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**SCHOOL OF FOOD TECHNOLOGY NUTRITION AND BIO-  
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ENGINEERING**

**ASSESSING THE POTENTIAL OF ORGANIC WASTES AS SOIL  
AMENDMENTS TO INCREASE WATER RETENTION**

**BY**

**KYAZIKE JANET FLORENCE**

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**A RESEARCH PROJECT REPORT SUBMITTED TO THE DEPARTMENT OF  
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FULFILMENT FOR THE AWARD OF BSC. DEGREE IN AGRICULTURAL  
ENGINEERING OF MAKERERE UNIVERSITY**

### DECLARATION

I, **Kyazike Janet Florence**, declare that this research project is my work and it has never been submitted, in part or in full, to this university or to any other university or institution of learning in the world for any award.

Signature.....

Date.....31/07/2019.....

This work was done under the guidance of the supervisors mentioned below of the department of Agricultural and Bio Systems Engineering, Makerere University.

### SUPERVISORS' APPROVAL

PROF. NOBLE BANADDA

Signature.....

Date.....01.08.2019.....

DR WANYAMA JOSHUA

Signature.....

Date.....31/07/2019.....

## **DEDICATION**

I dedicate this report to my parents Mr. and Mrs. Kigoonya John and my aunty Nalwadda Prossy for their tireless support towards my education.

## **ACKNOWLEDGEMENTS**

I thank God for the good health, wisdom, providence and a good working environment throughout this project.

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## LIST OF ACRONYMS AND SYMBOLS

SSA	Sub-Saharan Africa
WAMs	Water Absorbent Materials
SAPs	Super Absorbent Polymer
DMAP	Dimethylamino pyridine
TEMED	Tetramethylethylenediamine
CO <sub>2</sub>	Carbon dioxide
O <sub>2</sub>	Oxygen
N.E.A	Not Easily Available
E.A	Easily Available
ANOVA	Analysis Of Variance
GMA	Glycidyl MethAcrylate
PHB	Polyhydroxybutyrate
AFM	Atomic Force Microscopy
UV	Ultra Violet
OECD	Organization for Economic Co-operation and Development
SAP	Super absorbent polymer
NaCl	Sodium chloride

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## ABSTRACT

Water Absorbent Materials are widely proposed for agricultural use with the aim to improve water availability for plants by increasing water holding properties of growing media (soils or soilless substrates). However, commercially found water absorbent materials especially super absorbent polymers (SAPs) are not biodegradable and hence impose environment issues like land pollution. This work aims at assessing the potential of organic wastes as soil amendments to increase water retention. The water retention materials were formulated from polysaccharide rich materials which included sweet potato peels, orange peels irish potato and cassava peels. A small surface area of 2cm pieces of the peels was ensured for ease of carrying out the proceeding activities (drying, fermentation). Sweet potato and irish potato peels underwent fermentation and orange peels boiling for softening.3kg of each of the peels were mixed with 1kg of avocado peels Avocado peels contain oils which prevent clogging when water is poured on the final product. The peels were dried and milled to particle size 250µm. The orange peel based WAM was obtained at this step. The other three underwent gelatinization where after the gel was dried to films which were milled to particle size 250µm and hence WAMs formed. A water retention test was done by measuring the amount of water that was retained by the test sample (30g of the mixture of different WAM to soil ratios. A biodegradability test was also carried out by pouring water on the WAM, putting it in an air tight container and left for a month to see if any growth would appear on it, proving biodegradability. The highest amount of water was retained by the orange peel WAM, cassava peel WAM and sweet potato and Irish potato peel based WAMs in that order. It was also observed that, as the amount of WAM in the soil increased, the water retention of the soil hence increasing the soil's water retention capacity. The product prepared was found to be biodegradable. It is therefore advisable to use the orange based WAM in the ratios 1:300:60 for WAM (g): water (ml): soil (g) respectively for best results. It was therefore recommended to do more research about how different crops react to different water absorbent materials and how different WAMs perform in a given type of soil.

## CHAPTER ONE: INTRODUCTION

### 1.1 Background

Drought is regarded as the leading cause of food insecurity in sub-Saharan Africa (SSA) since the region depends on rain-fed agricultural production (Akwango *et al.*, 2017). Drought undermines farm yields and national harvests by reducing household and national food availability, and agricultural income that is derived from crop. Poor harvests threaten food security and livelihoods at both household and national level as per dependence regime on agriculture for its food and income (Williams and Funk 2011; Mugerwa 2013; Shiferaw *et al.*, 2014). Drought reduces water available for crop use. Soils for example sand soils experience high infiltration rates resulting into percolation losses. In the process there is no water available for crop use hence water stress on the plant.

Many developed countries; united states, Germany, Italy (Krzysztof *et al.*, 2018) and a few developing countries a have tried to combat this effect of water stress on the plant through the use of water absorbent materials (WAMs).The most commonly used water absorbent materials in these countries are super absorbent polymers(SAPs). The use of these materials has been seen to significantly reduce water depletion while drastically increasing plant survival and growth rate. However, commercially found water absorbent materials are not biodegradable (Ezeano, 2010), hence impose environment issues like land pollution. Thus, the need to prepare a biodegradable soil water absorbent material.

### 1.2 Problem statement

Water is one of the requirements for crop growth. However sometimes this water is not readily available for plant use due to loses through infiltration, deep percolation, and evaporation leading to water stress on the plant hence need for water conservation technologies. One of the technologies that can be used to conserve this water is the use of water absorbent materials. These have a great water absorption capacity relative to its own weight (Nnadi and Brave 2011). Water absorbent materials are water reservoirs and the water contained in them can only be absorbed by plant roots and it cannot be lost through processes like evaporation (Ekebafé *et al.*,2011). Preparation of a biodegradable water absorbent material using readily available resources (agricultural wastes) would be a breakthrough in the area of soil and water management for sustained crop production.

### **1.3 Objectives**

The objectives of the project include the main objective and the specific objectives.

#### **1.3.1 Main objective**

The general objective of this project is to assess the potential of organic wastes as soil amendments to contribute to efficient use of water in the soil.

#### **1.3.2 Specific objectives**

The specific objectives of this project are;

- i. To formulate water absorbent materials
- ii. To test the absorbency of the water absorbent materials
- iii. To test the biodegradability of the water absorbent material

### **1.4 Justification**

Soil water loss during the period of crop growth leads to poor and low yields, poor crop production and decrease/low national food availability. Soils lose water through infiltration, percolation, evaporation rates leading to water stress on the plant. The use of currently available water absorbent materials for water retention in the soil is seen to cause land pollution since they are not biodegradable. This project aimed at assessing the potential of organic wastes as soil amendments to contribute to efficient use of water in the soil which if adopted will help reduce land pollution, increased food production and farm yields and hence increased national food availability.

### **1.5 Scope**

This project covered the preparation of biodegradable water absorbent materials from readily available agricultural wastes. These wastes were peels of sweet potatoes, Irish potatoes, cassava and oranges chosen basing on the how rich in polysaccharides, biodegradability, renewability, ease of availability and low cost. These peels were subjected to different treatments due to their different properties, composition and chemical reactions to achieve the final product. The final product was to be tested for its degree of absorbance using the water absorbency test. The product was tested using a soil at different product-soil ratios as a mixture with a fixed amount of

water. The product with the highest degree of absorbency was tested for biodegradability. The biodegradability test was carried out using the composting test for biodegradability.

## **CHAPTER TWO: LITERATURE REVIEW**

### **2.1 Drought prone areas in Uganda**

North Eastern Uganda i.e. Karamoja and the Eastern parts of Ankole i.e. the Ankole – Masaka corridor experience semi-arid and arid climate /semi desert & desert climate (Jordaan, 2015). In addition Semi desert climate is also experienced in the Western Rift valley region around Lake George and Lake Edward. Karamoja has three livelihood zones which include the pastoralist zone, agro-pastoralist zone and the agricultural zone. Most of the crops grown in the agricultural zone of Karamoja region for example maize, sesame, sweet potatoes and potatoes can be used to develop a water absorbent material for water retention in the soil. Since these materials (WAMs) solve the issue of water stress on the plant, the issue of food insecurity in the region can be reduced or completely solved.

