N content (132500ppm), bone meal due to its high P (59000ppm) and Ca (127000ppm)

content, cow dung for its good P content (3000ppm) and the goat droppings due to its relatively good P (5000ppm) and Mg (3000ppm) content.

Blends were done for the filter aid waste with these four organic fertilizers so as to carry out a field test of the effectiveness of the filter aid waste as a fertilizer. The blending was done with P chosen as the limiting nutrient and thus applications for all were done with the KARI recommended levels of DAP fertilizer of 500kg DAP/Ha. From this recommended value, a scaling down calculation was done so as to ensure that the level of the limiting nutrient that was planted in each bag was within the recommended levels of P.

10 bags of potatoes were planted in a controlled environment under irrigation. The 10 bags included a blank of just the plain soil, the filter aid waste bag as the control, cow dung, goat droppings, blood meal and bone meal bags along with the respective blends for the organic fertilizers. In the bags irrigation was done at similar intervals. Due to the small margins of error and the relatively small test field, a pure breed of potato was chosen, the *Asante* variety so as to try as much as possible to present uniform growth conditions with the only variable being the fertilizer used.

Monthly leaf uptake analysis tests were conducted in addition to regular physical checks so as to document the development of the potatoes throughout the growth phase. The physical analysis revealed that potatoes were growing healthily for all the bags at every monthly check. This was evidenced by the robust growth of the leaves for these periods of tests. Chemical uptake analysis revealed that the content of NPK, Ca, Mg, Fe, Cu, Mn and Zn were within the expected ranges. The composition levels of all the nutrients tested throughout the three months of tests for all the 10 bags gave an expected trend except for the levels of Zn in the filter aid waste and plain soil bags. This was mainly due to deficiencies in other micronutrients such as iron and copper in these bags which necessitate the increase in the uptake Zn during the growth period of the potatoes.

All the 10 bags gave a healthy harvest of potatoes that were devoid of any nutritional deficiencies as evidenced by the physical tests done on the harvest. Chemical analysis of the tubers also revealed that the levels of the elements tested in all the bags were within the recommended range.

There was however difficulties in classifying which bag gave the best yield due to the various parameters for the determination of yield. Based on these parameters, the benefit of using

blends over pure organic fertilizers wasn't as easy to ascertain. For instance, the yield performance index based on physical parameters, the blends in some bags performed better than the pure form. A good example was the cow dung bags, goat droppings bags and blood meal bags were the blends gave better yield performance index results. This was in stark contrast to the yield performance index based on chemical parameters whereby the quality of the yields showed that the pure organic fertilizers gave better yields than their respective blends.

A pre and post-harvest soil analysis showed that the intervention as a result of addition of organic fertilizers inherently improved the quality of the soil. This means that for the next planting cycle, due to the better soil quality, the crops planted will have a relatively better performance.

5.2 Recommendations

- 1) Due to the elemental composition and the performance of the diatomaceous earth filter aid waste as a fertilizer as demonstrated in this project, EABL should look into alternative uses for its filtration wastes. More specifically, EABL should consider using the filtration wastes as an organic fertilizer whether in its pure form or as a blend.
- 2) Do more research on the nature of the wastes for use as a fertilizer for use in other application methods such as a foliar spray. This could be an important research objective that can be done in later stages. The main reason is because the project utilized the 1 year waste that had composted within the backfilling site as opposed to waste that had been freshly deposited due in part to its ease in handability. If further research can reveal that the use of freshly deposited waste can be equally, if not, as potent as the composted waste when applied as a foliar fertilizer, then EABL can significantly reduce the backlog of waste that is within their premise. As a matter of fact if research can show that the waste while still in a slurry/sludge state can be used for agricultural purposes, then EABL can get rid of the backfilling site completely and even use that space for future plant expansion.
- 3) Look into the qualities of the Filter Aid Waste that can enable it to be used for soil conditioning purpose. This arises from the fact that diatomaceous earth has very interesting properties such as its highly porous nature. It is this porosity that makes it a good filtration media that is widely used in the brewing industry. If research can be done that can factor in this porosity quality especially its use in water-logged soils, then farmers can use the waste for conditioning their soil. Such conditioning can be used to improve on the root development of the crops grown and aeration of the soil among other benefits of improved soil porosity.

