UNIVERSITY OF NAIROBI

SCHOOL OF ENGINEERING

DEPARTMENT OF ENVIRONMENTAL AND BIOSYSTEMS ENGINEERING

EVALUATION OF THE EFFECTS OF SUPER ABSORBENT POLYMER (SAP) ON SOIL WATER RETENTION CHARACTERISTICS (WRC) OF DIFFERENT SOILS.

By

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(B.Sc. Env. and Biosystems Engineering, 2013)

A thesis submitted to the Department of Environmental and Biosystems Engineering, University of Nairobi, in partial fulfilment of the requirements for the Degree in Masters of Science in Environmental and Biosystems Engineering

December 2017
DECLARATION

I, Vincent Kiprono Ng’eno, hereby declare that this MSC Thesis is my original work. To the best of my knowledge, this work has not been submitted for a degree programme in any university.

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I dedicate this research to my parents Mr and Mrs Leonard Yegon. My family Magdalene Katuku and Ian Kipkosgei, my siblings and all the people who have assisted me throughout the study. Thanks, and God bless.
ACKNOWLEDGEMENT

I would like to thank the almighty God for the gift of life, strength and guidance throughout my studies. All the honour is to you Lord. I wish to pass my gratitude to my supervisors Dr. Christian Omuto and Dr. Duncan Mbuige for the advice, guidance and all the assistance provided to me throughout my research period.

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ABSTRACT

With reducing water availability worldwide there is a need for soil water management. One of the ways of reducing the cost of irrigation water is through *in situ* water harvesting at the plant roots. There have been suggestions in the literature that super absorbent polymer (SAP) can facilitate water harvesting at the plant roots. This study attempted to assess the effects of SAP on Soil Water Retention Curve (SWRC) coefficients in terms of plant available water (PAW) of different soils and modifying soil moisture release characteristics. The overall objective of this study was to assess if SAP can positively affect the WRC coefficients of different soil types for the benefit of PAW. SAP has been shown in the literature to be able to absorb and retain water up to five hundred times its own volume. In this study, SAP was sequentially added at the rate of 0.2%, 0.3% and 0.5% of the soil weight and its effects was assessed.

The moisture release characteristics of the original and SAP treated soils was studied using soil water retention curves (SWRC). The soil water retention curves (SWRC) were determined in ten pressure levels and the results modelled using the Gardner water retention model. PAW was estimated from SWRC as the difference between moisture content at 1.5bar and at 3bar and other WRC coefficients i.e. saturated water content ($\theta_s$), residual water content ($\theta_r$), air entry point ($\alpha$) and pore index ($n$) as determined using the Gardner model. SAP effect on soil samples was determined. The difference in SAP effect between original and treated soils was assessed at 5% level of significance to establish whether there was a significant effect on the soils due to treatment with SAP. Statistical analysis to determine the effect of SAP in the soils was by use of ANOVA. The WRC of all the samples were adequately found
to be described by the Gardner model (Coefficient of determinations \( r^2 \geq 98\% \) and residual standard error (RSE) \( \leq 0.04 \)).

The same soil samples were mixed with SAP at proportions of 0.2\%, 0.3\% and 0.5\% to the mass of the soil. A total of thirty-six samples were used: 27 had SAP and 9 did not have SAP. After samples were saturated, sand box and pressure plate apparatus were used for pH 0 to 2.0 and pH 3.0 to 4.2 respectively. Water retention curves were drawn for soils without SAP and the ones with SAP in different proportions of 0.2\%, 0.3\% and 0.5\% and predicted with Gardner model.

The results showed that, SWRC changed with the increase in SAP per centage in clay, sandy clay and sandy loam soils. Clay had a highest change than sandy clay and sandy loam. PAW in all the soil increased with an increase in SAP with clay having a greater effect. Clay increased with SAP from 0.3292 at zero SAP to 0.6223 at 0.5\% SAP. Sandy clay soil had an increase in PAW from 0.2721 at zero SAP to 0.5355 at 0.5\% SAP. Finally, sandy loam soils increased from 0.1691 at zero SAP to 0.3461 at 0.5\% SAP. Porosity (\( \theta_r \)), residual water content (\( \theta_r \)) and pore index (\( n \)) increased with SAP in all the soil but decreased in air entry point (\( \alpha \)). ANOVA showed that there was a significant effect of SAP on the soils.

In conclusion, PAW will therefore conserve irrigation and rainfall water in the plant roots and therefore reducing the cost since it has been lengthened. From the study, optimization on the values of SAP in the soil can be done to have a maximum benefit.
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<tr>
<th>Acronym</th>
<th>Description</th>
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<tbody>
<tr>
<td>ASAL</td>
<td>Arid and Semi-Arid Lands</td>
</tr>
<tr>
<td>AUL</td>
<td>Absorbency Under Load</td>
</tr>
<tr>
<td>AWC</td>
<td>Available Water Content</td>
</tr>
<tr>
<td>FC</td>
<td>Field Capacity</td>
</tr>
<tr>
<td>PAW</td>
<td>Plant Available Water</td>
</tr>
<tr>
<td>PWP</td>
<td>Permanent Wilting Point</td>
</tr>
<tr>
<td>SAP</td>
<td>Super Absorbent Polymer</td>
</tr>
<tr>
<td>SMT</td>
<td>Soil Moisture Tension</td>
</tr>
<tr>
<td>SPII</td>
<td>Super Porous Hydrogels</td>
</tr>
<tr>
<td>SWRC</td>
<td>Soil Water Retention Curve</td>
</tr>
<tr>
<td>WRMA</td>
<td>Water Resources Management Authority</td>
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<tr>
<td>WRC</td>
<td>Water Retention Curve</td>
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1.0 INTRODUCTION.

1.1 Background

Water is a scarce commodity in Kenya, in which only 24 per cent of it is surface water (WHO/UNICEF, 2015). Most of the water is ground water and not readily accessible to plants use. Again, Kenya’s land area is 582,646km², in which 17 per cent of it is classified as high potential agricultural land, with more than 700mm of precipitation for every year; which is suitable for rain-fed agriculture. The remaining land which is approximately 80 per cent is classified as arid and semi-arid lands (ASALs) and the remaining 3 per cent is forest land.

While re-emphasizing the relative nature of water shortage. (Abrams, 2009), characterized it as an idea portraying the connection between interest for water and its accessibility. Abrams, focused on the way that the demand change impressively between various nations and regions relying upon the sectoral utilization of water, and highlighted the way that it likewise differs as indicated by nearby climatic conditions.

The expanding nonattendance of water is an issue to farming which presently represents over 70 per cent of total water consumed. To guarantee food security, it is important to advance water-saving farming by methods for a coordinated framework that incorporates water proficient system, agronomic water sparing strategies and suitable farming administration (Wang et al., 2002)

Different methods of water retention should be introduced to curb this challenge. Vijayalakshmi et al (2012) described that in order to maintain water in the soil for longer periods after an irrigation or rainfall shower, some additional materials such as organic matter, soil conditioners are added into the soil.
Super Absorbent Polymer (SAP) is one of the added substance to enhance water holding capacity, it's been observed to be a basic and viable way for conserving water in different types of soil (Wang et al., 2002). Hence the water will be available to the plant for longer period of time and this will increase production. SAP has some other uses i.e. SAP has been used in hygiene especially in female napkins and expendable diapers where they catch emitted fluids e.g. urine, blood etc. (Elliot, 1997). It is also used in agriculture as soil additives, as nutrients reservoir and as water super absorbent in the soil (Abd.EI-Rehimm et al., 2004).

In this research, Gardner model was used for fitting the water retention curve. The model was designed by Gardener in 1958. It is a sort of nonlinear curve fitting model for water retention characteristics fitting utilizing trial information. Gardner model is contained in HydroMe package (Omuto, 2013) which is an additional software in R and freely downloadable. It is a fast, productive and precise estimation of soil pressure driven parameters in penetration and water retention models. The bundle is executable in R programming language, which is a freely downloadable programming software. R software contains different models for fitting water retention characteristics.

The main purpose of this study is evaluation of effects of Super Absorbent Polymer (SAP) in the soil water retention characteristics and be determined if it can help in managing water within the root zone.

1.2 Problem Statement

Water management in crop field has a huge impact on crop production. According to the International Water Management Institute (IWMI), agriculture which accounts for about 70 per cent of worldwide water withdrawals, is continually competing with residential,
mechanical and natural uses for a scarce water supply. For decades, water management
has been a notable issue in Kenya caused by deep percolation, runoff and evaporation.
Absence of precipitation influences likewise the capacity to get food and has prompted to
violence eruption in Kenya (World Bank, 2010).

According to WRMA, 80 per cent of the Kenyan land is classified as arid and semi-arid
lands (ASALs), 17% as high potential agricultural land and the remaining 3 per cent is
forest land. The arid and semi-arid lands receive very little amount of rainfall throughout
the year which is less than 500mm per annum. Farming in arid and semi-arid areas is
through irrigation but most water is lost through seepage and evaporation, hence a greater
loss to the little water available. The major problem of the water available in the field is
how to management it within the root zone. The water should be protected against
evaporation, deep percolation and runoff.

To ensure field water management, it is important to advance water-sparing farming by
methods for a coordinated framework that incorporates water-efficient irrigation,
agronomic water saving techniques and appropriate agricultural water management
(Wang et al., 2002). The field water management can be biological, chemical or synthetic
should be friendly to soil, should maintain the soil properties as it is for better crop
production.

The use of Super Absorbent Polymer (SAP) in water retention or the available water for
crops use during its growth period is used in this research. In this study, SAP is posited to
help reduce water loss through infiltration and evaporation, hence reducing water losses,
conserving or storing water when there is surplus in the soil and again reducing runoff and
hence conserving soil as well.
1.3 Objectives

1.3.1 Overall Objective

The overall objective of the study was evaluation of the effects of super absorbent polymer (SAP) on Soil Water Retention Characteristics of different soils.

1.3.2 Specific Objectives

The specific objectives of this study are to:

1. Determine water retention characteristics of different soils textural classes.
2. Evaluate effects of SAP on water retention characteristics of different soils.

1.4 Scope

The study was for the evaluation of the effects of super absorbent polymer (SAP) on Soil Water Retention Characteristics of different soils textural classes. The polymer used was sodium polyacrylate, which was mixed with soil in proportions of 0.2%, 0.3% and 0.5% to the weight of soil sample. The soil textural classes used were sandy loam, sandy clay and clay. These soils tested were for agricultural use and only textural classification was needed. The soils textural class and the SAP proportions was chosen for convenience.

The study was limited to testing the levels of SAP to detect ability to influence plant available water (PAW).
2.0 LITERATURE REVIEW

2.1 History of Polymers

Polymer is something made of many units (Jagdev, 2007). Super absorbent polymers (SAPs) are also called hydrogels and super porous hydrogels (SPH). The reason they are mostly used is that, they have the ability of absorbing large amounts of water (Kuruwita-mudivanelage, 2008). A unit gram of hydrogel can absorb water even more than 4000g in 20 minutes, with the other half of the water being retained inside the initial 12 minutes. SAPs were first presented by Union Carbide in the mid 60's and then created in the 70's to develop plants in the deserts, but they were not commercially used majorly because of their cost in comparison to their swell capacity (Jagdev, 2007).

In the early 80's super absorbent polymers started to be used in other fields such as baby diaper market (hundreds of thousands), this led to newer woodhouse with higher swelling capacity and other with long lasting life. SAPs have gained popularity more in different fields such as in baby diapers, feminine hygiene products hence replacing materials such as cloth, cotton, paper wadding and cellulose fibre because of its important parameter of water absorption, which would apply in storage facilities, rate of moisture absorption (swelling rate) and the amount of moisture absorbed per unit volume (swelling capacity).

The most productive and generally broadly used SAPs are built on polyacrylates, i.e. non-sustainable ingredients got from oil manufacturing that are accounted for to reduce at rates under 10% every year, by means of delamination, shear-actuated chain scission and photosensitive chain scission (Orts et al., 2000). From all of the described features, SAP will help in promoting the water storage in the soil hence aiding in boosting the water storage in the plant root zone.
2.2 SAPs Technical Features

SAPs performance is depended on its technical features which according to (Zohurian-mehr, 2006), ideal SAP material functional features is not limited to the following:

a) The highest absorption capacity (maximum equilibrium swelling) in saline soils;
b) Desired rate of absorption (preferred particle size and porosity) depending on the application requirement;
c) The highest absorbency under load (AUL);
d) The lowest soluble content and residual monomer;
e) It is cheap;
f) The highest durability and stability in the swelling environment and during the storage;
g) The highest biodegradability without formation of toxic species following the degradation;
h) PH-neutrality after swelling in water;
i) Colourlessness, odourlessness, and absolute non-toxicity;
j) Photo stability; and
k) Re-wetting capability (if required).