### **2.2 Water absorbent materials**

The most commonly used water absorbent materials are super absorbent polymers (SAPs).SAPs are examples of water absorbent materials. Super absorbent polymers (SAPs) are usually are able to absorb large amounts of water (Nnadi and Brave 2011). Generally, they consist of a network of chains that are cross linked to avoid dissolution. Usually there are ionic functional groups along the chains to encourage diffusion of water within network (Raju *et al.*,2003). SAPs capture water and swell from 100-400 times their weight to hold moisture for future beneficial use or remove water from an environment which may suffer deleterious effects from the presence of water.

### **2.3 Types of water absorbent materials and the common methods of making them**

The most commonly used water absorbent materials are super absorbent polymers. Due to the fact that they are not biodegradable, their way of performance and methods of manufacture can be adopted to the preparation of biodegradable water absorbent polymers which can do the same work of acting as water reservoirs for plant use and as well solve the issue of land pollution caused by the non-biodegradable ones.

### **2.3.1 Natural polymers or agro-polymers**

Natural polymers are formed in nature during the growth cycles of all organisms. Natural biodegradable polymers are called biopolymers. Polysaccharides, as starch and cellulose, represent the most characteristic family of these natural polymers. Other natural polymers as proteins can be used to produce biodegradable materials. These are the two main renewable sources of biopolymers. Another resource is lipids. To improve the mechanical properties of such polymers or to modify their degradation rate, natural polymers are often chemically modified.

### **2.3.2 Polysaccharide-based hydrogels prepared by emulsion technology**

Particulate superabsorbent hydrogels can also be produced through crosslinking/polymerization emulsion process. Emulsion polymerization offers advantages for simple, easy and quick preparation; products with high molecular weight (Bao *et al.*, 2011) and well-defined preparation stages. The stability of an emulsion is related both to chemical nature of interfacial film and to attraction/repulsion balance force occurring among the particles suspended in the liquid, which are important in the prevention of the droplets coalescence. An efficient strategy to prepare cross-linked polysaccharide particles with controlled size is the crosslinking/polymerization in a water-in-oil emulsion under vigorous stirring (Guilherme *et al.*, 2010). In such a case, the spherical structures results of a random movement of water droplets inwards the oil phase under vigorous stirring. Under these conditions, stable emulsion of oil phase-surrounded water droplets with controlled size within a certain range is formed. The reaction occurs within the small water droplets due to hydrophilicity of the reactants. Ultrasound-assisted polymerization is also an excellent tool in the production of hydrogel particles with defined outlines (Mauricio *et al.*, 2015).

### **2.3.3 Chemical hydrogels based on different vinyl-modified polysaccharides**

#### **Starch**

Starch is among the most widely used polysaccharides in superabsorbent hydrogel production, and has been the target of several studies including industrial and academic sectors (Ismail and Ahmad 2013) It is the second most abundant carbohydrate polymer in nature (next to cellulose) and stands out as one of the most important natural polymers. Beyond being obtained from renewable sources, this polysaccharide offers other important advantages such as low cost, ease

of chemical modification, ability to replace some synthetic polymers, good mechanical resistance and plasticity. The modification of starch with GMA has been commonly processed in the presence of catalytic agents such as 4-(N, N-dimethylamino) pyridine (DMAP) and N,N,N0,N0-tetramethylethylenediamine (TEMED). The product resultant from that reaction was able to undergo radical reaction that leads to hydrogelation.

Chemical starch hydrogels of high water absorption capacity were prepared through ultrasound-assisted radical crosslinking/polymerization reaction in the presence of acrylamide and acrylic acid. The as-obtained material was able to absorb approximately 150 g of water per gram of dry hydrogel after 200 min of immersion (Guilherme *et al.*, 2012).

### **Arabic gum**

Arabic gum was also successfully modified with GMA (Guilherme *et al.*, 2007). From then on, the use of potentially toxic reactants and of organic solvents in the modification reaction was discontinued. Vinylated Arabic gum was obtained by an adapted approach that uses water as solvent without catalytic agent. However, when only water is used as solvent, a further problem had to be overcome: GMA is insoluble in water. To address the challenges related to insolubility of the GMA in the reaction medium, a heterogeneous phase system composed of water-soluble Arabic gum and water-insoluble GMA was provided using high stirring speed at a temperature range of 60–65 C. Under these conditions, the polysaccharide is able to be vinyl-modified at the interface of the GMA–water system. The product was easily cross linked through reaction with acrylamide and sodium acrylate monomers, forming superabsorbent hydrogel. It absorbs ca. 500 g of water per gram of dry hydrogel in 60 min, without its mechanical stability being seriously affected (Guilherme *et al.*, 2007).

## **2.4 Biodegradable polymers**

### **2.4.1 Polymers for use in agriculture**

For this application, the most important property of biodegradable polymers is in fact their biodegradability (Chiellini *et al.*, 2003). Starch-based polymers are the most used biopolymers in this area. They meet the biodegradability criteria and have a sufficient life time to act.

Plastic films were first introduced for greenhouse coverings fumigation and mulching in the 1930s. Young plants are susceptible to frost and must be covered. The main actions of

biodegradable cover films are to conserve the moisture, to increase soil temperature and to reduce weeds in order to improve the rate of growth in plants. At the end of the season, the film can be left into the soil, where it is biodegraded (Mazollier *et al.*, 2003)

### **Properties of materials used to make water absorbent materials**

Materials to be used for making a material for water retention in the soil should have the following properties;

1. It should be rich in polysaccharides (cellulose and starch). Polysaccharides represent the most characteristic family of production of the biodegradable water absorbent materials.
2. Should be able to retain large amounts of water
3. Biodegradable to avoid soil pollution. Biodegradable materials help to conserve the moisture, to increase soil temperature and to reduce weeds in order to improve the rate of growth in plants.
4. Renewability for sustainability
5. Availability to be easily accessible and reduce on the production costs hence making it cheap to the final consumer.
6. Low cost so that they can be affordable by the poor communities in Uganda

### **Starch**

Starch is considered as a promising raw material for biodegradable water absorbent materials in agriculture because;

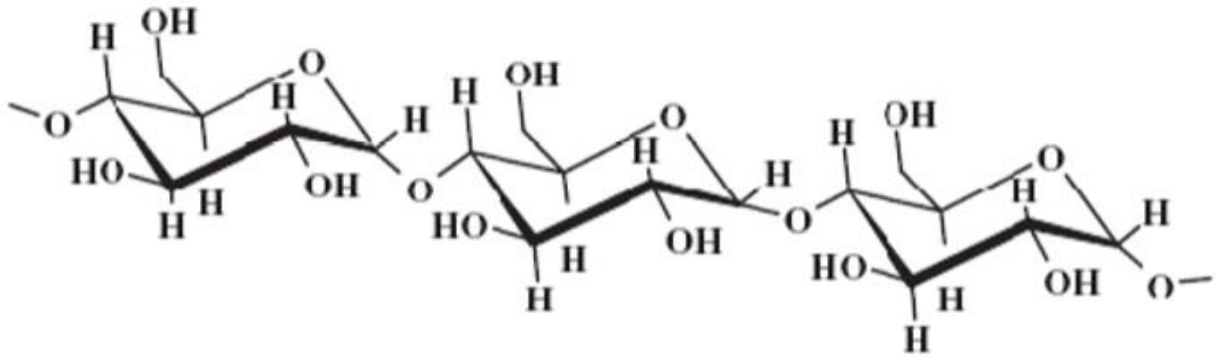
- starch is a natural polymer coupled with its low cost
- renewability
- unlimited availability and biodegradability

Starch is an organic food reserve which occurs as granules in the chloroplasts of green leaves and other photosynthetic cells, and in the amyloplasts of non-photosynthetic storage organs such as seeds, roots, and tubers. The starch granule is essentially composed of two main polysaccharides: amylose and amylopectin with some minor components such as lipids and proteins.