- 4) Due to the fact that the 1 year filter aid waste that was used was a dry sample, the blending with the other organic fertilizers was done in the solid phase. However, one of the most important determinants of the quality of a blend is the compatibility of the constituents. Compatibility is among other things dependent on the interactions of the molecules of the components and the case could be that if the Filter Aid Waste is to be used while in a slurry/sludge phase, then perhaps the blending should be done at that stage. Such blending could be beneficial to both the farmer and the company due to the fact that farmers can get the wastes and blend them with whatever fertilizers they use. The company will benefit from the fact that they can get rid of their waste as soon as they generate it without the added burden of backfilling.
- 5) Try basing the limiting nutrients on another macronutrients such as nitrogen or potassium and see whether the quality of the potatoes increase and whether the blend becomes more potent. This is due to the fact that in the choice of a limiting nutrient, it is only that nutrient that is made available in recommended quantities. Therefore, the choice of a different limiting nutrient will have a totally different bearing on the availability of other nutrients.
- 6) Different types of plants react differently to the application of even the same fertilizer. Therefore it would be an interesting project to see how other crop types such as legumes, cereals, vegetables and fruits perform under the filter aid waste organic fertilizer.
- 7) This project only observed the effects of the filter aid waste as a fertilizer in the growth of potatoes over one planting cycle. It would therefore be interesting to check for the effect that the fertilizer has on productivity after application over several planting cycles.
- 8) Look into using an agricultural field that had been used to plant other crops as opposed to virgin soil. From such we can check if the addition of the filter aid waste alongside its other blends helps in the uptake of other nutrients already present in the soil.
- 9) The blending of the filter aid waste was done only with other commonly used organic fertilizers. A different research could however go a different direction and look into blending with a variety of chemicals fertilizers.
- 10) Further research can look into conducting a more detailed uptake analysis that continually samples the crop throughout the growth period up to and including the stem translocation so as to understand better the availability ratios in both the filter aid waste and its various blends.
- 11) Look into other modes of fertilizer applications such as top dressing and different periods of fertilizer application which might end up being a more potent administration technique for the filter aid waste as an organic fertilizer.

- 12) Organic fertilizers are generally slow release therefore it will be interesting to observe the growth over 2-3 seasons so as to gauge the overall performance of the filter aid waste fertilizer in an agricultural field.
- 13) Due to the fact that this project was done in a highly controlled environment, the loss of nutrition through processes such as runoff was completely eliminated. However, in normal agricultural fields, surface runoff is a very huge factor in fertilizer application. It would thus benefit to look into the effect of nutrients runoff, leaching and other processes within the soil that might influence the filter aid waste uptake as a fertilizer or a blend.