The use of SAP depends on the application and hence should have the capacity to give back the soaked-up arrangement or to look after it (e.g. in agriculture or hygienic applications).

A single SAP cannot accomplish all the above features, i.e. the manufactured segments for accomplishing the greatest level of some of these highlights will prompt wastefulness of the rest. Hence, by and by, creation response factors must be enhanced with the end
goal that a suitable balance between the properties is accomplished. e.g. clean SAP must have the most notable ingestion rate, the least re-composing and the most reduced leftover, which is different to an agricultural SAP which its absorption rate isn't much vital; rather it must obtain higher AUL and least affectability to saltiness. Table 2.1 below shows the effects of the main synthetic factors affecting SAP material properties.

Table 2.1: Effect of the main synthetic (internal, structural) factors affecting SAP material properties (Zohourian-mehr, 2006)

<table>
<thead>
<tr>
<th>Variation in synthetic factor</th>
<th>Absorption capacity</th>
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<th>Soluble fraction</th>
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<tr>
<td>Increase in crosslinker concentration</td>
<td>-</td>
<td>-</td>
<td>-</td>
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<td>+</td>
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<tr>
<td>Increase in monomer concentration</td>
<td>-</td>
<td>+</td>
<td>-</td>
<td>+</td>
</tr>
<tr>
<td>Increase in reaction temperature</td>
<td>+</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Increase in particles porosity</td>
<td>×c</td>
<td>+</td>
<td>-</td>
<td>+</td>
</tr>
<tr>
<td>Surface cross-linking</td>
<td>-</td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
</tbody>
</table>

Key: + = increasing, - = decreasing, × = varied, depending on the reagents and/or techniques employed. (b) Each factor is considered under a constant value of the rest factors. (c) Some authors have reported absorption enhancement; however, no absorption rise has to be logically observed if more accurate methods are employed for swelling measurement, e.g., centrifuge method.

2.3 Analytic Evaluation of SAP Properties

2.3.1 Free-Absorbency Capacity

For the most part, at the point when the terms swelling or sponginess are utilized without demonstrating its conditions; it infers take-up of polished water while the example is openly swollen, i.e., no heap is set on the testing test. There are a few straightforward strategies for the free-retentiveness testing which are reliant for the most part on the measure of the accessible example, the specimen sponginess level, and the technique's
exactness and precision. The methods that are used to show absorbency of SAPs and its capacity to hold water includes: Tea bag; centrifuge and sieve methods.

a. **Tea Bag Method**

This technique is the most traditional, quick, and reasonable for restricted measures of tests (W₀ = 0.1-0.3 g) (Mahdavinia et al., 2006). The SAP test is put into a tea-bag (acrylic/polyester gauze with fine systems) and the bag is dunked in an abundance measure of water or saline response for sixty minutes to accomplish the congruity swelling. At that point overabundance arrangement is expelled by hanging the pack until the point that no fluid is released. The tea bag is measured (W₁) and the swelling limit is figured by equation (2.1). The technique's accuracy has been resolved to be approximately ±3.5%.

\[ S_c = \frac{(W_1 - W_0)}{W_0} \]  \hspace{1cm} (2.1)

b. **Centrifuge Method**

The centrifuge method is more precise than the tea bag technique and is often detailed in licenses and information sheets (Buchholz and Peppas, 1994. Shokubai, 2005). The approach is as follows: 0.2 g (W₁) of SAP is set into a bag (60×60 mm) made of nonwoven texture. The pack is plunged in 100 mL of saline solution for thirty minutes at room temperature. It is taken out, and afterward extra solution is evacuated with a centrifuge separator (3 min at 250 g). At that point, weight of pack (W₂) is measured. Similar stages are completed with an unfilled bag, and the heaviness of bag (W₀) is determined. The swelling limit is computed by the equation (2.2).

\[ S_c = \frac{(W_2 - W_0 - W_1)}{W_1} \]  \hspace{1cm} (2.2)
Since particle to particle fluid is detectably expelled by this technique, the measured values are frequently more exact and lower than those acquired from the teabag method values.

c. Sieve Method

SAP sample (W1, g) is filled in abundance measure of water or a solution and scattered with mild magnetic mixing to achieve equilibrium swelling (0.5-3 h relying upon the sample particle size). The swollen specimen is separated at wanted time through measured 100-work (150 μm) wire gauze (sieve). At that point it is dewatered carefully and quickly using a piece of soft open-cell polyurethane froth (by repetitive rubbing under gauze base and squeezing the froth) until the gel never again slips from the strainer when it is held vertical (Kabiri et al., 2003. Omidian et al., 1999). The quantitative Figures of swelling can be calculated by equation (2.3).

\[ S_t = \frac{|(A_t - B) - (B + W_1)|}{W_1} \]  \hspace{1cm} (2.3)

Where, \( S_t \) = swelling at time \( t \), g/g (gram of absorbed fluid per gram of polymer sample)

\( A_t \) = weight (g) of water-taken in polymer at time \( t \);

\( B \) = weight (g) of the sieve;

This method, also called filtering and rubbing method (Omidian et al., 2004), needs more samples (1-2 g).

2.3.2 Absorbency Under Load (AUL)

The absorbency under load (AUL) information is normally given in the patent writing and specialized information sheets by mechanical SAP makers (Shokubai, 2005). At the point when the term AUL is utilized without indicating its swelling media; it infers a take-up of
0.9\% NaCl arrangement while the testing test is pressurized by a few loads (regularly determined to be pressures of 0.3, 0.6, or 0.9 psi). A typical AUL analyzer is a basic yet finely made gadget including a macro-porous sintered glass filter plate (porosity 0, d=80 mm, h=7 mm) put in a Petri dish (d=118 mm, h=12 mm). The weighed dried SAP test (0.90±0.01g) is consistently set on the surface of polyester gauze situated on the sintered glass. A cylindrical solid load (Teflon, d=60 mm, variable height) is put on the dry SAP particles while it can be openly slipped in a glass cylinder (d=60 mm, h=50mm). Wanted load (applied pressure of 0.3, 0.6, or 0.9psi) is put on the SAP test (Figure 2.1). Saline solution (0.9\% NaCl) is then added when the liquid level is equivalent the height of the sintered glass filter. The entire set is secured to anticipate surface evaporation and likely change in the saline concentration. After 60 min, the swollen particles are measured once more, and AUL is ascertained by use of the equation (Harandi et al., 2006).

\[
\text{AUL (g/g)} = \frac{W_2 - W_1}{W_1} \quad (2.4)
\]

Where, \(W_1\) and \(W_2\) denote the weight of dry and swollen SAP, respectively.

The AUL is taken as a measure of the swollen gel quality of SAP materials (Harandi et al., 2006, 2008).
2.4 Swelling Rate

a. Vortex Method

The vortex technique, the most quick and straightforward approach to assess the SAP swelling rate, is frequently utilized in R&D and specialized research centers (Zohourian-mehr, 2006). Water or saline arrangement (50.0 g) is poured in a 100-mL beaker and its temperature is balanced at 30°C. It is mixed at 600 rpm utilizing a magnetic stirrer (stirrer bar length 400mm). Superabsorbent test (mesh 50-60, W0=0.50-2.0 g) is included and a stopwatch is begun. The time slipping by from the increase of SAP quantity into the liquid to the disappearance of vortex (tvd, sec) is measured. This swelling rate (SR, g/g.s) is calculated by equation (2.5).

\[ SR = \frac{50}{W_0} / t_{vd} \]  
\[ (2.5) \]

b. Swelling-Time Profile

The trend of swelling versus time (min) is acquired by means of isolating swelling measurements of tests retained wanted fluid at back to back time interims. Either, tea-bag,
rotator, or sieve approaches can be used for the estimations relying upon the measure of the accessible example and the wanted accuracy. Regularly, several 2 L Erlenmeyer flasks containing distilled water or wanted solutions are named and SAP samples (e.g. 1.0 g, 50-60 mesh) is filled every cup and is scattered with mellow mixing. At continuous time intervals (e.g., 15, 30, 45, 60, 90, 120, 180, 300, 600, 1800 s), the absorbency of the specimen is measured by sieve method (Omidian, 2004). A typical profile is shown in Figure 2-2.

![Figure 2.2: Representative curve for swelling kinetics of a hybrid SAP sample in distilled water (Motazed et al, 2006).](image)

The swelling energy of the SAPs can be deliberated by technique of Voigt-based viscoelastic model (Omidian, 1998):

\[ S_t = S_e (1 - e^{-kt}) \]  

(2.6)

Where:

- \( S_t \) = Is the level of swelling (g/g) at any minute,
$S_e$ = Is the uniform swelling, will be swelling at boundless time or most extreme waterholding limit,

$\tau$ = Is the swelling time (s), and

$r$ = Is the rate parameter (s), is the time required to achieve 0.63 of the uniform swelling.

The swelling values acquired from the above estimations are anticipated into equation (2.6), utilizing a reasonable programming like Easy plot, to discover the estimations of the rate parameters. As per (Kabiri et al., 2005), swelling rate (SR, g/g.s) is defined as shown in equation (2.7):

$$SR = \frac{S_{\text{sw}}}{\text{t}_{\text{sw}}}$$

(2.7)

Where:

$S_{\text{sw}}$ = Is the swelling at the time related to minimum rate parameter,

$t_{\text{sw}}$ (s) = Obtained from comparable SAP samples or SAPs prepared from a set of similar experiments (Figure 2.2). Actually,

$t_{\text{sw}}$ = Is same to the point where exit from maximum swelling rate takes place.

2.5 Uses of Polymers

2.5.1 Uses in Agriculture

A spearheading test completed by a Japan owned organization in a desert in Egypt, in the mid-1990s showed the capability of manufactured SAPs used in management of water during agricultural applications (Shimomura et al., 1994). Similarly (Woodhouse and Johnson, 1991) utilized manufactured SAPs as a form of soil conditioners as plant
foundation and development in places experiencing little to no rainfall. SAP improves the soil properties to hold/absorb more water.

Super absorbent polymers are also utilized as soil added substance, as repository of supplements and as water superabsorbent in the soil (Abdi El-Rehim et al., 2004). As soil additives, SAPs have been established to improve the physical properties of soil in the perspective of expanding their water holding limit expanding water use efficiency, upgrading soil penetrability and penetration rates, lessening irrigation frequency, diminishing compaction tendency, halting erosion and water run-off and expanding plant performance, particularly in structure-less soils in places subjected to drought (Abdi El-Rehim et al., 2004).

In a test appraisal of the utilization of a type of SAP known as novel for the advancement of water used in an irrigation process, (Demetri et al., 2014) discovered that soil mixed with SAP can hold a lot of water and can discharge it progressively to the roots of plant surrounding it when required, henceforth SAP can display a capable result for the justification of water resources, particularly in desert areas.

Super absorbent polymer has a great effect on water penetration rate in soil, bulk density, soil structure and the rate of water loss from the soil surface (Seved Seraji et al., 1389).

While increasing water-holding limit of porous soils, super absorbent polymer can address soil penetrability issues of impermeable soils and troubles in washing fertilizers (Askaris et al., 1994). Since that super absorbent polymer retain water hundreds of times its own weight and being changed over to durable gels, have an exceptional place in agriculture, land scaping and degradation reduction. SAPs rapidly retaining water and raising retention
productivity of water acquired from uneven precipitation and also on account of watering soil, they increase irrigation interval (Allahdadi, 2002).

SAPs have also been utilized as a holding material as seed additives (used to assist in germination and seedling growth), seed coating, root dips and for immobilizing plant development controller or securing agents for controlled release (Abd EL-Rehim et al., 2004).

(Abd EL-Rehim, 2004) said that SAP has been effectively utilized as a soil amendment in the horticulture industry to enhance the physical properties of soil in perspective of expanding their water-holding limit as well as supplement maintenance of soil textures of sandy to be similar to textures of silty mud or topsoil. It additionally impacts the following soil properties: permeability, density, structure, texture; evaporation and infiltration rate of penetration within the soil medium. Particularly the gels reduces the rate of water application and compaction tendency this is because of its ability to be spongy when saturated hence compaction is difficult, stop soil loss and water loss through runoff and also increase pores within the soil and soil microbial activities.