Starch is a biopolymer composed of anhydroglucose units and is the major storage energy in various plants in nature. It can be widely found in cereal grain seeds (e.g. corn, wheat, rice, sorghum), tubers (e.g. potato), roots (e.g. cassava, sweet potato, arrowroot), legume seeds (e.g.

peas, beans, lentils), fruits (e.g. green bananas, unripe apples, green tomatoes), trunks (e.g. sago palm) and leaves (e.g. tobacco).

In general, cereal starches (e.g. corn, wheat, rice) contain relatively high levels of lipids (0.2-0.8%) and protein (0.2-0.5%) resulting in a lower paste transparency and a pronounced and persistent “raw cereal flavor” of the starch gels. Tuber (e.g. potato) and root (e.g. tapioca) starches have lower levels of lipids (0.1-0.2%) and protein contents (0.1-0.2%). Potato starch is the only native starch containing significant amounts of chemically bound phosphate ester groups (degree of substitution = 0.003 ~ 0.005) located in amylopectin.



**Figure 2. 1: Backbone of starch molecule (Panda et al., 2018)**



**Figure 2. 2: Polymer applied around plant roots**

## **2.5 Biodegradability tests for water retention materials**

Previously SAPs have been used as water absorbent materials for water soil water retention and their tests for biodegradability include the following which can as well be used to test for the biodegradability of this project's prepared water absorbent material.

### **Visual observation**

Here effects used to describe degradation include roughening of the surface, formation of holes or cracks, de-fragmentation, changes in color, or formation of bio-films on the surface. These changes do not prove the presence of a biodegradation process in terms of metabolism, but the parameter of visual changes can be used as a first indication of any microbial attack. After an initial degradation, crystalline spherulites appear on the surface; that can be explained by a preferential degradation of the amorphous polymer fraction, etching the slower-degrading crystalline parts out of the material.

### **Weight loss measurements: determination of residual polymer**

This test deals with testing the mass loss of test specimens although again no direct proof of biodegradation is obtained. Problems can arise with correct cleaning of the specimen, or if the material disintegrates excessively. A sieving analysis of the matrix surrounding the plastic samples allows a better quantitative determination of the disintegration characteristics. For finely distributed polymer samples (e.g., powders), the decrease in residual polymer can be determined by an adequate separation or extraction technique (polymer separated from biomass, or polymer extracted from soil or compost).

### **Changes in mechanical properties and molar mass**

As with visual observations, changes in material properties cannot be proved directly due to metabolism of the polymer material. However, changes in mechanical properties are often used when only minor changes in the mass of the test specimen are observed. For an enzyme-induced depolymerization, the material properties only change if a significant loss of mass is observed (the specimen becomes thinner because of the surface erosion process; the inner part of the material is not affected by the degradation process), for abiotic degradation processes (which often take place in the entire material and include the

hydrolysis of polyesters or oxidation of polyethylenes) the mechanical properties may change significantly, though almost no loss of mass due to solubilization of degradation intermediates occur at this stage. As a consequence, this type of measurement is often used for materials where abiotic processes are responsible for the first degradation step (Tsuji and Suzuyoshi, 2002).

### **Carbon dioxide (CO<sub>2</sub>) evolution / oxygen (O<sub>2</sub>) consumption**

Microbes, under aerobic conditions, use oxygen to oxidize carbon and form carbon dioxide as one of the major metabolic end product. The consumption of oxygen (respirometric test) (Hoffmann *et al.*, 1997) and the formation of carbon dioxide (Sturm test) are good indicators for polymer degradation, and are the most often used methods to measure biodegradation in laboratory tests.

Carbon dioxide (CO<sub>2</sub>) is trapped in a basic solution, (±pH 11.5) with continuous titration or detection of the dissolved inorganic carbon (Pagga *et al.*, 2001). Carbon dioxide is trapped using an inert, carbon-free and porous matrix, wetted with a synthetic medium and inoculated with a mixed microbial population. This method proved practicable for simulating compost conditions (degradation at ~60 °C) (Bellina *et al.*, 2000), but has not yet been optimized for soil conditions. For polymer degradation in soil, CO<sub>2</sub> detection proved to be more complicated than in compost because of slower degradation rates that led not only to long test durations (up to 2 years) but also low CO<sub>2</sub> evolution as compared to that from the carbon present in soil.

### **Clear formation**

The clear-zone test is a very simple semi-quantitative. This is an agar plate test in which the polymer is dispersed as very fine particles within the synthetic medium agar; this gives the agar having an opaque appearance. After inoculation with microorganisms, the formation of a clear halo around the colony indicates that the organisms are at least able to depolymerize the polymer, which is the first step of biodegradation. This method is usually applied to screen organisms that can degrade a certain polymer (Abou-Zeid *et al.*, 2001), but it can also be used to obtain semi-quantitative results by analyzing the growth of clear zones.

## **Enzymatic degradation**

The enzymatic degradation of polymers by hydrolysis is a two-step process: first, the enzyme binds to the polymer substrate then subsequently catalyzes a hydrolytic cleavage. PHB can be degraded either by the action of intracellular and extracellular depolymerases in PHB degradation is the hydrolysis of an endogenous carbon reservoir by the accumulating bacteria themselves while extracellular degradation is the utilization of an exogenous carbon source not necessarily by the accumulating microorganisms (Tokiwa and Calabia 2004). During degradation, extracellular enzymes from microorganisms break down complex polymers yielding short chains or smaller molecules, e.g., oligomers, dimers, and monomers, that are smaller enough to pass the semi-permeable outer bacterial membranes. The process is called depolymerization. These short chain length molecules are then mineralized into end products like carbon dioxide, water and (methane) and the degradation is called mineralization, which are utilized as carbon and energy source (Gu, 2003).

## **Controlled composting test**

The treatment of solid waste in controlled composting facilities or anaerobic digesters is a valuable method for treating and recycling organic waste. Composting of biodegradable packaging and biodegradable plastics is a form of recovery of waste which can cut the increasing need of new land filling sites. Only compostable materials can be recycled through biological treatment, since materials not compatible with composting could decrease the compost quality and impair its commercial value. The environmental conditions of the composting test are the following: high temperature (58 °C); aerobic conditions; proper water content (about 50%). Mature compost is used as a solid matrix, as a source of thermophilic microorganisms (inoculum), and as a source of nutrients. The test method is based on the determination of the net CO<sub>2</sub> evolution, i.e. the CO<sub>2</sub> evolved from the mixture of polymer compost minus the CO<sub>2</sub> evolved from the unamended compost (blank) tested in a different reactor (Bellina *et al.*, 1999).

## **2.6 Recorded advantages of water absorbent materials (WAMs)**

Super absorbent polymers are developed to improve the physical properties of soil in view of:

- Increasing their water-holding capacity,

- Increasing water use efficiency
- Enhancing soil permeability and infiltration rates
- Reducing irrigation frequency
- Reducing compaction tendency
- Stopping erosion and water run-off
- Increasing plant performance (especially in structure -less soils in areas subject to drought)

## **2.7 Previous work done to prepare water absorbent materials for water retention in the soil**

Previously SAPs have been used as water absorbent materials for water soil water retention and their methods of preparation can be adopted for preparation of this project's water absorbent material.