REFERENCES

- Alexander, P. A., Alloway, B. J., & Dourado, A. M. (2006). Genotypic variations in the accumulation of Cd, Cu, Pb and Zn exhibited by six commonly grown vegetables. *Environmental Pollution*. 144: 736–745. DOI: 10.1016/j.envpol.2006.03.001.
- Alina, Kabata-Pendias (2011). *Trace Elements in Soils and Plants*. 4th Edition. New York, NY: CRC Press
- Allen V. Barker, David J. Pilbeam. (2007). *Handbook of Plant Nutrition*. CRC Press Book. Boca Raton, FL.
- American Society of Agronomy (ASA) & Soil Science Society of America (SSSA) (2010). *Methods of Soil Analysis, Part 2-Chemical and Microbiological Properties*. Madison, WI: American Society of Agronomy Publications.
- American Society of Plant Physiologists (1998). *Phosphorus Uptake by Plants: From Soil to Cell*. Rockville, Maryland: American Society of Plant Physiologists.
- Atkinson, D., Geary, B., Stark, J., Love, S. and Windes, J. (2003). *Potato Varietal Responses to Nitrogen Rate & Timing*. Presented at the Idaho Potato Conference, January 22, 2003.
- Barchet, R. (1993). Hot Trub: Formation and Removal. *Brewing Techniques*, 1: 1-6.
- Better Crops (1998). Potassium Availability and Uptake. *Better Crops*, 82(3): 1-15.
- Boekhout, T. and Vincent, R. (2003). *Yeasts in Food: Beneficial and Detrimental Aspects*. Berlin: Behr's Verlag DE.
- Bohl W., Love, S., Corsini, D., Stark, J., and Olsen, N. (2002). Cultural Management of Bannock Russet Potatoes. *CIS 1103*.
- Bohl, W., and Love, S. (2003). Cultural Management of Russet Norkotah Potatoes. *CIS 863*.
- Bohn H., McNeal, B. & O'Connor G. (1985). *Soil Chemistry*, 2nd Edition. Hoboken, NJ: John Wiley & Sons.
- Brian J. Alloway (2004). *Micronutrient Deficiencies in Global Crop Production*. Springer Science + Business Media, B.V. NY: New York.
- Briggs, D., Boulton, C., Brookes, P. and Stevens, R. (2004). *Brewing Science and Practice*. Boca Raton, FL: CRC Press LLC and Woodhead Publishing Limited.
- Bustamante, M., Paredes, C., Moral, R., Moreno-Caselles, J., Perez-Espinosa, A. & Perez-Murcia, M. (2005). Uses of Winery and Distillery Effluents in Agriculture: Characterization of Nutrient and Hazardous Components. *Water Science Technology*, 51(1): 143-147.

- Carvalho, F., Estevez, M., Parajo, J. Pereira, H and Girio, F. (2004). Production of Oligosaccharides by Auto Hydrolysis of Brewer's Spent Grain. *Bioresource Technology*, 91-93.
- Chesworth, W. (2008). *Encyclopedia of Soil Science*. Berlin: Springer.
- Christopher A. Guesta, Darrell G. Schulze, Ian A. Thompson and Don M. Huber (2002). Correlating Manganese X-Ray Absorption Near- Edge Structure Spectra with Extractable Soil Manganese. *Soil Science Society Journal*. 66:1172–1181. DOI:10.2136/sssaj2002.1172.
- Cotrufo, C., Nelson, D.C. and Lana, P. (1963). Effects of Micronutrients on Yield, Tuber Set and Specific Gravity of Potatoes Grown in North Dakota. *American Potato Journal*. 40: 88-94.
- Davis, J.R., Huisman, O.C., Westermann, D.T., Everson, D.O., Schneider, A., and Sorensen, L.H. (2004). Some Unique Benefits with Sudan grass for Improved U.S. #1 Yields and Size of Russet Burbank Potato. *American Journal of Potato Research*. 81: 403-413.
- Dittmer, P., & Desmond, J. (2005). *Principles of Food, Beverage, and Labor Cost Controls*. New York, NY: John Wiley & Sons.
- Driessen, W and Vereijken, T. (2003). Recent Development in Treatment of Brewery Effluent. *The Institute and Guild of Brewing Convention*, Livingstone, Zambia, March 2-7.
- Ducic, T. and Polle, A. (2005). Transport and detoxification of manganese and copper in plants. *Brazil Journal of Plant Physiology*. 17: 103-112.
- DuPont (1996). *Chemical Engineering: Essentials of Process Control*. New York: McGraw Hill.
- Fillaudeau, L., Blanpain-Avet, P. and Daufin, G. (2006). Water, Wastewater and Waste Management in Brewing Industries. *Journal of Cleaner Production*, 14: 463-471.
- Frans J. M. Maathuis and Dale, Sanders. (1996). Mechanisms of potassium absorption by higher plant roots. *Physiologia Plantarum*. DOI: 10.1111/j.1399-3054.1996.tb00197.x
- Frans, J.M. Maathuis and Dale Sanders (1996). Mechanisms of Potassium Absorption by Higher Plant Roots. *Physiologia Plantarum*. 96(1): 158-168.
- Gugala M., Zarzecka K. and Mystkowska J. (2012). Potato tuber content of magnesium and calcium depending on control methods. *J. Elementol*. DOI: 10.5601/jelem.2012.17.2.07, 247–254.
- Guinness Beer Documentary (2009). World's Best Beer and Brewery. *National Geographic Megafactories*