Investigation on the planning of superabsorbent moderate discharge nitrogen fertilizer moderate discharge NPK compound compost with superabsorbent and water retention, (Liu et al., 2007, 2008) they found that the hydrogel likewise acts as a precise discharge system by approving the take-up of some supplement components, holding them firmly and postponing their disintegration. Thus, the crop can at present reach a portion of the fertilizer, bringing about enhanced development and performance rates. This demonstrates that coating of the seeds with fertilizer and SAP is conceivable and works similarly well.
A particular example for agricultural application of SAP has been as of lately practiced. (Abedi-koupai et al., 2006), in the impacts of hydrophilic polymer on the field execution of an ornamental plant found that SAP effect on an ornamental plant (Cupressus arizonica) in a reduced water application and regimes in the field and on the soil water retention in a research centres as shown in the Figures below. There were impressive reactions in the time to permanent wilting point (PWP) because of polymer application and increase in polymer concentration shown in Figure 2.3.

![Figure 2.3: Time to reach PWP when applying 4 and 6g/kg Super absorbent A200 (Abedi-koupai et al., 2006).]

Again (Mousavinia et al., 2005), they conducted a research on SAP effects on the characteristics of grass used in the field, the water use of the grass is high specifically in hot and dry climates due to evaporation and infiltration. Shown in Figure 2.4 (a) and (b). Figure 2.4 (a) shows that wilting decreases with increase in SAP because of SAP water holding increase with its per cent and also crop colour increases with SAP. Figure 2.4 (b) shows that crop density increases with SAP and coverage of increases to a certain point then it doesn’t change with increase in SAP.
Figure 2.4: impacts of different quantity of SAP on sport grass characteristics: (a) colour and wilting, (b) coverage and density based on the NTEP standards (Mousavinia et al., 2005).

Another field of agriculture that SAP has been used in the field of grain and seed handling, especially in maize drying.

In the research to determine moisture sorption in seed maize during hermetic drying using super absorbent hydrogel, the seed maize rapidly gave up its moisture to the hydrogel
(Gatwiri et al., 2013). The experiment was conducted in an air tight glass container with lid, wire mesh basket and a stand. The container was cylindrical with lid hence formed a hermetic system. As the seed maize reached equilibrium with the hydrogel the rate of drying slowed down. Final moisture content of the seed maize reduces with increase in temperature from 25°C, 30°C, 35°C and 40°C (Gatwiri et al., 2013). The drying curves show significant moisture reduction within the first 50 hours due to low relative humidity created by the superabsorbent hydrogel. The drying rate reduced as the hydrogel approached saturation. The least final moisture content for each set of treatment was observed for samples that were dried at 40° C compared to those dried at 25, 30 and 35° C. It was found that lower moisture content was achieved with a higher drying temperature and ratios as revealed in the study (Gatwiri et al., 2013).

Plant available water tends to give the best effect of SAP in different types of soils. The concept of PAW as given by (Veihmeyer and Hendrickson; 1949; 1931 and 1927), where they defined it as the distinction in the content of water in the soil between field capacity (FC) at upper limit and permanent wilting point (PWP) at the lower limit. It indicates the capacity of different soils to retain and release water to the roots. With SAP having high water storage, in this study it also showed that it prevents water trickling to seepage hence increasing PAW in the soil (Abedi-Koupai et al., 2008).

2.5.2 Other Uses of SAP

Super Absorbent Polymer (SAP) is not only used in agriculture. A number of research works have been conducted in this other fields. Some of this fields are, artificial snow, baby diapers, decorative (coloured) items, engaging/instructive toys and apparatuses,
building inside enhancements, fire dousing/retarding gels, cryogenic, sustenance/ment bundling etc. (Po R, 1994).

In the electrical industry, it has been used in the reduction of the ground-resistance, whereby (Yameni, et al., 1994) deduced while finding out another ground lessening material on water retentive polymer in electrical appliances.

Again, while checking concrete strengthening a research was done to identify strength of aluminium concrete changed by super absorbent polymer/silt composite by (Heimann, et al., 1997).

2.6 Soil Texture Analysis

Soils are the most important resource in every country in the world. Particle size distribution is the simplest level of understanding soil. Particle size distribution can be defined as a list of qualities or a mathematical function that characterizes the relative measures of particles present, arranged depending on size. It is also known as grain size distribution (Rohaya, 2011). Methods used to determine Particle Size Distribution is called particle size analysis. The two main methods of particle size analysis are sieve analysis and hydrometer test.

2.6.1 Hydrometer Test

Hydrometer analysis uses Stokes’ law which forecasts on the speed of free falling spherical soil particles in water in light of molecule measure. The bigger the particle size, the quicker the settling speed. The water viscosity is influenced by temperature, and along these lines an estimation adjustment is vital for temperatures veering off from a standard temperature of 20°C. The determination of soil texture examination is proficient first by the expansion of a chemical
dispersant sodium hexa-metaphosphate, with ensuing mechanical unsettling. Density of the soil suspension is measured using the Bouyoucos hydrometer at specific times as a function of the particle size being measured (Gee and Bauder, 1986). As an alternative, the sand per cent can be determined removal of the sand fraction using a 270 mesh (53.3 μM) screen and subsequent gravimetric measurement.

The compound dispersant may not totally scatter soil particles within the sight of soil constituents, for example, organic matter, carbonate minerals, soluble salts, and a few oxides. These soil constituents coagulate particles by means of different forces that are stronger than force of scattering given by the dispersant. Accordingly, the expulsion of organic matter, carbonates, soluble salts, and oxides might be important relying upon the concentration of the components and the precision required. These soil constituents can be detached by pre-treating the soil. Pre-treatment alternatives are exhibited in this technique. A nittier gritty introduction of pre-treatment options is provided by (Sheldrick and Wang, 1993), and (Gee and Bauder, 1986) and in (ASTM D422 – 63, 2007) standard test strategy for particle size investigation of soils. Calculation is done as follows:

\[
\text{%sand} = 100 - 2(H_1 - B_1) + 0.36(T_1 - 20) \\
\text{%clay} = 2(H_2 - B_2) + 0.36(T_2 - 20) \\
\text{%silt} = 100 - (\text{%sand} + \text{%clay})
\]  

(2.10)  
(2.11)  
(2.12)

2.6.2 Textural Classification

Soil texture classification is done with the help of a textural triangle. Textural triangle is used to categorise the different texture class of a soil. The sides of the soil texture triangle are arranged in per cent of sand, silt, and clay. It is related to weathering and rocks as parent materials. The differences in horizons may be due to the differences in texture of
their respective parent materials or rocks where soil formed (Gee and Bauder, 1986). There are a number of types of textural triangle in the literature (Table 2.2).

**Table 2.2: Soil Texture Triangle Types (Gee and Bauder, 1986)**

<table>
<thead>
<tr>
<th>No</th>
<th>Soil Texture Types</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>The USDA soil textural classification</td>
</tr>
<tr>
<td>2</td>
<td>Whitney 1911 USDA soil textural classification</td>
</tr>
<tr>
<td>3</td>
<td>The European soil map (HYPRES) soil textural classification</td>
</tr>
<tr>
<td>4</td>
<td>The French 'AISNE' soil textural classification</td>
</tr>
<tr>
<td>5</td>
<td>The French 'GEPPA' soil textural classification</td>
</tr>
<tr>
<td>6</td>
<td>The German Bodenartendiagram (B.K 1994) soil texture classification</td>
</tr>
<tr>
<td>7</td>
<td>The German 'Standorfsetzerkundungswaisung' (SEA 1974) soil texture classification for forest soil</td>
</tr>
<tr>
<td>8</td>
<td>The German 'landwirtschaftlicheBoden' (TGL 24300-05, 1985) soil textural classification for arable soil</td>
</tr>
<tr>
<td>9</td>
<td>UK soil survey of England and Wales texture classification</td>
</tr>
<tr>
<td>10</td>
<td>The Australian soil textural classification</td>
</tr>
<tr>
<td>11</td>
<td>The Belgian soil texture classification</td>
</tr>
<tr>
<td>12</td>
<td>The Canadian soil texture classification</td>
</tr>
<tr>
<td>13</td>
<td>The Romanian soil texture classification</td>
</tr>
<tr>
<td>14</td>
<td>The Polish soil texture classification</td>
</tr>
<tr>
<td>15</td>
<td>The Brazilian 1996 soil texture classification</td>
</tr>
<tr>
<td>16</td>
<td>The Brazilian 2013 soil texture classification</td>
</tr>
</tbody>
</table>

**2.7 Soil Water**

Although water is involved in chemical reactions in the soils either as a solvent or as a reactant, it’s important to crops is in large measure related to its physical functions. The functions are, (a) nutrient dissolution in the soil and solute absorption by plant roots (b) effects on soil temperature, aeration and microbial activity (c) physiological processes in plant cells (e.g. maintaining cell turgidity and transport of solutes and photosynthetic products).
Water stress in plants is most critical at the floral initiation of the crop as indicated in the study of bananas by (Holder and Gumbs, 1982).

### 2.7.1 Categories of Soil Water

#### i. Gravitational Water

Gravitational water is the one which moves through the soil due to gravitational pull. It is available to plants in very brief periods when it comes in contact with roots and occurs only when the soil is saturated by heavy down pour or water application. Gravitational water is not held in the soil by any suction force. It is of little use to plants because it drains quickly out of the root zone to lower depths. With SAP this water can be held within the root zone and be available to the plant when needed.

#### ii. Capillarity Water

Capillarity water is the one left in the macro pores and around the periphery of the soil particles after gravitational water has drained out of the macro pores. It is the layer of moisture held around the particles by adhesive and cohesive forces collectively called matric suction or matric potential. This form of water may be viewed as concentric rings of successive monomolecular layers of water around the particles, each layer bound to the particle with decreasing energy from the innermost (nearest the particle surface) to the outermost layer. Thus, the outer molecular layers of capillary water (held less tightly by matric suction) are much more readily available to plants while the inner layers (held more tightly by matric suction) are not as readily available. (Foth, 1978) reported that capillary water consists of 15 to 20 molecular layers and the outer 2/3 of these layers, called cohesion water (held by cohesive forces between water molecules), are available to plants.
The remaining 1/3 inner layers called adhesion water (bound by adhesive force between the soil particles and the water molecules), are available to plants.

iii. **Hygroscopic Water**

Hygroscopic water is a form of soil water which is adsorbed by strong electrostatic bonding on the surface of air-dry (AD) soil particles and is in equal to the relative humidity of the surrounding air. Hygroscopic water is not available to plants.

### 2.7.2 Energy (Soil Water Potential (SWP)) State of Soil Water

SWP is defined by (Baver et al., 1972) is any force acting on the soil water, impacting into it the tendency to move from one point to another. The total energy condition of water within the soil is characterized by its comparable potential energy, as determined by the different forces following up on the water per unit quantity. In general, flow rates of water in soils are too little to consider kinetic energy. Hence, the energy condition of soil water is characterized by its equal potential force that is by virtue of its position in a power field. The total water potential had been defined by (Baver et al., 1972) in the equation below:

\[ \Psi_t = \Psi_p + \Psi_z + \Psi_s + \Psi_a \]  

(2.10)

Where:

- \( \Psi_p \): pressure;
- \( \Psi_z \): gravitational;
- \( \Psi_s \): solute (osmotic), and
- \( \Psi_a \): air pressure potentials. The unit of pressures are in \( \text{N/m}^2 \).
2.7.3  Soil Moisture Tension (SMT)

Water potential in soils is often referred to as water suction or soil moisture potential (SMT). SMT is a negative (-) quantity (the highest value is 0 at saturation point). SMT is expressed in bars of pressure but commonly used is kpa.

a. Range of SMT in Soils

Soil water availability to plants and SMT are inversely related as shown in the Table 2.3. The soil water available to plants is in the range between WP (wilting point), which has SMT of 1,500kpa (15bars), and FC (Field capacity) with SMT of 33kpa (1/3bar).

Table 2.3: Interrelationships between Soil Water Content, SMT and PS occupied by soil water (Foth, 1978).