### **2.7.1 Environmentally friendly superabsorbent polymers for water conservation in agricultural lands**

According to Nnadi and Brave, 2011, this type of polymer was developed using commercial cassava starch powder (Ayoola Foods), commercial cornstarch powder (Pinnacle Foods), commercial potato starch powder (Bob's Red Mill), and commercial yam starch powder (AyoolaFoods) without further purification. Carboxymethyl cellulose sodium salt (Acros Organics) with an average molecular weight of 90000 and DS = 0.7 was used with starch to synthesize superabsorbent polymers. Aluminum sulfate octadecahydrate was used at reagent grade to crosslink the polymer complex.

#### **Preparation of the superabsorbent polymer (SAP)**

Their preparation of the SAP followed a procedure described by Suo *et al.*, (2007) and Weerawarna (2009). Carboxymethyl cellulose sodium salt (20 g) was mixed with 2.0 l of distilled water in a large beaker using a magnetic stirrer. Each of the four starches types (1.2 g) was gelatinized in 50 ml of distilled water at 80°C for 45 min. The gelatinized starch was added to the CMC solution and allowed to mix for 1 hour. Then varying amounts of aluminum sulfate were added to the beaker to investigate the optimum cross linkage, and the solution was allowed to mix for another 30 min. The solution was then spread on Teflon baking pans and dried at 70°C

until a film is formed. The film was shredded with a blender and then ground into a powder with a mortar and pestle. This was repeated for each type of starch investigated.

The polymer samples (0.1 g) were immersed in 100 mL of distilled water. The slurry was then filtered through a coarse glass filter under a slight vacuum for 10 min. The amount of retained water is calculated as follows:

$$\text{Water Retention} = (G_s - G_i) / G_i,$$

Where  $G_s$  is the weight of the swollen hydrogel and  $G_i$  is the initial weight of the polymer sample

The water retention reported for the different hydrogels were as follows;

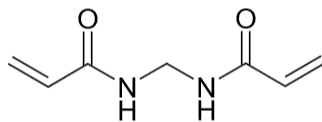
**Table 2. 1: Water retention for hydrogels cross linked at optimum with 2.3% wt.  $\text{Al}_2(\text{SO}_4)_3 \cdot 18\text{H}_2\text{O}$ , (g/g)(Nnadi and Brave ,2011)**

Cassava starch	Corn starch	Potato starch	yam starch
73	56	66	65

### 2.7.2 Design of the novel superabsorbent polymer

According to Rajakumar and Jayasree 2016, the two main components of efficient SAPs are higher absorption capacity and fast swelling rate. In order to achieve this, core-shell structured SAP particles were designed. The excellent hydrophilicity of acrylic acid was the ideal choice for the main polymer backbone. In addition, acrylic acid is cheap and easily polymerizable. Acrylic acid was partially neutralized with sodium chloride, NaCl. Partially neutralized acrylic acids polymers swell faster with better water absorbing capacity due to the increment of total ionic chargers inside the polymer network.

Partially neutralized acrylic acid show better absorption properties only in distilled or deionized water whereas in salt solutions osmotic pressure reduces drastically and thus will show poor water absorbance. Anon-ionic co-monomer into the network to reduce the salt resistance. Acrylamide monomer is the best choice due to its low cost, ease of use and most of all, its non-ionic yet hydrophilic character. Acrylamide thus can suppress the salt resistance. Poly acrylic-co-polyamide can dissolve or swell infinitely in water due to their higher water affinity. To avoid this, need to introduce a suitable cross linker. Cross linker itself has to be hydrophilic to enhance the swelling capacity yet should have the ability to hold the polymer backbone preventing of dissolving. The suitable candidate for this purpose was N,N'methylenebisacrylamide (BIS)



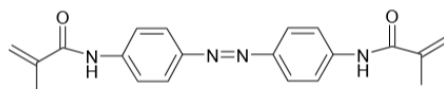
**Figure 2. 3: The cross linker N,N'-methylenebisacrylamide (BIS) (Panda et al., 2018)**

The choice of method of polymerization was inverse suspension polymerization technique. Inverse suspension polymerization results granular particles and the particle size can easily control by the reaction conditions. The idea of preparing the granular SAP particles was supported by many facts. According to the Tanakas' theory of gel swelling, response rate of the gel is inversely proportional to the square of the smallest dimension of the gel. Therefore, reducing gel size increase the swelling kinetics. Additionally, smaller particles have higher surface to volume ratio and thus have higher area to contact with the surrounding water molecules. Sorbitanmonostearate (Span 60) has chosen as the surfactant in the polymerization process.

When SAP particles swell, they could display structural deformations. This deformation of SAP particles blocks the water molecules diffuse into the inner particles, behaving as a sealer. This is called "gel blocking". Deformation can reduce by increasing the crosslinking concentration in the polymer network. But this will sacrifice the water absorbing capacity. Therefore, to achieve both these properties, higher absorption and lower deformation, we modify the SAP particles by introducing a hydrophobic surface cross linker to gain a shell structure. According to the gel swelling kinetic theory advanced by Tanaka. Surface cross-linking increases the swelling rate of SAPs.

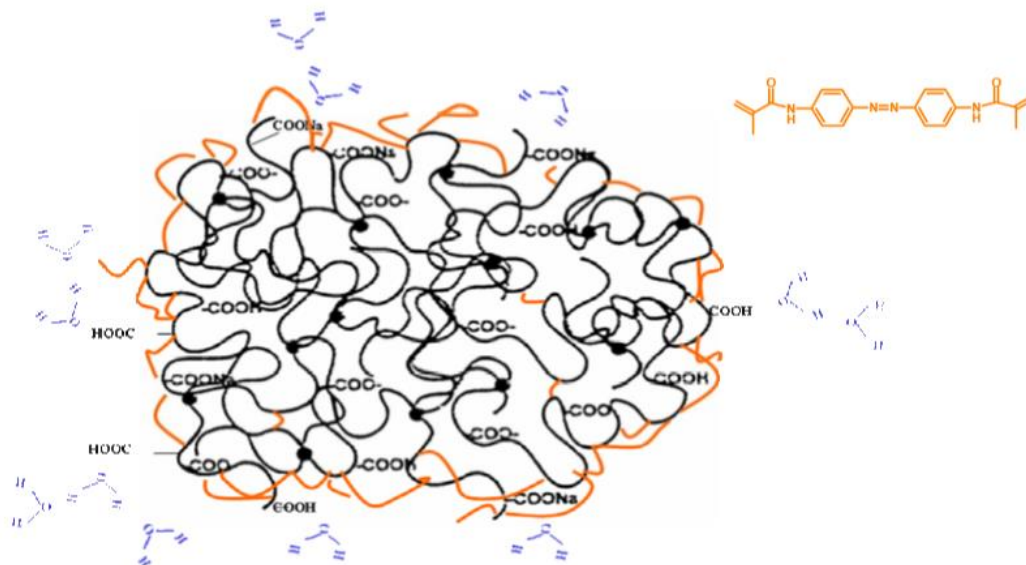
The rate of swelling can be represented by the cooperative diffusion coefficient of the network. The cooperative diffusion coefficient is inversely proportional to the friction coefficient which describes the viscous interaction between polymer chains and solvent and is directly proportional to the osmotic longitudinal modulus. Surface crosslinking increases the modulus of swelling while the friction coefficient remains almost unchanged, thus increasing the swelling rate of the Saps. There are various reports that consider SAPs to have a highly surface cross linked shell with a less cross linked core or a core-shell structure. And also, when surface cross-linked SAP

particles are fully swollen, adjacent SAP domains are independent of one another. Bis (methacryloylamino)azobenzeneas was chosen as the surface cross linker. Azobenzeneas derivatives were the best choice as the surface cross linker due to their environment stability, easy process ability and photosensitive behavior.



**Figure 2. 4: The surface crosslinkerbis (methacryloylamino) azobenzene(Rajakumar and Jayasree 2016)**

Hydrophobic surface cross-linked SAPs were prepared via an inverse suspension polymerization. An acrylic acid (AA), acrylamide (AM) copolymer was cross-linked with N,N'-methylene bisacrylamide (BIS). After initial polymerization, a hydrophobic surface cross-linker (bis(methacryloylamino)-azobenzene) was introduced to the polymer. The design core -shell structured SAP particles are expected to exhibit higher water absorption capacity and faster swelling rates.