- Ha, J., Shah, N., Ul-Islama, M. and Park, J. (2011). Potential of the Waste from Beer Fermentation Broth for Bio-Ethanol Production without Any Additional Enzyme, Microbial Cells and Carbohydrates. *Enzyme and Microbial Technology*, 49(3): 298–304.
- Hashemi, M., Razava, H., Shojaosadati, A. and Mousavi, M. (2011). The Potential of Brewers Spent Grain to Improve the Production of α -Amylase by *Bacillus* sp. KR-8104 in Submerged Fermentation System. *New Biotechnology*, 28(2): 165-172.
- Hinsinger P., Plassard C., Jaillard B. (2006). Rhizosphere: A new frontier for soil biogeochemistry. *J. Geochem. Explor*, 88: 210–213.
- Holford, I. (1997). Soil Phosphorus: Its Measurement & Its Uptake by Plants. *Australian Journal of Soil Research* 35: 227-239.
- Hue, N.V., G.R. Craddock, and F. Adams. (1986). Effect of organic acids on aluminum toxicity in subsoils. *Soil Sci.Soc.Am.J.* 50: 28-34.
- International Fertilizer Industry Association (IFA) (2011). *Recommended Best Practice for the Analysis of Potassium Content in Potassium Chloride (KCl) Fertilizers*. Paris, France: IFA Publications.
- Khattaka, A., Khana, T., Haa, J., Ul-Islama, M., Kanga, M. and Parka, J. (2013). Enhanced Production of Bioethanol From Waste of Beer Fermentation Broth at High Temperature Through Consecutive Batch Strategy by Simultaneous Saccharification and Fermentation. *Enzyme and Microbial Technology*, 53(5): 322–330.
- King, B.A., Tarkalson, D.D., Bjerneberg, D.L. and Taberna, J.P, Jr. (2011). Planting System Effect on Yield Response of Russet Norkotah to Irrigation and Nitrogen under High Intensity Sprinkler Irrigation. *American Journal of Potato Research*. 88: 121-134.
- Kirkby, E.A. and Pilbeam, D.J. (1984). Calcium as a Plant Nutrient. *Plant Cell & Environment*. 7, 397-405.
- Kleinkopf, G.E., Westermann, D.T. and Dwelle, R.B. (1981). Dry Matter Production and Nitrogen Utilization by Six Potato Cultivars. *Agronomy Journal*. 73: 799-802.
- Kleinschmidt, G.D. (1984). *Starter Fertilizer for Optimum Potato Yields*. Proceedings of the University of Idaho Winter Commodities Schools, 1984.
- Koenig, R & Johnson, M. (2011). *Selecting and Using Organic Fertilizers*. Utah State University Cooperative Extension.
- Love, S., Bohl W., Corsini, D., Stark, J., and Olsen, N. (2001). Cultural Management of Gem Russet Potatoes. *CIS 1093*.
- Love, S., Pavek, J., Corsini, D., Stark, J., Whitmore, J., and Bohl, W. (1998). Cultural Management of Ranger Russet Potatoes. *CIS 919*.