<table>
<thead>
<tr>
<th>Item compared</th>
<th>OD</th>
<th>HP</th>
<th>WP</th>
<th>FC</th>
<th>SP</th>
</tr>
</thead>
<tbody>
<tr>
<td>SMT (kpa)</td>
<td>$10^6$</td>
<td>3,100</td>
<td>1,500</td>
<td>33</td>
<td>0</td>
</tr>
<tr>
<td>Approximate % PS Occupied by water</td>
<td>0</td>
<td>15</td>
<td>25</td>
<td>50</td>
<td>100</td>
</tr>
</tbody>
</table>

b. Factors Affecting SMT or Soil Moisture Availability

Three items affect SMT and available water in the soils. First is the soil texture, the finer the texture, the more water is in the soil at a specific soil moisture status as shown in the Table 2.4. The relationship between clay and SMT in soils has been studied quite extensively, according to (Gangaiya et al., 1982) on Fijian soil, he related per cent clay with 1500kpa SMT, using NRCS formula (USDA Handbook No.436):

\[
\% \text{ clay} = 2.5 \times 1500 \text{kpa gravimetric water (\%)} \quad (2.11)
\]
They obtained results in close agreement with per cent clay by mechanical analysis of the soils in the laboratory.

**Table 2.4: Influence of Soil Water Content. (Brady, 1974).**

<table>
<thead>
<tr>
<th>Soil water content (%) at</th>
<th>Sandy</th>
<th>Loam</th>
<th>Loam</th>
<th>Silt</th>
<th>Loam</th>
<th>Clay</th>
</tr>
</thead>
<tbody>
<tr>
<td>SP*</td>
<td>14.6</td>
<td>30.0</td>
<td>43.0</td>
<td>51.4</td>
<td>55.0</td>
<td>50.0</td>
</tr>
<tr>
<td>FC</td>
<td>7.3</td>
<td>15.0</td>
<td>21.5</td>
<td>25.7</td>
<td>27.5</td>
<td>27.5</td>
</tr>
<tr>
<td>WP</td>
<td>3.7</td>
<td>7.7</td>
<td>10.9</td>
<td>13.6</td>
<td>15.0</td>
<td>15.6</td>
</tr>
<tr>
<td>Available Water**</td>
<td>3.6</td>
<td>7.3</td>
<td>10.6</td>
<td>12.1</td>
<td>12.5</td>
<td>11.9</td>
</tr>
</tbody>
</table>

*Calculated to be approximately 2FC.
**Available water=FC (%) - WP (%).

The second item that affects SMT is the OM content of the soil. The effect of soil OM on SMT is similar to that of clay but in a much more marked manner. The third factor influencing SMT is the amount of salts (fertilizers included) in the soil. Salts have very high hygroscopicity (affinity for water) and so, increases the SMT by increasing the osmotic suction.

**2.7.4 Measuring SMT and Available Soil Water**

There are several ways by which the amount of water in the soil is determined (Saleth et al., 2009).

**a. Thermogravimetric Method**

A quick estimate of the available water in soils may be done by determining its per cent moisture at SP and FC. Soil at 33kpa SMT, at SP, 0kpa SMT; and half of the quantity of water in the soil at SP is considered FC. Per cent water (H₂O) is measured as follows:

\[
\%H₂O = \frac{\text{Moist wt} - \text{OD wt} \times 100}{\text{OD wt}} = \frac{\text{wt of water lost by oven drying}}{\text{OD wt}} \quad (2.12)
\]

*OD - Oven dry
*wt - Weight
A sample of soil that has been oven dried is then brought to SP by using the saturated paste method (USDA NRCS Handbook No. 60). The original water content of the soil (before oven dried) may then be compared with the moisture content at FC.

b. Suction (Tensiometric) Method

There are two devices used in the suction or tensiometric method of determining soil water. These instruments use either suction or pressure in the evaluation of water content in the soil. One of the instruments is a tensiometer. The column is water filled and the instrument is buried vertically in the soil with porous cup down and the vacuum gauge sticking out of the soil surface. If the soil water stress, it will move from the column to the soil through the porous cup, creating a vacuum or suction pressure which is measured by the gauge. The reading in the gauge is calibrated as kpa or bars and it works well in the range of 10 to 80kpa. Its reliability decreases as the (soil moisture tension) SMT increases above 100kpa (1bar) (Mahilum, 2004).

The other tensiometric device is the pressure-membrane apparatus. Pressure is passed through the soil sample and the porous membrane forcing the soil water through the porous membrane into another chamber and hence to the water collector. The pressure at equilibrium (reached when more water drops into the collector) is thus noted and the volume of water extruded from the soil sample is measured. The pressure causing the elution from the soil sample is inversely related to the soil moisture (Mahilum, 2004).
c. Electrical Resistance Method

The electrical resistance method of soil moisture uses the principle that electrical conductivity of the soil that absorbs the water increases with increasing water content. This method has been found to be accurate in SMT measurements from 100 to 5,000 kpa (1 to 50 bars) (Mahilum, 2004).
2.8 General Characteristics of Water Retention Curve and Important Parameters

The notations used pertain to air-water systems only since the assumption is that water and air are the only wetting and non-wetting fluid.

Figure 2.6 below shows a chart of a typical soil water retention curve.

![Figure 2.6: Schematic diagram of a typical soil water retention curve with definition of parameters. (Too et al., 2014).](image)

The parameters in Figure 2.6 above can be defined as follows:

- $\theta$ is the volumetric water content.
- $\theta_s$ is the saturation water content
- $h_m$ is the soil matric head
- $\theta$ is equal to $\theta_s$ if only $h_m$ is equal to zero.
- $\theta_r$ is the residual water content
The point at which soil starts to desaturate is called the air-entry value, \( h_{ma} \), which is inversely proportional to the maximum pore size forming a continuous network of flow paths within the soil. As the matric head starts to decrease below the air-entry value, \( (h_{ma}) \), then the volumetric water content starts to decrease according to s-shaped curve with an inflection point \( (h_{mi}) \).

As the matric head \( (h_m) \) decreases further, \( \theta \) equally decreases towards a soil-specific minimum water content known as the residual water content \( \theta_r \).

Most models describing retention curve are in the range of \( \theta_r \leq \theta \leq \theta_i \). Effective saturation is given as \( S_e = (\theta - \theta_r)/(\theta_i - \theta_r) \), and it varies between 0 and 1. Most retention models include a dimensionless parameter, which characterizes the width of the soil pore size distribution, in addition to the four parameters, \( h_{ma} \), \( h_{mi} \), \( \theta_r \), and \( \theta_i \).

**2.9 Soil Water Retention Models**

There are different models that have been developed for water retention curves.

These models include: Van Genuchten (1980), Campbell (1974), Tani (1982), Exponential, Gardner (1958), Ruso, Brook-corey (1964), Kosugi (1999), Fredlund-Xing (1974) and Biexponential (Omuto, 2009). These models are summarized in Table 2.4 below.

In this research the Gardner model will be used and it is discussed further below.

**2.9.1 Gardner Model**

Gardner Model was developed by Gardner in 1958. It is a four-parameter water retention model.
Gardner model is a type of nonlinear curve fitting model for fitting water retention characteristics using exponential data. It requires initial parameter estimates for the model to work.

The model is described as follows.

\[ \theta(h) = \theta_r + (\theta_s - \theta_r) \left[ 1 + (\alpha h)^n \right]^{-1} \]

Where:

- \( \theta \) is the volumetric water content
- \( h \) is the pressure head or the matric potential
- \( \theta_s \) is the saturated water content
- \( \theta_r \) is the residual water content
- \( \alpha \) and \( n \) are the empirical shape parameters.

**Table 2.5: Summary of Water Retention Models (Too et al., 2014).**
2.10 R Software

R software can be found to be an object-oriented scripting language that consolidates:

- a programming language called S created by John Chambers at Bell Labs, that can be utilized for numerical re-enactment of deterministic and stochastic dynamic models.
- a broad arrangement of capacities for established and current factual information examination and demonstrating
- graphical capacities for envisioning information and model yield
- a user interface with a couple of essential menus and broad help offices.

R is an open-source venture, accessible for nothing download through the Web. Initially an examination venture in measurable computing (Ihaka and Gentleman, 1996) it is presently overseen by an improvement group that incorporates various all around respected analysts, and is broadly utilized by factual specialists (and a developing number of hypothetical environmentalists) as a stage for making new techniques accessible to clients.

R is a charge line translator like BASIC or PYTHON. R actualizes frameworks, so from the charge line R can include or even modify grids without unequivocal circles. R's information structures incorporate scalars, vectors, networks, information outlines (like tables in a social database) and records. The R protest framework has been reached out by bundle creators to characterize objects for relapse models, time-arrangement and geospatial directions.
It also underpins procedural programming with capacities and question arranged programming with nonexclusive capacities. A bland capacity acts distinctively relying upon the sort of contentions it is passed. At the end of the day, the nonexclusive capacity perceives the sort of question and chooses (dispatches) the capacity (technique) particular to that kind of protest. For instance, R has a non-specific print work that can print practically every kind of protest in R with a basic "(print object name)" language structure.

2.11 HydroMe

HydroMe is an add-on package in R and it is easily got in the net. The package contains a program for evaluating pressure driven parameters in penetration and water retention models. The water powered capacities parameters are evaluated from test information.

Curve fitting uses Gaus-Newton criteria which is an alternative algorithm for least-squares curve fitting for continuous and continuously differentiable models (Gourdin and Bourmahrat, 2002).

The algorithm inputs incorporate a scientific model with parameters to be evaluated which starts parameter values, first-arrange halfway subsidiaries of the model as for the parameters, and test information to encourage the estimation procedure (Subramanian and Xiu, 1997).

Hydrome package contains a number of water retention models which are written as R functions according to Gauss-Newton algorithm requirements. Example for Van Genuchten it is written as ssvar, Gardner as ssgardner and the same for all other models.
2.12 Some Research Done in the Same Field

A study of the absorption and desorption of fluid water by a superabsorbent polymer (Effect of polymer in the drying of the soil and the quantity of certain plants) by (Bakass et al., 2000). The polymer used in the research was superabsorbent polyelectrolyte formed from acrylic acid, which was in spherical balls of diameter (10-100μm).

The soils used were clay, fine silt and coarse silt and fine sand and coarse sand, which were representative of the area of Haouz in Morocco. From the analysis, the soil was marginally fundamental and low in natural issue and rich in potassium and phosphorus.

The impact of polymer over the life expectancy of specific plants (corn and expansive) after their watering was studied. This study was carried out in plastic pots of (30x40cm) which contained soil and polymer. Polymer was conveyed on the soil surface. For each studied plant, the effect of polymer was tested in 50 pots with each pot comprising two seeds. Four polymers in the bracketed rates (0.1, 0.3, 0.5 and 1.0 wt. %) were examined and soil mass used in all pots was 10kg.

Results amid drying of this sort of blend of soil and polymer, showed that the gel dried faster than drying of the soil toward the finish of the response. Soil preserved water longer than does without polymer, it preserves water 8days more. Polymer also modified the kinetic modes of soil, controlling the drying kinetics of the soil.

(Demetri et al., 2014) in a research on test evaluation of the utilization of a novel superabsorbent polymer (SAP) for the advancement of water utilization in horticultural water system process. To attain this, three types of experiments were done.

i). Portrayal of the retention limit of the SAP in both refined and tap water.
ii). Evaluation of the effects of SAP when in different soils and at different depths.

iii). Evaluation of the effects of SAP in condition resembling open field method.

An advanced cellulose-based superabsorbent polymer (SAP) alternative to acrylate-based SAP was used in the experiment.

The soils used were red and white Mediterranean soils and the plants used in the experiment were tomatoes and chicory.

In the assessment of absorption capacity of SAP, two samples weighing approximately 1g were added with 100g of water ($W_{\text{add}}$) and after 24 hours after SAP had reach saturation, SAP was passed through a membrane filter and weighed using a precision electronic balance ($W_{\text{not - abs}}$) and the weight weight of water absorbed was determined as $W_{\text{add}} - W_{\text{not - abs}}$.

To assess the effects of SAP on soil, 80 pots were filled with soil with SAP. Four arrangements of tests were readied with two sets planted with chicory and another two with tomatoes. Each set comprised of 20 pots and each set consisted of 10 pots filled with red soil and the other 10 pots with white soils. Weight of SAP ($W_{\text{SAP}}$) used was added to each pair of samples, at (0, 0.2, 0.5, 1.0, 1.5 wt. %) of SAP. In half of the pots, SAP was placed on the surface and the other half placed deep in the soil.

The samples were weighed before water was added and after. The gravimetric method was used in checking per cent water content from time to time for 78 days and water was added to the sample whenever it dropped below the available water limit (Aw). This investigation was done in a greenhouse so as to assess if cellulose-based SAP was effective in preventing natural evaporation phenomena of applied water.
The results showed that in each concentration of SAP, there is variation of moisture content ($\theta_c$) during observation period for different values of SAP.