**Figure 2. 5:Schematic representation of the designed core-shell structured SAP particle (Rajakumar and Jayasree 2016)**

## **CHAPTER THREE: METHODOLOGY**

### **3.1 Formulating the water absorbent materials**

#### **Material selection**

The criteria for selecting materials to use to prepare water absorbent materials were as follows:

- It should be rich in polysaccharides (cellulose and starch). Polysaccharides represent the most characteristic family of production of the biodegradable water absorbent materials.
- Able to retain large amounts of water
- Biodegradable. To avoid soil pollution Biodegradable materials, help to conserve the moisture, to increase soil temperature and to reduce weeds in order to improve the rate of growth in plants.
- Renewability. This is to guarantee sustainability
- Should be easily available accessible and reduce on the production costs such as transportation costs.
- Low cost. This makes the final product cheap to the final consumer and affordable by the farmers in Uganda.

The amount of polysaccharides in the sweet potato peels (66%), yam peels (65%), cassava peels (73%) and corn (56%) according to Nnadi and Brave, 2011.

Based on the above criteria the materials that were selected were irish potato peels, sweet potato peels, cassava peels and orange peels. Corn starch is majorly from maize which is used as food and no peels/wastes for it like other materials. It is not listed among the four options due to the need to avoid competition for it with human consumption. The yams are also not readily available like other materials hence not included. The four material samples were used to prepare water absorbent materials for water retention in the soil with each having preparation processes depending on the properties it has.

#### **Procedure of formulating the water absorbent materials**

Procedure followed in preparing the water absorbent materials included the following steps:

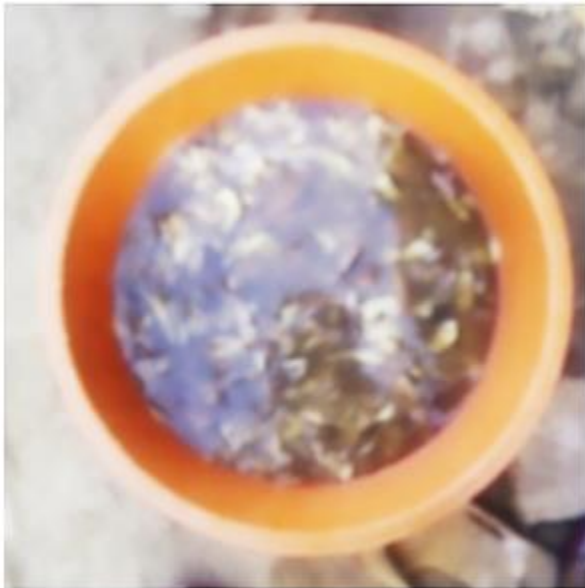
- i. Collecting of the materials; peels of sweet potatoes, cassava, oranges and irish potatoes.

- ii. Treatment of the peels depending on the properties of the kind of peels to prepare the water absorbent materials

For all the water absorbent materials (WAMs) in their preparation, they were mixed with avocado peels. Avocado peels contain oils which prevent clogging in the final product/material when water is applied to it.

### **Procedure of formulating the water absorbent materials**

- The peels were collected from Kalerwe market.
- They were washed to remove the soil as shown in Figure 3.1



**Figure 3. 1: Washing sweet potato peels**

- 3kg of the peels were measured and cut into small pieces of about 2cm to create a small surface area.
- Sweet potato and irish potato peels were fermented (Adegunloye and Oparinde,2017) and orange peels boiled to soften them.
- 1 kg of avocado peels was measured on a weighing scale and cut into small pieces of about 2cm.
- The 3kg of the peels were mixed with 1kg of avocado peels and then left in the sun to dry as shown in Figure 3.2.



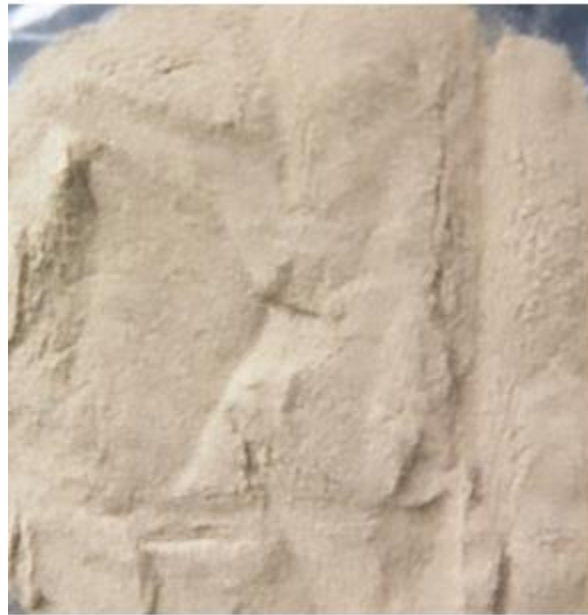
**Figure 3. 2: Sun drying of orange peels mixed with avocado peels**

- The product was ground to fine particles using a milling machine as shown in Figure 3.3



**Figure 3. 3: Milled sweet potato peels**

- The fine particles were sieved to particle size 250 $\mu$ m. At this step the orange peel based polymer was formed.
- The other three, sweet potato, Irish potato and cassava peel milled particles underwent gelatinization.
- The gel was dried on metal pans into a film
- The gel film was ground to fine particles using a milling machine. The fine particles were sieved to particle size 250 $\mu$ m. These fine particles are what was termed as the water absorbent materials. The water absorbent materials formulated are as shown in the Figures, 3.4 - 3.7.



**Figure 3. 4: The orange peel based WAM**



**Figure 3. 5: The Irish potato peel based WAM**



**Figure 3. 6: The cassava peel based WAM**



**Figure 3. 7: The sweet potato peel based WAM**

**Note:** The water absorbent materials were ground to particle size  $250\mu\text{m}$  since since it was the smallest size of the sieve available for use in the laboratory.

### **3.3 Soil texture analysis**

Particle size analysis of the soil that was used to test for water absorbency with the prepared water absorbent materials was carried out from the soil science laboratory at the college of agricultural and environmental sciences, Makerere University. The soil particle size analysis was carried out using the Bouyoucos or hydrometer method as according to Okalebo *et al.*, 2002.

#### **Procedure**

- Soil was sieved using a 2mm sieve
- 50 g of the sieved soil were weighed into a 400ml beaker.
- The soil was saturated with distilled water and 10 ml of Calgon solution added. The mixture was allowed to stand for 10 minutes.

- The suspension was transferred to the dispersing cup and water level made up to the mark in the cup with distilled water.
- The suspension was mixed for 2 minutes with an electric high speed stirrer.
- The suspension was transferred into a graduated cylinder and the remaining soil in the cylinder rinsed with distilled water. Water was added to the graduated cylinder up to 1130ml.
- The cylinder was covered with a tight-fitting rubber bung and the suspension mixed by inverting the cylinder carefully ten (10) times.
- 2 drops of amyl alcohol were added to the soil suspension to remove froth and after 20 seconds the hydrometer was gently placed into the column.
- A hydrometer reading was taken at 40 seconds and the temperature of the suspension measured. The hydrometer reading was 23g/litre and temperature 25<sup>0</sup>c
- Step 6 (mixing of the soil suspension 10 times) was repeated and the cylinder allowed to stand undisturbed for 2 hours.
- After two hours, both hydrometer and temperature readings were taken. The hydrometer reading was 18g/litre and temperature 25<sup>0</sup>c.