- Love, S.L. (1986). *Seed Spacing and Pre-plant Nitrogen Requirements of Three Potato Cultivars*. A proceeding of the University of Idaho Winter Commodity Schools, 1986.
- Markovic, R., Grujic, O. and Pejin, J. (2003). Conventional and Alternative Principles for Stabilization of Protein and Polyphenol Fractions in Beer. *APTEFF*, 34, 3-12.
- Mathias, T., Moretzshohn de Mello, P. and Sérvulo, E. (2014). Solid Wastes in Brewing Process: A Review. *Journal of Brewing and Distilling*. 5(1): 1-9.
- Mayumi, Aizaki., Uwasawa, Masashi., Kawasaki, Akira. Naito, Narihiro., Nakamura, Munetomo., Noguchi, Akira., Yazima, Kazuyuki and Yasui, Akemi. (2013). *Testing Methods for Fertilizers 2013*. Tokyo, Japan: Incorporated Administrative Agency: Food and Agricultural Materials Inspection Center (FAMIC).
- Monica Peris, Carolina Micó, Luis Recatalá, Raúl Sánchez, Juan Sánchez (2007). Heavy metal contents in horticultural crops of a representative area of the European Mediterranean region. *Science of the Total Environment*. 378 (1-2): 42-48.
- Moore, A.D., N.L. Olsen, A.M. Carey, and A.B. Leytem. (2011). Residual Effects of Fresh and Composted Dairy Manure Application on Potato Production. *American Potato Journal of Research*. 88, 324-332.
- Morel, I. and Lehmann, E., (1997). Brewer's grains silage in cattle fattening. *Agrarforsc.*, 4 (3): 111-114.
- Niemi, P., Martins, D., Buchert, J. and Faulds, B. (2013). Pre-hydrolysis with Carbohydratases Facilitates the Release of Protein from the Brewer's Spent Grain. *Bioresource Technology*, 136: 529-534.
- Nisar, Ahmad., Avais, M.A., Saqib, M., Bhatti, K.M. and Anwar, S.A. (2000). Response of potato (*Solanium Tuberosum*) to seed and foliar application of Iron and Manganese. *Pak. J. Agri.Sci.* 37 (3-4): 158-160.
- NPCS Board of Consultants and Engineers (2007). *Potato and Potato Products Cultivation, Seed Production, Manuring, Harvesting, Organic Farming, Storage and Processing*. Delhi, India. NIIR Project Consultancy Services.
- Nso, E., Aseaku, J., Zangué, S., Ngulewu, C., Aleambong, D. and Taira, A. (2013). Comparison of the mashing and Brewing Potentials of Crude Extracts of *Abrus Precatorius*, *Burnatia Enneandra* and *Cadaba Farinosa*. *Journal of Brewing and Distilling*. 4(2): 46-50.
- Olajire, A. (2012). The Brewing Industry and Environmental Challenges. *Journal of Cleaner Production*, 1-21.
- Oyoo, J. E. Muiru, S. Otieno, M. Otipa and C. Lung'aho (2013). Effects of Yadbiovitalizer on Yield of Irish potatoes in Limuru Area, Kenya. *E. Afr. agric. For. J.* 79(1): 35-44.