The graphs 2.7 shows the variation of moisture content in red and white soils for 78 days both on the surface ($P_{\text{surf}}$) and deep in the profile ($P_{\text{deep}}$).

**Figure 2.7:** Difference of moisture content of red soil during 78 days observation time. For deep $P_{\text{deep}}$ (a) and $P_{\text{surf}}$ (b) samples, with different percentages of SAP. (Demitri et al., 2014).

**Figure 2.8:** Difference of moisture content of white soil during 78 days observation time. For deep $P_{\text{deep}}$ (a) and $P_{\text{surf}}$ (b) samples, with different percentages of SAP. (Demitri et al., 2014).
Again, from it, it was depicted that SAP lost its efficiency with time. With crops, plants that had a higher per centage of SAP looked healthier than ones without or with less SAP per centage.

In summary, it can be seen from the research that SAP cannot work alone, it should be mixed with soil to retain water for longer period than when it is left alone (Bakass et al., 2000). It modifies the soil drying kinetics

Again (Demitri et al., 2014) saturated SAP takes up to 8 days before it loses its water and tap water takes longer than distilled water. SAP loses its effectiveness with time. Water was added at first after 35 days but later it lost water faster hence prompting the adding of water after 15 days. SAP on the surface and deep in the soil performs the same work and a higher per centage of SAP takes longer. From this study, it can be used to conserve water in the soil in a scarce water environment and it can also conserve water from evaporation.

Again, it can be deduced that SAP alone cannot work well until it is mixed with soil. This is depicted from the research, in that SAP on its own it loses water faster than soil hence mixing it with soil it gives a better holding capacity.

Again, it can be deduced that SAP alone does not work well until it is mixed with soil. This is depicted from the research in that, SAP on its own it loses water further than soil hence mixing it with soil it gives a better holding capacity.
3.0 MATERIALS AND METHODS

3.1 Materials

1) Super Absorbent Polymer (SAP)

The Super absorbent polymer (SAP) used in the researches is poly (acrylic acid), sodium salt, moderately cross-linked, and obtainable from Sigma Aldrich (product number 43,636-4) as a powder with particle size < 1,000 μm (99%). This is the primary polymer that was used in water retention in the soil.

2) Soil textures

The soils were the primary material in this research. They were mixed with SAP and water retention tested in the presence and absence of SAP. The soils textural classes were clay, sandy clay and sandy loam. These were the soils identified after classification from the soil samples taken.

3) Weighing Machine

Weighing machine that takes data to two decimal places was used to weigh soil samples. It was used to weigh the samples from the pF machines for the purpose of water content in the soil samples.

4) Sandbox

It was used to determine lower pF of 0 - 2.0 (0 - 0.1 bar). It contains control board, suction levelling stand, water supply bottle with stand, filter material (140-150 micron), various compartments, manufactured sand, grain measure around 73 micron and different embellishments.
A most extreme of 40 soil test rings can be set on the sandbox. The specimens that are measured are taken utilizing soil test rings.

5) Pressure plate pF machine

Is appropriate for determination of pF-curves in the range pF 2.0 - 4.2 (0.1 - 15 bar of suction). This machine provides a system of most entire scope of extractors for deciding water holding limits (water retention curve) of soils and permeable materials.

3.2 Methods

3.2.1 Soil textural analysis

Soil textural analysis conveys an idea of the textural make up of soil and it also gives an indication of the physical properties and soil textural class names. Many soil samples from the Kabete soil lab were subjected to test for purpose of textural analysis. The soil samples were passed through a 2mm sieve before they were subjected to analysis. Figure 3.1 below shows Hydrometer analysis.
Figure 3.1: Hydrometer Analysis

Hydrometer method was utilized for the investigation of the soil samples. Several 51g of air dried samples that were first passed through a 2mm sieve were put in several beakers of 250mm. The samples were then moistened with distilled water to reduce reaction of hydrogen peroxide. Hydrogen peroxide was then added to help in pre-treatment until no reaction was observed and then 50ml calgon was added and left for 24hours. The samples were then put inside several shaking bottles of 1,000cm³ and then to a reciprocal shaker which was then shaken for 6hours. After 6hours the soil suspension was transferred into glass cylinder and distilled water added until it had reach one litre mark. The samples were then stirred a stirrer until all the soils were in suspension.

Hydrometer was then slowly driven into the suspension in the glass cylinders until the hydrometer was seen floating, then the first readings were taken and recorded as (H₁) and
the temperature of each suspension was taken and recorded as \( T_1 \). The second readings was
done after 3 hours and recorded as \( H_2 \) and \( T_2 \) for hydrometer and temperature respectively.
The first readings measured the per centage of sand in suspension and the second readings
indicated the per centage of clay in suspension. This was repeated in all the samples. Per
centages of soil was then calculated as follows:

\[
\%\text{sand} = 100 - 2(H_1 - B_1) + 0.36(T_1 - 20) \\
\%\text{clay} = 2(H_2 - B_2) + 0.36(T_2 - 20) \\
\%\text{silt} = [100 - (\%\text{sand} + \%\text{clay})]
\]  

(3.3)  
(3.4)  
(3.5)

Where: \( H_1 \) is hydrometer reading one, \( B_1 \) is hydrometer reading blank, \( T_1 \) is temperature one,
\( H_2 \) is hydrometer reading two, \( T_2 \) is temperature reading two and \( B_2 \) is hydrometer reading
blank two.

After the soil per centage was determined (with the help of USDA-SCS, 1982 textural
triangle) the soils were then classified and three soil types were identified. Textural triangle
is shown in appendix 1.

### 3.2.2 Determination of water retention characteristics of different soils.

Each class of the three textural classes was then replicated three times. On each replicate
there was a sample in a core ring. Core rings of 100cm\(^3\) open at both ends were used. One
side of the core rings was closed by use of a cloth gauze and fixed in place by use of a
rubber band. 70g of each soil type was put in the core rings by pouring to avoid
compaction then placed inside a sandbox.
Sandbox records lower pF values hence avoiding errors with logarithmic transformation when plotted. Sand box was then filled with distilled water until it was one centimetre below the top of the rings.

The samples were left for two days to attain its saturation and also it had achieved hydrostatic equilibrium, then the weight of the samples were taken and recorded, this represented a 0 bar reading. The core rings after weighing they were returned into the exact spot with slight pressing to increase soil sand contact then changed to pressure 0.48 bar. The discharge valve was then opened to allow water in the sandbox to be drained until when the hydrostatic equilibrium had been achieved. All the other pressure of 1.0, 1.5, 1.8 and 2.0 bar was taken after every two days and after the hydrostatic equilibrium had been reached i.e. no water still flows from the sand box to the drainage basin.

After 2.0 bar the soil samples were transferred to the pressure plate pF machines for higher pF readings. Pressures of 3, 5, 8, 10 and 15 bars were taken here. Between 1.5-3bars it represents the plant available water (PAW) in the soil and at 15bars it represents the permanent wilting point (PWP). Water retention was then analysed by drawing a graph of saturation against log pressure to attain an S curve. Different WRC coefficients/indices of different soils were found. This are the Plant available water (PAW), porosity/ saturated water content ($\theta_s$), residual water content ($\theta_r$), air entry point ($\alpha$) and pore index ($n$). This analysis was achieved with the help of R software. R software contains a HydroMe package which contains Gardner model that assisted in fitting the curve. The data was first uploaded into the software.
3.2.3 Evaluation of the effects of SAP on Water retention characteristics of different soils textural classes.

Each class of the three textural classes was then replicated three times. On each replicate there were samples mixed with SAP in proportions of 0.2%, 0.3% and 0.5% in core ring of 100cm$^3$ to the weight of the sample in the core rings. The samples of soil texture with no SAP at 0% was used as a control. After several studies, it was established that it was not possible to go beyond 0.5% of SAP in 100cm$^3$ core ring. 0, 0.2%, 0.3% and 0.5% were chosen for convenience. In each percentage there were nine core rings for each soil sample and at long last having a total of twenty-seven core rings in all the three soil types with SAP and nine without SAP hence total of thirty-six core rings. 70g of the samples were used in each core ring. Then all samples were placed inside a sandbox. Sandbox recorded lower values of 0bar to 2.0 bars hence avoiding errors with logarithmic transformation when it was plotted. Sand box was then filled with distilled water until it was one centimetre below the top of the rings.

The samples were left for two days to attain its saturation and also it had achieved hydrostatic equilibrium, then the weight of the samples were taken and recorded as 0bar. The core rings after weighing, they were returned in the exact spot they were with slight pressing to increase soil sand contact then moved to the next pressure bar of 0.48. The discharge valve was then opened to allow water in the sandbox to be drained until when the hydrostatic equilibrium had been achieved. All the other pressure bars of 1.0, 1.5, 1.8 and 2.0 were taken after every two days and after the hydrostatic equilibrium had been reached i.e. no water still flowed from the sand box to the drainage basin. Samples were arranged as shown in Figure 3.2 below.
After here, the samples were transferred to the pressure plate pF machines for higher pF or pressure readings. Pressures of 3, 5, 8, 10 and 15 bars were taken here. Between 3-5 bars it represents the available water in the soil. After fifteen bars had been achieved, the soil samples were put in an oven, to be oven dried overnight. The samples in the pressure plate were arranged as shown in Figure 3.3.

Calculations of the soil water retained in each pressure level was done using the equation 3.6 below.
\[ W = \frac{W_{\text{wet}}}{W_{\text{dry}}} \times 100 \]

\[ W = \frac{(\text{Wet wt.}) - (\text{Dry wt.})}{\text{Dry wt.}} = \frac{\text{Weight loss in drying}}{\text{wt of dried sample}} \times 100 \quad (3.6) \]

Then soil water retention curves were analysed by drawing a graph of moisture content to log pressure to attain an S curve. This analysis was achieved with the help of R software. R software contains a HydroMe package which contains Gardner model which assisted in fitting the curve. The data was first uploaded into the software.

The coding in Appendix 3 was used in achieving the various graphs of moisture content against pressure potentials at different per centages of SAP.

The difference in the effect of SAP at per centage 0%, 0.2%, 0.3% and 0.5% in the soil textural classes properties of water holding were determined statistically by use of one-way ANOVA. Null hypothesis described as \( H_0: \mu_0 = \mu_{0.2} = \mu_{0.3} = \mu_{0.5} \) and alternate hypothesis described as \( H_1: \mu_0 \neq \mu_{0.2} \neq \mu_{0.3} \neq \mu_{0.5} \).

The effect of SAP on different soils on water retention characteristic (SWRC) coefficients was then determined, the coefficients include: plant available water (PAW), porosity/saturated water content (\( \theta_s \)), residual water content (\( \theta_r \)), air entry point (\( n \)) and pore index (\( n \)). PAW is the difference between pressure of 1.5bar and 3bar. Relevant conclusions were then made about the effect of SAP on different types of soil.
4.0 RESULTS AND DISCUSSIONS

4.1 Results

4.1.1 Water Retention of Different Soil textures

The hydrometer test produced three types of soil textures which are sandy loam, sandy clay and clay. The Table 4.1 below gives the data obtained from hydrometer test for different soil texture.

<table>
<thead>
<tr>
<th>Soil Sample</th>
<th>H₁</th>
<th>H₂</th>
<th>T₁</th>
<th>T₂</th>
<th>B₁</th>
<th>B₂</th>
<th>Sand %</th>
<th>Clay %</th>
<th>Silt %</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>20</td>
<td>11</td>
<td>20</td>
<td>21</td>
<td>1</td>
<td>1</td>
<td>62</td>
<td>20.72</td>
<td>17.28</td>
<td>Sandy Loam</td>
</tr>
<tr>
<td>B</td>
<td>25</td>
<td>21</td>
<td>20</td>
<td>21</td>
<td>1</td>
<td>1</td>
<td>52</td>
<td>40.72</td>
<td>7.28</td>
<td>Sandy Clay</td>
</tr>
<tr>
<td>C</td>
<td>31</td>
<td>26.6</td>
<td>20</td>
<td>21</td>
<td>1</td>
<td>1</td>
<td>40</td>
<td>51.92</td>
<td>8.08</td>
<td>Clay</td>
</tr>
</tbody>
</table>

Soil sample A after calculation using equations 3.3, 3.4 and 3.5 was found to contain 62% sand, 20.72% clay and 17.28% silt from the equations respectively. After reading the corresponding percentages in the textural triangle, the soil sample was found to be Sandy Loam soil.