## Calculations

### a) The percentage sand

$$(50-23) = 27\text{g/l}$$

$$\text{Sand \%} = \frac{27}{50} * 100$$

$$= 54\%$$

### b) The percentage clay

$$\text{Clay \%} = \frac{18}{50} * 100$$

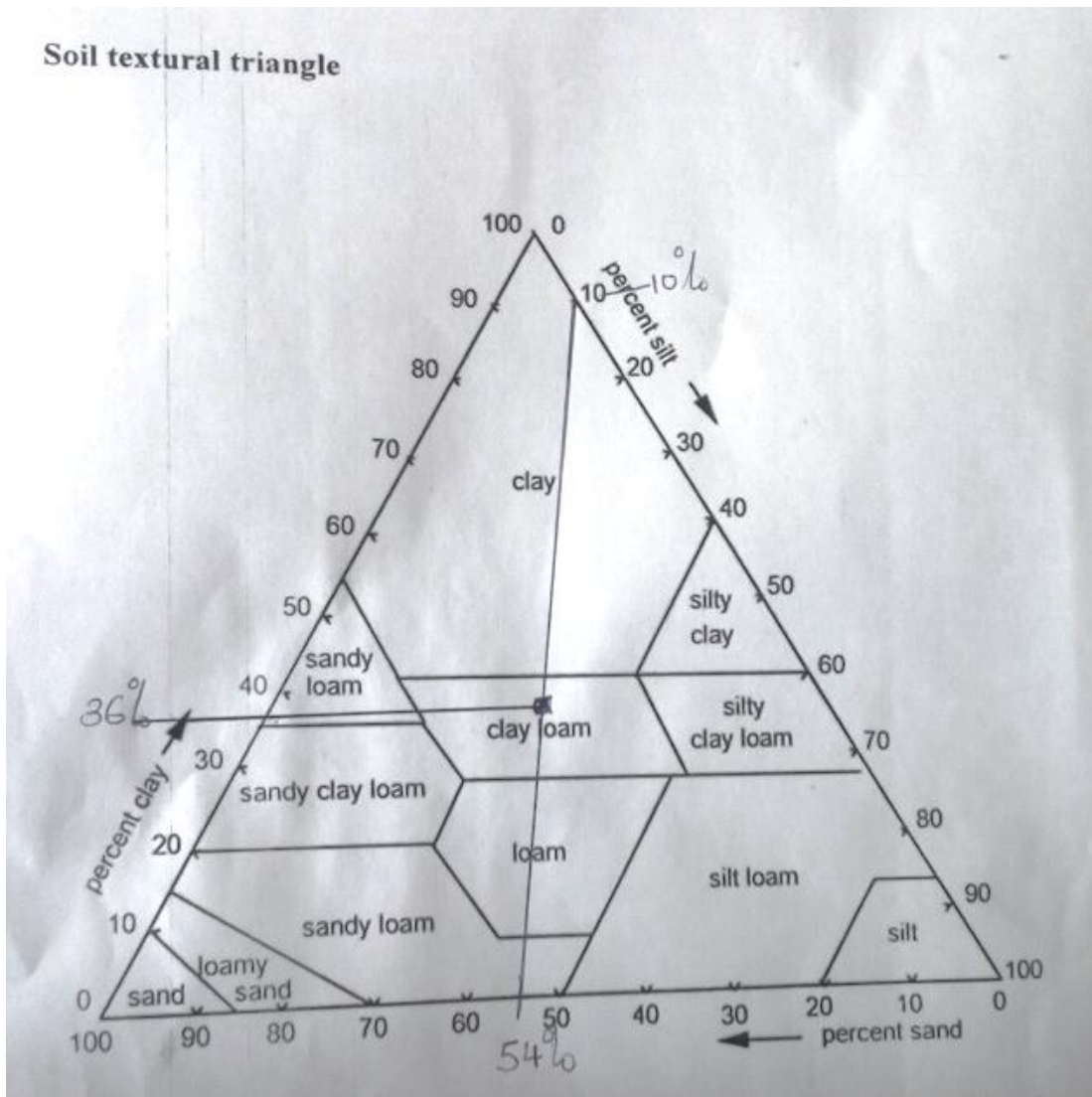
= 36%

**c) The percentage silt**

Silt% = 100 – (54% sand + 36% clay)

= 10%

After measuring the sand, silt and clay distribution, the soil was assigned to a soil textural class using the soil textural triangle as shown in Figure 3.8



**Figure 3. 8: Soil textural triangle**

From the soil textural triangle, the soil texture was **clay loam**

### 3.4 Experimental design

Table 3.1 shows the experimental design for measuring the amount of water that was retained by each WAM. The experiment was carried out using a completely randomized design with four treatments (polymer from cassava (C); sweet potatoes (S); oranges (O); Irish potatoes (I)) and five levels (2g of the WAM + 28g of soil (T<sub>1</sub>)) ratio 2:28 (4g of the WAM + 26g of soil (T<sub>2</sub>)) ratio 4:26, (6g of the WAM + 24g of soil (T<sub>3</sub>)) ratio 6:24, (8g of the WAM + 22g of soil (T<sub>4</sub>)) ratio 8:22, and (10g of the WAM + 20g of soil (T<sub>5</sub>)) ratio 10:20, and these were replicated three times. The different WAMs to soil ratios were made ensuring a total mass of 30g of the mixture. The control experiment 30g of soil without the WAM 0:30 (T<sub>0</sub>), also replicated three times.

**Table 3. 1: Experimental design for measuring the amount of water that was retained by each WAM**

Treatment	Amount of WAM (g)	Amount of soil (g)
T <sub>0</sub>	0	30
T <sub>1</sub>	2	28
T <sub>2</sub>	4	26
T <sub>3</sub>	6	24
T <sub>4</sub>	8	22
T <sub>5</sub>	10	20

### 3.5 Experimental set up

#### Equipment used

The equipment used in carrying out the water retention for the water absorbent materials included:

- i. Test sample
- ii. Transparent plastic funnel
- iii. 250ml transparent glass bottle
- iv. 100ml transparent plastic measuring cylinder

- v. Dr. Watts filter paper, diameter 12.5cm

### **Test sample**

The test sample was a mixture of various amounts of the water absorbent materials and the soil. The different soil and WAM amounts (test samples) were measured as shown in Figure 3.9



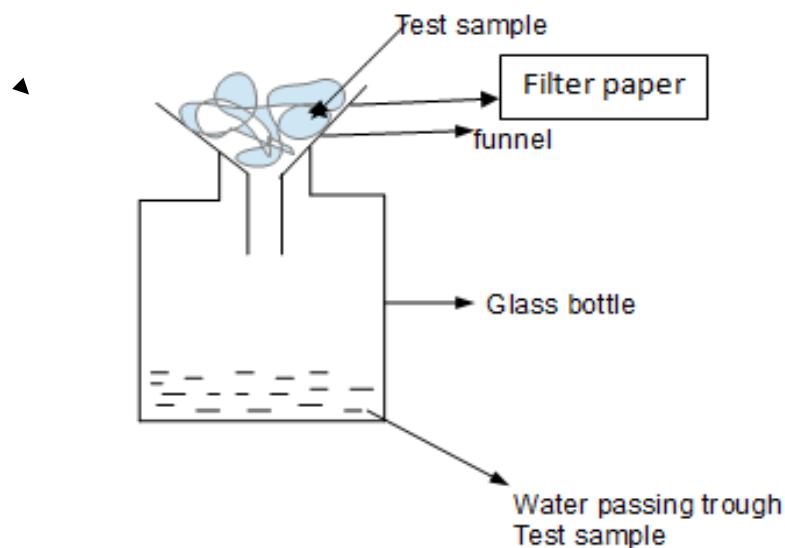
**Figure 3. 9: Measuring test samples**

## Experimental procedure

Experimental procedure used in carrying out the water retention for the water absorbent materials was as follows;

- A filter paper was placed in the funnel
- Funnel placed on top of a bottle
- The test sample was placed on the filter paper in the funnel
- 50ml of water were poured on the sample

The set up was left to stand until no more water was dripping out of the funnel (Daramola *et al.*, 2017). In this experiment, took 30 minutes for water to stop dripping out the funnel. The experimental set up was as shown in Figure 3.10



**Figure 3. 10: Experimental setup for the water absorbency test**

### 3.6 Testing procedure

A water retention test was carried out as shown in Figure 3.11.