- Pierzynski, G. (2000). *Methods of Phosphorus Analysis for Soils, Sediments, Residuals and waters*. Southern Cooperative Series Bulletin Number 396. Manhattan, Kansas.
- Priest, F. and Stewart, G. (2006). *Handbook of Brewing*, 2nd Edition. Boca Raton, FL: CRC Press.
- Rayment, G. and Lyons, D. (2011). *Soil Chemical Methods: Australasia*. Collingwood, Victoria: CSIRO Publishing.
- Richardson, A. (1994). Soil Microorganisms and Phosphorus Availability. *Soil Biota*, 50-62.
- Rowell, D. (1994). *Soil Science: Methods & Applications*. New York, NY: Routledge.
- Russ, W., Mortel, H., Meyey-Pittroff, R. and Babeck, A. (2005). Kieselguhr Sludge from the Deep Bed Filtration of Beverages as a Source for Silicone in the Production of Calcium Silicate Bricks. *Journal of European Ceramic Society*, 26: 2547-2599.
- Smith, S. & Hui, Y. (2004). *Food Processing: Principles and Applications*. Hoboken: NJ: Blackwell Publishing.
- Stark, J., Bohl, W., Love, S., Novy, R., Whitworth, J., Olsen, N., Brandt, T., Miller, J., Fuller, J., and Helms, T. (2008). Cultural Management of Western Russet Potatoes. *CIS 1152*.
- Stark, J., Bohl, W., Novy, R., Whitworth, J., Olsen, N., and Brandt, T. (2008). Cultural Management of Blazer Russet Potatoes. *CIS 1149*.
- Stark, J.C., Novy, R.G., Love, S.L., Whitworth J.L., Corsini, D.L., Pavek, J.J., Vales, M.I., James, S.R., Hane, D.C., Charlton, B.A., Brown, C.R., Knowles, N.R., Pavek, M.J., Brandt, T.L., and Olsen, N. (2009). Highland Russet: A Full Season, Processing Variety with High Yields of Uniform U.S. No. 1 Tubers. *American Journal of Potato Research*. 86: 171-182.
- Stephanopoulos, G. (1999). *Chemical Process Control: An Introduction to Theory and Practice*. Englewood Cliffs, NJ: PTR Prentice Hall.
- Stryer, L. (1975). *Biochemistry*. New York, NY: W. H. Freeman & Company.
- Subramanian, Nithya K., Philip J. White, Martin R. Broadley, and Gavin Ramsay (2011). The three-dimensional distribution of minerals in potato tubers. *Annals of Botany* 107 (4): 681-691.
- Tan, K. (1998). *Principles of Soil Chemistry*, 2nd Edition. New York, NY: M. Dekker Publisher.
- Tan, K. (2005.) *Soil Sampling, Preparation and Analysis*, 2nd Ed. Boca Raton, FL: Taylor and Francis.
- Thornton, M., Beck, D., Stark, J., and Hopkins, B. (2008). *Potato Variety Response to Phosphorus Fertilizer*. Proceedings of the Idaho Nutrient Management Conference. March 4, 2008. Jerome, ID.

- Tindall, T.A., Stark, J.C., Falen, C.L., and Bywater, L.D. (1997). *Idaho's Cooperative Fertilizer Evaluation Program Potato Nutrient Management*. Presented at the Idaho Potato Schools, January 22, 1997.
- Udeh, H. & Kgatla, T. (2013). Role of Magnesium Ions on Yeast Performance during Very High Gravity Fermentation. *Journal of Brewing and Distilling*. 4(2), 19-45.
- Varnam, A. & Sutherland, J. (1994). *Beverages: Technology, Chemistry and Microbiology*. London, UK: Chapman & Hall.
- Viets FG (1962). Chemistry and availability of micronutrients in soils. *Journal of Agriculture and Food Commodity* 10: 174-178.
- Yash P. Kalra (1998). *Handbook of Reference Methods for Plant Analysis*. Taylor & Francis Group, LLC CRC Press. Boca Raton, FL.
- Zhao, T., Heyduk, T. and Eissenberg, J.C. (2001). Phosphorylation site mutations in Heterochromatin Protein 1 (HP1) reduce or eliminate silencing activity. *J. Biol. Chem.* 276(12): 9512--9518.

APPENDICES

Appendix 1: Movement of nitrogen between the soil and the plant

Monthly Leaf Uptake Analysis

Bag/Test	Pre-Planting Analysis (ppm)	1st Month (ppm)	2nd Month (ppm)	3rd Month (ppm)	Tuber Analysis (ppm)	Post-Harvest Soil Analysis (ppm)
Soil	1100	31500	29200	24500	17500	1800
Diatomaceous Earth	5300	38500	22800	17500	17500	2000
Cow Dung	15200	28000	19500	14000	14000	2200
Cow Blend	20500	28000	25900	21000	24500	2200
Goat Droppings	16000	24500	24500	24500	31500	1100
Goat Blend	21300	35000	27200	21000	14000	1400
Blood Meal	109000	45500	38900	24500	35000	500
Blood Blend	114300	49000	37200	35000	35000	1000
Bone Meal	49700	52500	43900	24500	21000	700
Bone Blend	55000	70000	61800	14000	21000	800