Also, soil sample B after calculation using equations 3.3, 3.4 and 3.5 was found to contain 52% sand, 40.72% clay and 7.28% silt from the equations respectively. After reading the corresponding percentages in the textural triangle, the soil sample was found to be Sandy Clay soil.

Finally soil sample C after calculation using equations 3.3, 3.4 and 3.5 was found to contain 40% sand, 51.92% clay and 8.08% silt from the equations respectively. After
reading the corresponding percentages in the textural triangle, the soil sample was found to be clay soil.

Water retention in soils is represented in a curve known as soil water retention curve. It is an S curve and different soil textures have their own according to its rate of water retention.

![Soil Water Retention Curve](image)

**Figure 4.1: Water Retention Curves of Clay, Sandy Clay and Sandy Loam soils**

Figure 4.1 above shows the combined soil water retention curves of clay, sandy clay and sandy loam soils at its *in-situ* state.

Clay soil has a higher water retention than sandy clay and lastly sandy loam and this is also evident in Figure 4.1 above. Clay has higher moisture content at saturation (0 bar pressure) being 0.95 and lowest at permanent wilting point (PWP) (15 bar or 150 cm) being 0.32 is shown having red a colour, sandy clay has a higher moisture content at saturation
being 0.85 and lowest at PWP is 0.30 as shown by the blue colour and sandy loam had the lowest value of moisture content at saturation being 0.43 and lowest at PWP being 0.11 as shown by the blue colour. This is because clay has small particle than sandy clay and sandy loam hence increasing the surface area of water intake.

The WRC coefficients/indices were found from Figure 4.1. PAW of clay was higher at 0.3291, then sandy clay at 0.2721 and lastly sandy loam at 0.1691. Saturated and residual water content was higher in clay with 0.965 and 0.3722 respectively then sandy clay with 0.834 and 0.329 respectively and the least being sandy loam with 0.430 and 0.1420 respectively. This shows that clay is naturally good in water retention and any soil with higher clay texture has good water retention this is because of small particle hence increasing water retention. Sandy soils have poor water retention.

![Figure 4.2: Water Retention Curves of Clay, Sandy Clay and Sandy Loam soils](image)
Figure 4.2 above further shows the difference in water retention curves. Clay is clearly shown as having a higher SWRC hence higher retention properties than sandy clay and the last being sandy loam. Sandy clay is better than sandy loam since it has clay particles. Clay being having small particles enables it to absorb more water since it increases its surface area of water retention than in coarse soils like sand which has larger particles.

Figure 4.3: Predicted Curve of Clay, Sandy Clay and Sandy Loam soils at SAP=0.

Figure 4.3 above shows a graph of measured against predicted. Using Gardner model within R software to fit the water retentions of clay, sandy clay and sandy loam soils at zero SAP. The residual standard error (RSE) is less than 4% and the coefficient of determination is ($r^2$) is greater than 98%, these shows that the measured data to the predicted is almost the same and has very small error.
4.1.2 Effects of SAP on Water Retention of different soil textural classes

With Supper Absorbent Polymer (SAP) having the property of absorbing water up to 500 times its size, it affected the soil water retention curve of clay, sandy clay and sandy loam as shown in the Soil water retention curves below.

![Soil water retention curves](image)

**Figure 4.4: SAP of 0.2-0.5 in clay, Sandy Clay and Sandy Loam soils.**

Figure 4.4 above shows a combined soil water retention curve (SWRC) of clay, sandy clay and sandy loam from 0.2% to 0.5% of SAP with 0% SAP used as a control. From the graph, it shows that an increase in SAP per centage brings about the increase in water retention and hence affecting the SWRC. Clay soil has the highest water retention with the red colour then sandy clay with green colour and lastly sandy loam with blue colour. The effect of SAP from the graph from 0.2% to 0.5% comparing with the control at 0% SAP in all the soil is evident since the graphs shape changes as the SAP increases. This is because the soil with the presence of SAP increases the water retention.
Figure 4.5: SWRC of Clay, sandy clay and sandy loam soils at SAP=0%-0.5%.

Figure 4.5 above shows clearly how the effect of SAP affects each soil differently. SAP at 0.2% is of red colour, 0.3% green colour and 0.5% blue colour. There is a change in SWRC with the change in the amount of SAP in the soil. The lowest graph with red colour is soil at 0% SAP which acts as a control experiment, green colour 0.2% SAP, blue colour 0.3% SAP and purple colour 0.5% SAP in clay, sandy clay and sandy loam soils. These curves depict an increase in SWRC with SAP. Clay soil has a high change then followed by sandy clay and lastly sandy loam, this is because clay soil has the best water retention properties than loam and sandy soils. To fit the graph with Gardner model an error (RSE) less than 2% and coefficient of determination, $r^2$ greater than 98% was achieved.

Table 4.2 and Figure 4.6 below shows how the change of SAP affects the soil at field capacity and at permanent wilting point.
Table 4.2 below show the effect of SAP on the SWRC coefficients. The coefficients
looked at are: Plant available water (PAW) which was obtained as the difference of
pressures between 1.5bar and 3bar; porosity/ saturated water content (θ₃); residual water
content (θₑ); air entry point (α) and pore index (n). PAW in clay increased much with an
increase in the SAP, with the highest being at 0.5%, then sandy clay also increased further
with increase in the amount of SAP and lastly sandy loam increased with SAP but not as
much as in clay and sandy clay as shown from values in the table. This is evident with a
research on the effect of hydrogel amendment to different soils on plant available water
and survival of trees under drought conditions (Agaba et al., 2010). When the plants were
planted with different per centages of SAP of 0.2% to 0.4% and watered for some time
and then it was subjected to drought. It was found out that the soils and plants with SAP
at 0.4% had an increase in PAW hence it took long to dry.

<table>
<thead>
<tr>
<th>Soil Texture</th>
<th>SAP Treatment (%)</th>
<th>Soil WRC coefficients</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>PAW</td>
<td>θₑ</td>
</tr>
<tr>
<td>Clay</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>0.3291</td>
<td>0.9652</td>
</tr>
<tr>
<td>0.2</td>
<td>0.336</td>
<td>0.9787</td>
</tr>
<tr>
<td>0.3</td>
<td>0.5053</td>
<td>1.0329</td>
</tr>
<tr>
<td>0.5</td>
<td>0.6223</td>
<td>1.186</td>
</tr>
<tr>
<td>Sandy clay</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>0.2721</td>
<td>0.8349</td>
</tr>
<tr>
<td>0.2</td>
<td>0.3188</td>
<td>0.8924</td>
</tr>
<tr>
<td>0.3</td>
<td>0.4262</td>
<td>0.9219</td>
</tr>
<tr>
<td>0.5</td>
<td>0.5355</td>
<td>0.9637</td>
</tr>
<tr>
<td>Sandy loam</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>0.1691</td>
<td>0.4307</td>
</tr>
<tr>
<td>0.2</td>
<td>0.1870</td>
<td>0.6641</td>
</tr>
<tr>
<td>0.3</td>
<td>0.2108</td>
<td>0.7007</td>
</tr>
<tr>
<td>0.5</td>
<td>0.3461</td>
<td>0.9914</td>
</tr>
</tbody>
</table>

*PAW- Plant available water
*θₑ- Porosity/ Saturated moisture content
*θₑ- Residual moisture content
*α- Air entry point
*n- Pore index
Porosity/saturated water content ($\theta_s$) in all the soils increased with an increase in SAP per centage. Clay at 0% SAP was 0.9652 and at 0.5% SAP had increased to 1.186. Sandy clay at 0% SAP 0.8349 and at 0.5% SAP increased to 0.9637. Also, sandy loam increased much from 0.4307 at 0% SAP to 0.9914 at 0.5% SAP. The residual water content ($\theta_r$) also experienced the same effect of increase in water retention at residual to the increase in SAP per centage, air entry point ($\alpha$) reduced with the increase in SAP per centage in all the soils and pore index ($n$) index increase with the increase in SAP per centage from 0% to 0.5%. These shows that SAP can help in retaining water within the plants roots and improving water retention in poor water retention soils like sand. This is true and equally appreciated and concurred in that the use of SAP in the soil increases water holding capacity and available water in the soil, therefore irrigation watering interval increases (Kanmi et al., 2008).

The difference in SAP effects in the soil was determined by use of one-way ANOVA as shown from the Table 4.3 of clay, Table 4.4 of sandy clay and Table 4.5 of sandy loam below. The table shows that with analysis in ANOVA, the effect of SAP at different per centages had a difference or effect on soil water retention. Null hypothesis $H_0$: $\mu_0 = \mu_0.2 = \mu_0.3 = \mu_0.5$, described that SWRC of the all the soil textures with SAP is not the same hence statistically different as with the alternate hypothesis of $H_1$: $\mu_0 \neq \mu_0.2 \neq \mu_0.3 \neq \mu_0.5$. 

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### Table 4.3: Clay Soil ANOVA Analysis

<table>
<thead>
<tr>
<th>Soil Texture</th>
<th>SUMMARY</th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Groups</td>
<td>Count</td>
<td>Sum</td>
<td>Average</td>
<td>Variance</td>
</tr>
<tr>
<td>0% SAP</td>
<td>30</td>
<td>17.149</td>
<td></td>
<td>0.571</td>
<td>0.061</td>
</tr>
<tr>
<td>0.2% SAP</td>
<td>30</td>
<td>19.734</td>
<td></td>
<td>0.657</td>
<td>0.038</td>
</tr>
<tr>
<td>0.3% SAP</td>
<td>30</td>
<td>21.731</td>
<td></td>
<td>0.724</td>
<td>0.035</td>
</tr>
<tr>
<td>0.5% SAP</td>
<td>30</td>
<td>27.555</td>
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<td>0.918</td>
<td>0.026</td>
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### ANOVA

<table>
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<tr>
<th>Source of Variation</th>
<th>SS</th>
<th>df</th>
<th>MS</th>
<th>F</th>
<th>P-value</th>
<th>F crit</th>
</tr>
</thead>
<tbody>
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<td>1.958</td>
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<td>0.652</td>
<td>16.152</td>
<td>7.72E-09</td>
<td>2.6828</td>
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<tr>
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<td></td>
<td></td>
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</tr>
</tbody>
</table>

### Remarks
- H₀:μ₀ = μ₀.2 = μ₀.3 = μ₀.5
- H₁: μ₀ ≠ μ₀.2 ≠ μ₀.3 ≠ μ₀.5
- P<0.05 7.72E-09 < 0.05
- F>F crit 16.15 > 2.68
- There is statistically significant difference

### Table 4.4: Sandy Clay Soil ANOVA Analysis

<table>
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<tr>
<th>Soil Texture</th>
<th>Sandy Clay</th>
<th>SUMMARY</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Groups</td>
<td>Count</td>
<td>Sum</td>
<td>Average</td>
<td>Variance</td>
</tr>
<tr>
<td>0% SAP</td>
<td>30</td>
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<td>0.042</td>
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<tr>
<td>0.2% SAP</td>
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<td>17.618</td>
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<td>0.587</td>
<td>0.029</td>
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<tr>
<td>0.3% SAP</td>
<td>30</td>
<td>18.326</td>
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<td>0.610</td>
<td>0.031</td>
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<tr>
<td>0.5% SAP</td>
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<td>0.668</td>
<td>0.028</td>
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</tbody>
</table>

### ANOVA

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>SS</th>
<th>df</th>
<th>MS</th>
<th>F</th>
<th>P-value</th>
<th>F crit</th>
</tr>
</thead>
<tbody>
<tr>
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<td>0.113</td>
<td>3.4994</td>
<td>0.018943</td>
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<tr>
<td>Within Groups</td>
<td>3.826041</td>
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<tr>
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</tr>
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</table>

### Remarks
- H₀: μ₀ = μ₀.2 = μ₀.3 = μ₀.5
- H₁: μ₀ ≠ μ₀.2 ≠ μ₀.3 ≠ μ₀.5
- P<0.05, 0.0189 < 0.05
- F>F crit, 3.45 > 2.68
- There is statistically significant difference
### Table 4.5: Sandy Loam Soil ANOVA Analysis

<table>
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<th>Sandy Loam</th>
<th>SUMMARY</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
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<tr>
<td>0% SAP</td>
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</tr>
<tr>
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<tr>
<td>0.3% SAP</td>
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<tr>
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<td>21.4064</td>
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</table>

### ANOVA

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<th>Source of Variation</th>
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<th>MS</th>
<th>F</th>
<th>P-value</th>
<th>F crit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Between Groups</td>
<td>3.1227</td>
<td>3</td>
<td>1.0409</td>
<td>67.857</td>
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<tr>
<td>Within Groups</td>
<td>1.779</td>
<td>116</td>
<td>0.0153</td>
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<td></td>
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</tr>
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<td>Total</td>
<td>4.902193</td>
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</tbody>
</table>

**Remarks**

H₀: μ₀ = μ₀.2 = μ₀.3 = μ₀.5  
H₁: μ₀ ≠ μ₀.2 ≠ μ₀.3 ≠ μ₀.5  
P < 0.05, 2.06E-25 < 0.05  
F > F crit, 67.86 > 2.68  
There is statistically significant difference

---

![PLANT AVAILABLE WATER AGAINST SAP TREATMENT](image)

**Figure 4.6:** Plant Available Water (PAW) in different SAP percentages
The trend of fine soil is higher than that of coarse soil in Figures 4.6, 4.7 and 4.8 is because fine soil has small particle which increases the surface area of water absorption compared to coarse soil. Figure 4.6 above shows the PAW effect with SAP from 0% to 0.5%. Clay increased steadily to almost 63% compared to 33% at 0% SAP, sandy clay increased also to 54% compared to 27% at 0% SAP and sandy loam increased to 34% compared to 16% at 0% SAP. This shows that with SAP, sandy soils having a lower PAW it can be improved to a point it can hold water for some time in the root zone.