**Figure 3. 11: Conducting a water retention test**

The amount of water that passed through the test sample to the transparent glass bottle ( $W_2$ ) was measured using a 100ml plastic measuring cylinder. The amount of water retained by the test sample was calculated using equation 3.1

$$\text{Percentage of water retained} = \frac{W_1 - W_2}{W_1} * 100 \qquad \text{Equation 3.1}$$

$W_1$  (ml) is the amount of water added to the test sample,  $W_2$  (ml) water that passed through the test sample (Krzysztof *et al.*, 2018)

### **3.7 Statistical analyses**

The data for the percentage amount of water retained by the test samples were statistically analyzed using the Microsoft excel and Genstat soft wares. Microsoft excel was used to analyze how the water retention of the soil varies with increase in amount of water absorbent material (WAM). Using Gestate software, an ANOVA was done using Duncan's multiple range test to determine the statistical significant difference between the different treatment proportions for the retention of water by the water absorbent material and was used at 0.05 significance level.

### **3.8 Testing for biodegradability**

The WAM that would show the highest degree of absorbency was taken as the WAM of choice and was tested for biodegradability using the test procedure below.

#### **Procedure**

- 5g of the WAM were measured
- Poured into a transparent tin
- 50 ml of water were poured in the tin
- The set up was left for a month. Any growth on the sample would indicate biodegradability (Bellina et al.,2012).

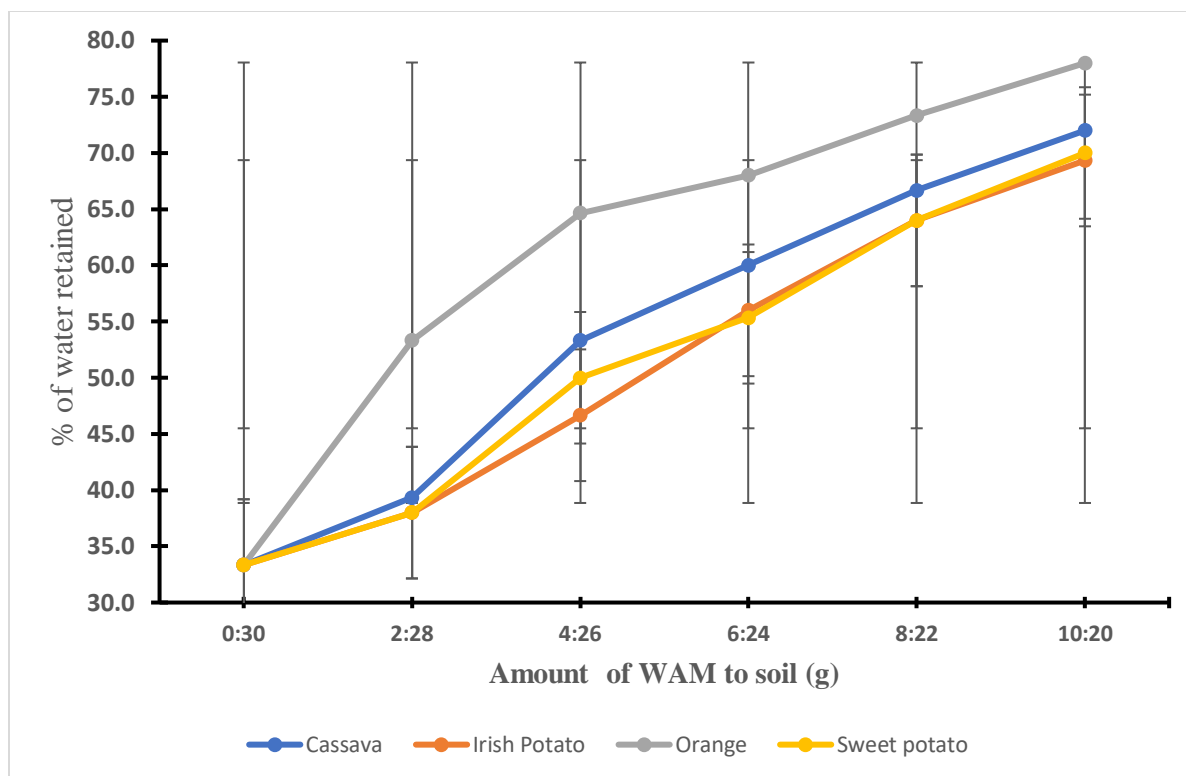
## CHAPTER FOUR: RESULTS AND DISCUSSION

### 4.1 Water retention capacity of the water absorbent materials

The average values of the water retained by each WAM to soil ratio were used to plot the graph of water retained against WAM to soil ratio for the different water absorbent materials. Table 4.1 shows the values that were used to plot the graph of water retained against WAM to soil ratio for the different water absorbent materials in Figure 4.2.

**Table 4. 1: Average of water retained by each WAM to soil ratio for the different water absorbent materials**

Proportions (WAM to Soil)	Cassava WAM (%)	Irish WAM (%)	Potato Orange WAM (%)	Sweet potato WAM (%)
0:30	33.3± 0.47	33.3± 0.47	33.3± 0.47	33.3± 0.47
2:28	39.3±0.94	38.0± 0.47	53.3±0.94	38.0± 0.47
4:26	53.3±0.94	46.6±0.94	64.7±0.94	50.0± 0.47
6:24	60.0± 0.47	56.0± 0.47	68.0± 0.47	55.3±0.94
8:22	66.6±0.94	64.0± 0.47	73.3±0.94	64.0± 0.47
10:20	72.0± 0.47	69.3±0.94	78.0± 0.47	70.0± 0.47



**Figure 4. 1: A graph of water retained against WAM to soil ratio for the different water absorbent materials (WAMs)**

The vertical bars represent standard deviation

### Observation

From the graph in figure 4.2, the orange peel based WAM retained the highest amount of water, followed by the cassava peel based WAM and then sweet potato and Irish potato peel based WAM. It was also observed that as the amount of WAM in the soil increased, the water retention of the soil increased.

### Discussion of the results of the water retention test

The sweet potato and irish potato peel based WAMs retained the least amount of water since they have the lowest amount of polysaccharides amongst the four selected materials. Polysaccharides make the most characteristic family of production of the biodegradable water absorbent materials (Nnadi and Brave ,2011). The difference in the amount of water retained also could have been due to the preparation methods where for orange peel based WAM, it was

boiled first and then other methods followed yet for other WAMs there was no boiling. Boiling increases the amount of water retained though it couldn't be performed on the other WAMs according to the literature of their preparation. The observation that, as the amount of based water absorbent material based (WAM) in the soil increased, the water retention of the soil increased proves the fact that the developed WAM increases the amount of water retained by the soil once the WAM is added to it. If it was not the case; as the amount of WAM in the soil increased, the water retention of the soil decreased, the point that prepared WAM increases the amount of water retained by the soil once the WAM is added to it would be false.

#### 4.2 ANOVA for water retention

Using the Genstat software, the data was analyzed for water retention capacity first basing on the water retention of the water absorbent materials, within the water absorbent material and then the water retained by each water absorbent material to soil ratio across all the water absorbent materials. The different WAM to soil ratios were 0:30, 2:28, 4:26, 6:24, 8:22 and 10:20. Table 4.2 shows the significant differences in the amount of water retained by the WAMs.