Appendix 2: Movement of phosphorus between the soil and the plant

Monthly Leaf Uptake Analysis

Bag/Test	Pre-Planting Analysis (ppm)	1st Month (ppm)	2nd Month (ppm)	3rd Month (ppm)	Tuber Analysis (ppm)	Post-Harvest Soil Analysis (ppm)
Soil	31000	4100	3900	3800	4500	96000
Diatomaceous Earth	390	4100	3700	3500	4100	12000
Cow Dung	1100	4100	3600	3800	5200	27400
Cow Blend	1490	4500	4200	4500	4900	488000
Goat Droppings	2685	4400	4800	5000	4600	211000
Goat Blend	3075	4200	5000	5200	4200	220000
Blood Meal	960	3400	3100	2300	3500	40000
Blood Blend	1350	3200	3300	3500	3800	169
Bone Meal	85000	4300	4100	3500	5100	109000
Bone Blend	85000	3200	3400	3500	4200	109000

Appendix 3: Movement of potassium between the soil and the plant

Monthly Leaf Uptake Analysis

Bag/Test	Pre-Planting Analysis (ppm)	1st Month (ppm)	2nd Month (ppm)	3rd Month (ppm)	Tuber Analysis (ppm)	Post-Harvest Soil Analysis (ppm)
Soil	565.50	42100	37600	31600	21600	14100
Diatomaceous Earth	1540	32200	31200	29300	22600	13500
Cow Dung	140	39700	32800	26300	26600	16100
Cow Blend	1680	37500	25800	16900	25600	17700
Goat Droppings	203	32200	29500	27300	28600	12100
Goat Blend	1743	39600	36300	33000	21600	12900
Blood Meal	2600	41500	37700	28600	30300	11800
Blood Blend	4140	45500	41100	30300	31000	8400
Bone Meal	1520	41400	27500	17200	22200	8400
Bone Blend	3060	43400	28700	14900	21200	8600

Appendix 4: Movement of calcium between the soil and the plant

Monthly Leaf Uptake Analysis

Bag/Test	Pre-Planting Analysis (ppm)	1st Month (ppm)	2nd Month (ppm)	3rd Month (ppm)	Tuber Analysis (ppm)	Post-Harvest Soil Analysis (ppm)
Soil	669.20	16200	18700	19500	1400	181000
Diatomaceous Earth	89.10	12700	12300	12000	1300	179000
Cow Dung	1100	23600	17300	14800	1400	167000
Cow Blend	1100	22400	16800	15300	1400	197000
Goat Droppings	1800	20100	20200	20500	18800	137000
Goat Blend	1800	14300	22200	24500	17200	135000
Blood Meal	2300	18800	24500	26900	26800	169000
Blood Blend	2300	14800	19900	26800	18100	97000
Bone Meal	178200	6800	13900	17500	4800	97000
Bone Blend	178200	13600	14100	14500	10300	150000

Appendix 5: Movement of magnesium between the soil and the plant

Monthly Leaf Uptake Analysis						
Bag/Test	Pre-Planting Analysis (ppm)	1st Month (ppm)	2nd Month (ppm)	3rd Month (ppm)	Tuber Analysis (ppm)	Post-Harvest Soil Analysis (ppm)
Soil	133.50	1700	1500	1300	500	41500
Diatomaceous Earth	85.10	700	700	500	500	40400
Cow Dung	750	1800	1100	800	500	40400
Cow Blend	835.1	2700	2200	1100	600	40900
Goat Droppings	920	3300	1700	900	500	23600
Goat Blend	1005.10	3300	2600	1100	500	27000
Blood Meal	1500	1300	1300	1300	800	23900
Blood Blend	1500	3700	2400	800	700	20700
Bone Meal	7200	3400	2900	600	700	20900
Bone Blend	7200	3800	1200	400	400	23400

Appendix 6: Tuber elemental content ranking

Bag/Ranking	N	P	K	Ca	Mg
Soil	5	5	7	6	4
Diatomaceous Earth	5	7	5	7	4
Cow Dung	6	1	4	6	4
Cow Blend	3	3	5	6	3
Goat Droppings	2	4	3	2	4
Goat Blend	6	6	7	4	4
Blood Meal	1	9	2	1	1
Blood Blend	1	8	1	3	2
Bone Meal	4	2	6	6	2
Bone Blend	4	6	8	5	4