![Graph: Saturated Water Content Against SAP Treatment]

**Figure 4.7: Saturated water content ($\theta_s$) in different SAP per centages**

Figure 4.7 above shows the effect of SAP on water saturation. Clay has natural good saturation hence there is no much effect. Sandy clay also experienced little increase with SAP at 0.5% because of the presence of clay texture in it. Sandy loam soil experience a major effect, twice its original amount with SAP at 0.5% hence shows an improvement in water retention with SAP in sandy soils. The gradient line of sandy loam is higher than
that for clay and sandy clay. It shows that saturation is increasing with increase in SAP content.

Figure 4.8: Residual water content ($\theta_r$) in different SAP percentages

Figure 4.8 above shows the effect of SAP at 0.5% on residual water content. Clay soil residual water content effect is more from 0.3722 at 0% SAP to 0.8115 at 0.5%. Sandy clay soil did experience much effect as it changed from 0.3298 at 0% to 0.5569 at 0.5% SAPs. Sandy loam soil experienced a greater change from 0.1420 at 0% to 0.6526 at 0.5% SAPs. The gradient lines and the equations show the changes well. The effect was evident as it shows how SAP can help in improving water in a poorly retained soil.

For the purposes of retaining water within the plant roots, SAP has been found to be used in agriculture as water holding capacity medium and hence increasing plant available water (Bhat et al., 2009).
Clay and any soil with high clay texture of high percentage like sandy clay soil is good in water absorption and retention. Due to water shortage in the world, some methods of water minimisation such as drip irrigation and use of synthetic substances like SAP in water retention, have been used to retain water for a longer period in the soil (Jones, 2004). SAP in clay and sandy clay soils had a slight increase in water retention and also increased the PAW slightly. Sandy loam soil had the lowest PAW compared to clay and sandy clay soils at 0.1691 at 0% SAP increased to 0.3461 with SAP at 0.5%. This showed that SAP improves the water retention in soils with poor water retention like sandy loam and hence can be used in improving the retention in areas with poor water holding capacity. Again, increasing PAW, $\theta_0$, $\theta_1$ and $n$ but reducing $a$ and hence the synthetic substance affects the SWRC positively.

4.2 Discussion

4.1.3 Water Retention of Different Soil textures

With the use of hydrometer method of classification and with the help of a USDA soil textural triangle, the soils were found to be sandy loam, sandy clay and clay soils.

Water retention in different soils textures, showed that clay has a higher water retention with a saturation of 0.9 moisture content, then sandy clay at 0.85 moisture content and the lowest being sandy loam with moisture content at saturation of 0.43. This is evident from soil water retention curve (SWRC) produced in Figure 4.1 and 4.2. This was at the natural state of soil or soil without SAP (0%). The soil water retention model after fitted with Gardner model it produced a residual standard error less than 4% and coefficient of determination of ($r^2$).
4.1.4  Effects of SAP on Water Retention of different soil textural classes

When synthetic substance like super absorbent polymer (SAP) was added into soil, then its effect on SWRC properties was identified. The effect of SAP in the soil was realised when soil was mixed with SAP in proportions of 0%, 0.2%, 0.3% and 0.5% to the mass weight of soil. When SAP was added, water retention improved in all the soils. At 0.2% SAP it increased little, then at 0.3% SAP increased further and lastly at 0.5% SAP it reached maximum with respect to the size of core ring used. This showed water absorption and retention increases with increase in SAP in the soil. Clay soil had a better water retention property and was boosted with the presence of SAP which absorbed water up to 500 times its original size. Sandy clay soils water retention was further improved with an increase in SAP per cent. Sandy loam was also improved like clay and sandy clay but since it has lower water retention it did not increase much but an effect was felt to around 35%. This is shown from the SWRC of the soil. The difference in SWRC properties between 0% SAP and SAP presence in different proportions was seen in Figure 4.4 and 4.5.

Plant available water (PAW) is different in different soil types. Clay soil has higher PAW at 32.91% then sandy clay at 27.21% and lowest is sandy loam at 16.91%. With SAP, the PAW increased in all the soils as shown in Table 4.2 above. In clay it increased to 62.23% at 0.5% SAP, 53.55% in sandy clay soil at 0.5% SAP and 34.61% in sandy loam soil at 0.5% SAP. Other coefficients of WRC were also affected with the presence of SAP in the soil. $\theta_0$, $\theta_c$, and $n$ parameters increased with an increase in SAP per cent but reduced in $\alpha$ with SAP per cent.
ANOVA as a statistical analysis to determine the difference in the amount of SAP in the soil textures by use of SAP, showed that there exists a difference. This clearly proved why the SWRC properties changed with an increase the amount of SAP.

With the help of Gardner model in fitting the SWRC, a higher fit was found with coefficient of determination ($r^2$) greater than 98% and residual standard error (RSE) less than 4%. These has been summarised from Table 4.6 below.

<table>
<thead>
<tr>
<th>SAP%</th>
<th>Soil Type</th>
<th>$R^2$</th>
<th>RSE</th>
</tr>
</thead>
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<td>0</td>
<td>Clay</td>
<td>0.977</td>
<td>0.0478</td>
</tr>
<tr>
<td></td>
<td>Sandy Clay</td>
<td>0.968</td>
<td>0.0463</td>
</tr>
<tr>
<td></td>
<td>Sandy Loam</td>
<td>0.970</td>
<td>0.0247</td>
</tr>
<tr>
<td>0.2</td>
<td>Clay</td>
<td>0.996</td>
<td>0.0159</td>
</tr>
<tr>
<td></td>
<td>Sandy Clay</td>
<td>0.997</td>
<td>0.0125</td>
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<tr>
<td></td>
<td>Sandy Loam</td>
<td>0.975</td>
<td>0.2380</td>
</tr>
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<td>0.3</td>
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<tr>
<td></td>
<td>Sandy Clay</td>
<td>0.996</td>
<td>0.0135</td>
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<tr>
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<td>Sandy Loam</td>
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<tr>
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</tr>
<tr>
<td></td>
<td>Sandy Clay</td>
<td>0.994</td>
<td>0.0159</td>
</tr>
<tr>
<td></td>
<td>Sandy Loam</td>
<td>0.997</td>
<td>0.0109</td>
</tr>
</tbody>
</table>

The difference in WRC coefficients between original and treated soils was assessed at 5% level of significance to establish whether there was a significant effect in coefficients due to treatment with SAP and it was found that there was a significant difference. This is also corroborated by the ANOVA results in Table 4.3, 4.4 and 4.5.
5.0 ACONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

I. The objective of this research study was attained since the effect of SAP on SWRC on different soil texture was established. SWRC of clay, sandy clay and sandy loam were determined. Clay had a higher SWRC with its respective coefficients then followed by sandy clay and the least being sandy loam soil. These signified that water retention in clay soil is good compared to sandy and loamy soils.

II. When a synthetic substance such as SAP is added into the soil, it increases water retention. In this research study clay soil retained water more when SAP was added and increased with the increase in the amount of SAP. Sandy clay soil also increased steadily with SAP but not as much as clay soil. Sandy loam had its water retention improved with SAP. The retention increased with an increase in the percentage of SAP from 0.2%, then 0.3% and lastly 0.5%. SAP increases the water retention in all soil textures but also depends on its natural state of water retention.

WRC coefficients i.e. PAW, θs, θr, n and α were affected with per centages of SAP in the soil and hence change in WRC. This shows that SAP can be used to retain water within the plant roots for a longer period than when there is no SAP within the soil.

III. Poor water retention soil textures like sand or soils with higher sand per centages have low PAW. Addition of synthetic substances like SAP brings about an increase in water retention, hence increasing its PAW. This shows that SAP can be used for improvement of water retention in such kind of soil textures.
5.2 Recommendations

The following are the recommendations to be looked at:

i). A number of soil textural classes should be tested with different types of SAP

ii). Plant Available Water of different soils textural classes to be determined in different types of Super Absorbent Polymers (SAP).6
REFERENCES


Rohaya, Rasmin (2011) *Comparison between sieve analysis & hydrometer with laser particle analyzer to determine particle size distribution*. Faculty of Civil & Environmental Engineering, Universiti Malaysia Pahang.


Vijayalakshmi M, Nemichand Rappa K, Sreenivusreddy and Ayyanagowdar M.S. (2012). Effects of polymers on moisture retention and soil water holding capacity. College of Agricultural Engineering, Raichur (India)