**Table 4. 2: Significant differences for water retained by each WAM to soil ratio across all the WAMs**

WAM	Ratios					
	0:30	2:28	4:26	6:24	8:22	10:20
Cassava	33.33 a	39.33 b	53.33 c	60.00 b	66.67 b	72.00 b
Irish Potato	33.33 a	38.00 a	46.00 a	56.00 a	64.00 a	69.33 a
Orange	33.33 a	52.00 c	64.00 d	68.00 c	74.00 c	78.00 c
sweet potato	33.33 a	38.00 a	50.00 b	55.33 a	64.00 a	70.00 a

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## **Observation**

For the different WAM to soil ratios there is a significant difference between the water retained by each WAM to soil ratio within the WAMs.

At all WAM to soil ratios, sweet potato and Irish potato peel based WAM retain the least amount of water, followed by the cassava based WAM and then orange peel based WAM.

There is a significant difference between the different water absorbent materials to soil ratios across all the water absorbent materials, however, there is no significant difference between using the Irish and sweet potato peel WAMs at the WAM to soil ratios 2:28, 6:24, 8:22 and 10:20 since they are represented by the same letter “a” by the Duncan's multiple range test.

## **Discussion of the significant differences between water retained by the WAMs**

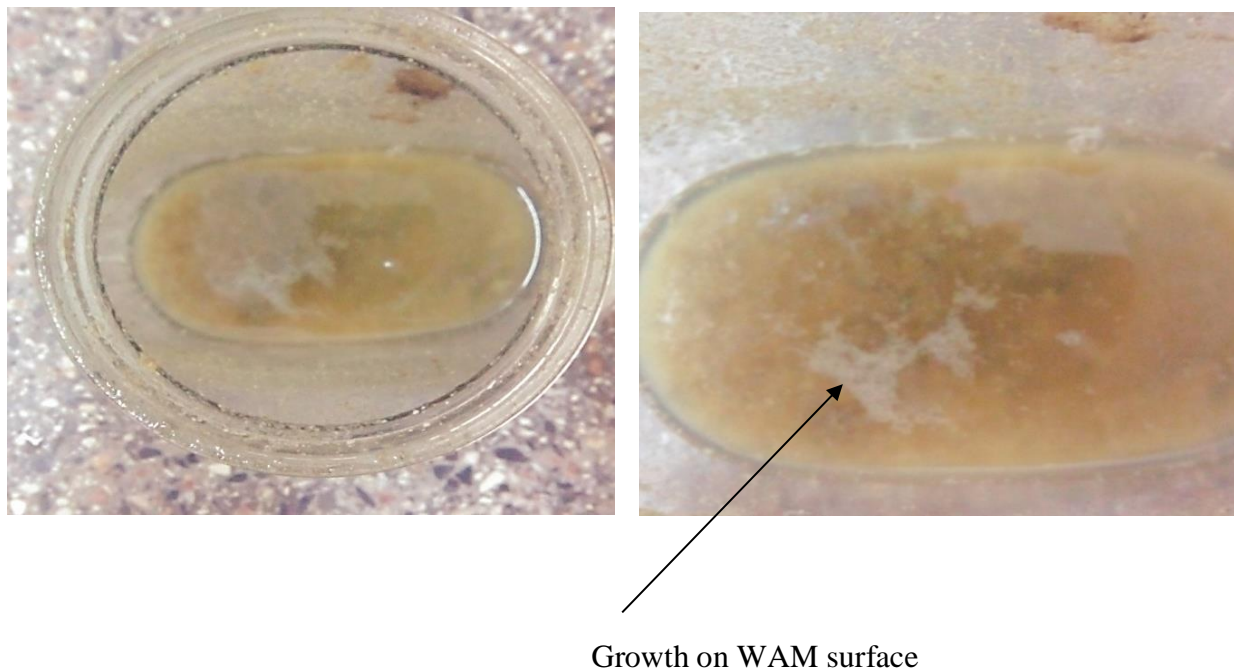
Within the water absorbent materials, there is a significant difference between the water retained by each WAM to soil ratio. This is because the higher the amount of WAM, the higher the amount of water retained. So there is no way water retained by 2g of the WAM can be the same as the amount of water retained by 4g,6g,8g or 10g of WAM. The significant difference between the different WAM to soil ratios across all the WAMs means that no WAM to soil ratio can be used instead of the other. The lack of significant difference between using the Irish and sweet potato peel WAM at the WAM to soil ratios means that at a given soil to WAM ratio, a sweet potato peel WAM can be used instead of the Irish potato peel WAM. This is due to the fact that they retain the same amount of water at the same WAM to soil ratio.

## **The water absorbent material's level of holding water**

The water absorbent material can be applied at any stage of plant growth. The amount of water the water absorbent material supplies to the plant depends on how dry or wet the soil is. The plant roots will be able to supply the water needed for crop growth depending on how much the plant requires. If the moisture content of the soil is high and also soil temperatures low, the soil will not be so dry hence the plant roots will take less water from the water absorbent material as compared to when the moisture content of the soil is low and soil temperature high.

### 4.3 Biodegradability test

Growth on the sample indicated that the sample is biodegradable. This is as shown in Figure 4.2



**Figure 4. 2: Biodegradability test results**

#### **Biodegradability period of the water absorbent material**

The water absorbent material is left in the soil at the end of the growing season where it is biodegraded. The water absorbent material takes 4-6 months in the soil to biodegrade and this depends on the temperature and moisture content of the soil. With high soil moisture content, the microorganisms are active and hence can do the biodegradability faster than in the dry environment.

#### **4.3 Characterizing the prepared material**

The water absorbent material is biodegradable as according to the biodegradability test performed. In the water retention test, the material is wettable by water hence hydrophilic. The product is also absorbent since it absorbed water poured on it during the water retention test. In the preparation procedure, the final product; water absorbent material, is a powder sieved to particle size 250 $\mu$ m.

Therefore the prepared material is a hydrophilic, biodegradable water absorbent powder of 250 $\mu$ m particle size.

#### **4.4 Application of the water absorbent material to the soil**

The water absorbent material is applied to the soil in the ratio of 1:300:60 for WAM (g): water (ml): soil (g) respectively. The 1g of WAM is mixed with 300ml of soil and applied in 60g of soil at a soil depth of 10-20cm depending on the root depth of the plant. The WAM can be applied at any stage of plant growth.

Water absorbent materials are water reservoirs and the water contained in them can only be absorbed by plant roots and it cannot be lost through processes like evaporation. Water will be removed from these reservoirs upon the root demand through osmotic pressure difference (Ekebafe *et al.*,2011). They consist of a set of chains thus forming a network. When water comes into contact with water absorbent material, it is drawn into the molecule by osmosis (Rajakumar and Jayasree,2016). Water rapidly migrates into the interior of the water absorbent material network where it is stored and at this step the WAM powder turns to water gel. The water gel's absorption ability is bigger than soil but less than roots of plants, the absorbed water by WAM will be released to plants when it is dry (Puoci *et al.*, 2008)

## **CHAPTER FIVE: CONCLUSIONS AND RECOMMENDATIONS**

### **5.1 Conclusion**

The orange peel based WAM retained the highest amount of water, followed by the cassava peel based WAM and then sweet potato and Irish potato peel based WAMs. It was also found out that the water absorbent materials improve the water retention of the soil. It is advisable to use the orange peel based WAM since it retained the highest amount of water compared to the rest of the water absorbent materials and besides it is cheap to prepare in terms of cost and time as compared to the other water absorbent materials. When we are to compare the orange peels to other peels; cassava, sweet potato and irish potato peels, the orange peels have less competition for uses like as animal feeds, hence higher chances of putting them to use to prepare water absorbent materials other than being left to rot away. In the biodegradability test carried out, it was found out that the product prepared was biodegradable hence ensuring an environmentally friendly product which prevents land pollution.

### **5.2 Recommendations**

It is recommended to do further research on the following;

- How different crops react to different water absorbent materials.
- How different WAMs perform in a given type of soil.
- Discover more materials that can be used to formulate Water absorbent materials.

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