APPENDICES

Appendix 1: Soil Textural Triangle (USDA)
## Appendix 2: Soil Moisture Data

<table>
<thead>
<tr>
<th>No</th>
<th>Sample</th>
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<th>Moisture</th>
<th>SAP</th>
<th>x</th>
<th>y</th>
<th>ID</th>
<th>Soils</th>
<th>Choise</th>
<th>Nos</th>
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| 294 | 112 | 1.5 | 37.54 | 0.2 | 15.2985 | 0.3754 | SandyLoam1120.2 | Sandy/oam | 119 | 30 |
| 295 | 112 | 1.8 | 37.41 | 0.2 | 18.3582 | 0.3741 | SandyLoam1120.2 | Sandy/oam | 155 | 30 |
| 296 | 112 | 2   | 37.33 | 0.2 | 20.398 | 0.3733 | SandyLoam1120.2 | Sandy/oam | 191 | 30 |
| 297 | 112 | 3   | 36.63 | 0.2 | 30.597 | 0.3663 | SandyLoam1120.2 | Sandy/oam | 227 | 30 |
| 298 | 112 | 5   | 36.37 | 0.2 | 50.995 | 0.3637 | SandyLoam1120.2 | Sandy/oam | 263 | 30 |
| 299 | 112 | 10  | 36.15 | 0.2 | 101.99 | 0.3615 | SandyLoam1120.2 | Sandy/oam | 299 | 30 |
| 300 | 112 | 15  | 34.44 | 0.2 | 152.985 | 0.3444 | SandyLoam1120.2 | Sandy/oam | 335 | 30 |
| 301 | 112 | 0   | 65.2  | 0.3 | 0.01  | 0.652  | SandyLoam1120.3 | Sandy/oam | 20 | 31 |
| 302 | 112 | 0.4 | 63.96 | 0.3 | 4.0796 | 0.6396 | SandyLoam1120.3 | Sandy/oam | 56 | 31 |
| 303 | 112 | 1   | 56.61 | 0.3 | 10.199 | 0.5661 | SandyLoam1120.3 | Sandy/oam | 92 | 31 |
| 304 | 112 | 1.5 | 42.54 | 0.3 | 15.2985 | 0.4254 | SandyLoam1120.3 | Sandy/oam | 128 | 31 |
| 305 | 112 | 1.8 | 42.63 | 0.3 | 18.3582 | 0.4263 | SandyLoam1120.3 | Sandy/oam | 164 | 31 |
| 306 | 112 | 2   | 42.62 | 0.3 | 20.398 | 0.4262 | SandyLoam1120.3 | Sandy/oam | 200 | 31 |
| 307 | 112 | 3   | 42.32 | 0.3 | 30.597 | 0.4232 | SandyLoam1120.3 | Sandy/oam | 236 | 31 |
| 308 | 112 | 5   | 41.97 | 0.3 | 50.995 | 0.4197 | SandyLoam1120.3 | Sandy/oam | 272 | 31 |
| 309 | 112 | 10  | 41.78 | 0.3 | 101.99 | 0.4178 | SandyLoam1120.3 | Sandy/oam | 308 | 31 |
| 310 | 112 | 15  | 40.46 | 0.3 | 152.985 | 0.4046 | SandyLoam1120.3 | Sandy/oam | 344 | 31 |
| 311 | 112 | 0   | 101.65| 0.5 | 0.01  | 0.10165| Sandyloam1120.5 | Sandy/oam | 29 | 32 |
| 312 | 112 | 0.4 | 101.19| 0.5 | 4.0796 | 0.1019 | Sandyloam1120.5 | Sandy/oam | 65 | 32 |
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| 314 | 112 | 1.5 | 73.75 | 0.5 | 15.2985 | 0.7375 | Sandyloam1120.5 | Sandy/oam | 137 | 32 |
| 315 | 112 | 1.8 | 72.98 | 0.5 | 18.3582 | 0.7298 | Sandyloam1120.5 | Sandy/oam | 173 | 32 |
| 316 | 112 | 2   | 71.82 | 0.5 | 20.398 | 0.7182 | Sandyloam1120.5 | Sandy/oam | 209 | 32 |
| 317 | 112 | 3   | 70.8  | 0.5 | 30.597 | 0.708  | Sandyloam1120.5 | Sandy/oam | 245 | 32 |
| 318 | 112 | 5   | 70.39 | 0.5 | 50.995 | 0.7039 | Sandyloam1120.5 | Sandy/oam | 281 | 32 |
| 319 | 112 | 10  | 69.92 | 0.5 | 101.99 | 0.6992 | Sandyloam1120.5 | Sandy/oam | 317 | 32 |
| 320 | 112 | 15  | 67.51 | 0.5 | 152.985 | 0.6751 | Sandyloam1120.5 | Sandy/oam | 353 | 32 |
| 321 | 113 | 0   | 42.82 | 0   | 0.01  | 0.4282 | Sandyloam1130 | Sandy/oam | 3  | 33 |
| 322 | 113 | 0.4 | 41.43 | 0   | 4.0796 | 0.4143 | Sandyloam1130 | Sandy/oam | 39 | 33 |
| 323 | 113 | 1   | 38.93 | 0   | 10.199 | 0.3893 | Sandyloam1130 | Sandy/oam | 75 | 33 |
| 324 | 113 | 1.5 | 27.08 | 0   | 15.2985 | 0.2708 | Sandyloam1130 | Sandy/oam | 111 | 33 |
| 325 | 113 | 1.8 | 25.18 | 0   | 18.3582 | 0.2518 | Sandyloam1130 | Sandy/oam | 147 | 33 |
| 326 | 113 | 2   | 25.36 | 0   | 20.398 | 0.2536 | Sandyloam1130 | Sandy/oam | 183 | 33 |
| 327 | 113 | 3   | 17.35 | 0   | 30.597 | 0.1735 | Sandyloam1130 | Sandy/oam | 219 | 33 |
| 328 | 113 | 5   | 15.48 | 0   | 50.995 | 0.1548 | Sandyloam1130 | Sandy/oam | 255 | 33 |
| 329 | 113 | 10  | 15.16 | 0   | 101.99 | 0.1516 | Sandyloam1130 | Sandy/oam | 291 | 33 |
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| 331 | 113 | 0   | 67.29 | 0.2 | 0.01  | 0.6729 | Sandyloam1130.2 | Sandy/oam | 22 | 34 |
| 332 | 113 | 0.4 | 66.71 | 0.2 | 4.0796 | 0.6671 | Sandyloam1130.2 | Sandy/oam | 48 | 34 |
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Appendix 3: R Coding

```r
#step1:get the libraries
library(nine)
library(minpack.lm)
library(HydroMe)

#step2:import data and export
data2=read.table("Final sept 2016.txt",header = T)
str(data2)
data=subset(data2, SAP=="0")
data

plot(data2$Sy~data2$Sx,main="Moisture content vs Suction Potential of All Soil(SAP=0-0.5)",
xlab="suction potential (cm)" ,ylab="moisture content (cm^-3-cm^-3)",
cex.main = "0.9", col.main = "blue", cex.lab = "0.8",
col=factor(data2$SAP), pch=18:22, cex.lab = "0.8", col.lab = "black")
legend("topright", legend = levels(factor(data2$SAP)),title="SAP", col = c(1:4), pch = 18:22,hori = TRUE).

#step3:fit the wr model
gard.is=nlsList(y~SSgardi(x,thr,ths,alp,scal) | Nos, data2, control=nls.lm.control(maxiter = 200))
gard.is

plot(predicted(gard.is))

plot(predicted(gard.is)~data2$Sy,ylab="Measured",xlab="Predicted",main="Measured vs Predicted Water Retention data at SAP 0-0.5",col="3", cex.main = 1, pch=18, cex.lab = 0.8)
cor(predicted(gard.is),data2$Sy)^2#R squared
abline(lm(predicted(gard.is)~data2$Sy))

- Using ggplot

title: "Soil Data"
author: "Vincent"
date: "October 17, 2016"
output: html_document
```
# load required library
library(ggplot2)

```
Load the data
```
```
kab<-read.csv("kabete.csv")
head(kab)
```

```
## Trellis plot with your data
Here is the Trellis graph of suction potential by moisture content for the different soil types.
```
```
ggplot(data=kab,Soils,mapping= aes(x=x,y=y, shape=factor(Soils), color=factor(Soils)))+
  geom_point()+
  scale_x_log10()+
  facet_wrap(~SAP)+
  geom_smooth(se=FALSE)+
  theme_bw()+
  labs(x="Suction Potential(log)",y= expression(paste("Moisture Content", (cm^3/cm^3))))
```

```
## Trellis plot
Here is the Trellis graph of suction potential by moisture content for the different soil types.
```
```
ggplot(data=kab,SAP,
shape=factor(SAP),color=factor(SAP)))+
  geom_point()+
  scale_x_log10()+
  facet_wrap(~Soils)+
  geom_smooth(se=FALSE, span=0.65)+
  theme_bw()+
  labs(x="Suction Potential(log)",y= expression(paste("Moisture Content", (cm^3/cm^3))))
```
```
Appendix 4: Results from R

```r
> # step1: get the libraries
> library(lme4)
> library(minpack.lm)
> library(hydroMe)
>
> # step2: import data and export
data2=read.table("Final sept 2016.txt", header =T)
>
> str(data2)
' data.frame': 360 obs. of 11 variables:
  $ No     : int  1 2 3 4 5 6 7 8 9 10 ...
  $ Sampl : int 121 121 121 121 121 121 121 121 121 121 ...
  $ pressure: num 0.4 1.5 1.8 2.3 5 10 15 ...
  $ Moisture: num 95.4 94.1 88.5 49.7 48.6 ...
  $ SAP    : num 0 0 0 0 0 0 0 0 0 0 ...
  $ x      : num 0.01 4.08 10.2 15.3 18.36 ...
  $ y      : num 0.954 0.941 0.885 0.497 0.486 ...
  $ ID     : Factor w/ 36 levels "Clay1210", "Clay1210.2", ..., 11 1 1 1 1 1 1 1 ...
  $ Soil   : Factor w/ 3 levels "Clay", "SandyClay", ..., 1 1 1 1 1 1 1 1 ...
  $ Choice : int 4 40 76 112 148 184 220 256 292 328 ...
  $ Nos    : int 1 1 1 1 1 1 1 1 1 ...
>
> data=data subset(data2, ID=="Sample")
>
> data2
No  Sampl pressure Moisture SAP  x  y  ID soils Choice
1   1  121   0.00  95.39 0.00 0.0100 0.9539 Clay1210 Clay   4
2   2  121   0.40  94.08 0.00 4.0796 0.9408 Clay1210 Clay   40
3   3  121  1.00  98.46 0.00 10.1990 0.8846 Clay1210 Clay   76
4   4  121  1.50  49.66 0.00 15.2985 0.4966 Clay1210 Clay   112
5   5  121  1.80  48.57 0.00 18.3582 0.4857 Clay1210 Clay   148
6   6  121  2.00  48.91 0.00 20.3980 0.4891 Clay1210 Clay   184
7   7  121  3.00  38.22 0.00 30.5970 0.3822 Clay1210 Clay   220
8   8  121  5.00  36.41 0.00 50.9950 0.3641 Clay1210 Clay   256
9   9  121 10.00  35.22 0.00 101.9900 0.3522 Clay1210 Clay   297
10 10 121  15.00  31.84 0.00 152.9850 0.3184 Clay1210 Clay   328
11 11 121  0.00  100.67 0.00 0.0100 1.0067 Clay1210.2 Clay   13
12 12 121  0.40  98.91 0.00 4.0796 0.9891 Clay1210.2 Clay   49
13 13 121  1.00  91.95 0.00 10.1990 0.9195 Clay1210.2 Clay   85
14 14 121  1.50  56.83 0.00 15.2985 0.5683 Clay1210.2 Clay   121
15 15 121  1.80  56.69 0.00 18.3582 0.5669 Clay1210.2 Clay   157
16 16 121  2.00  55.60 0.00 20.3980 0.5560 Clay1210.2 Clay   193
17 17 121  3.00  53.55 0.00 30.5970 0.5355 Clay1210.2 Clay   229
18 18 121  5.00  52.89 0.00 50.9950 0.5289 Clay1210.2 Clay   265
19 19 121 10.00  52.75 0.00 101.9900 0.5275 Clay1210.2 Clay   301
20 20 121 15.00  50.41 0.00 152.9850 0.5041 Clay1210.2 Clay   337
21 21 121  0.00 100.17 0.00 0.0100 1.0017 Clay1210.3 Clay   22
22 22 121  0.40  98.92 0.00 4.0796 0.9892 Clay1210.3 Clay   58
23 23 121  1.00  91.95 0.00 10.1990 0.9195 Clay1210.3 Clay   94
24 24 121  1.50  59.47 0.00 15.2985 0.5947 Clay1210.3 Clay  130
25 25 121  1.80  58.96 0.00 18.3582 0.5896 Clay1210.3 Clay  166
26 26 121  2.00  59.52 0.00 20.3980 0.5952 Clay1210.3 Clay  202
27 27 121  3.00  59.04 0.00 30.5970 0.5904 Clay1210.3 Clay  238
28 28 121  5.00  57.53 0.00 50.9950 0.5753 Clay1210.3 Clay  274
29 29 121 10.00  57.10 0.00 101.9900 0.5710 Clay1210.3 Clay  310
30 30 121 15.00  52.39 0.00 152.9850 0.5239 Clay1210.3 Clay  346
31 31 121  0.00 121.72 0.00 0.0100 1.2172 Clay1210.5 Clay   31
32 32 121  0.40 121.56 0.00 4.0796 1.2156 Clay1210.5 Clay   67
33 33 121  1.00 109.90 0.00 10.1990 1.0990 Clay1210.5 Clay   103
34 34 121  1.50  86.74 0.00 15.2985 0.8674 Clay1210.5 Clay   139
35 35 121  1.80  86.44 0.00 18.3582 0.8644 Clay1210.5 Clay   175
36 36 121  2.00  86.07 0.00 20.3980 0.8607 Clay1210.5 Clay   211
37 37 121  3.00  85.82 0.00 30.5970 0.8582 Clay1210.5 Clay   247
38 38 121  5.00  85.82 0.00 50.9950 0.8582 Clay1210.5 Clay   283
39 39 121 10.00  84.35 0.00 101.9900 0.8435 Clay1210.5 Clay   319
40 40 121 15.00  83.35 0.00 152.9850 0.8335 Clay1210.5 Clay   353

80
N0s
> plot(data2$y-data2$x,main="Moisture content vs Suction Potential of All Soil\(\text{SAP}=0.5\)")
+ xlab=suction-potential\((\text{cm})\),ylab=moisture-content\((\text{cm}$^3$-cm$^{-1}$-3),
+ col.main="blue",cex.lab="0.8",
+ col=factor(data2$SAP),pch=18:22,cex.lab="0.8",col.lab="black")
> legend("topright",legend = levels(factor(data2$SAP)),title="SAP",col = c(1:4), pc = 18:22,horiz=TRUE)
>
#step3:Fit the wrc model
> gard.lis=nlsList(y=SSgard(x,thr,ths,alp,scal)|N0s,data2, control=nls.lm.control(max ter = 200))
> gard.lis

Call:
Model: y \sim SSGard(x, thr, ths, alp, scal) | N0s
Data: data2

Coefficients:
thr
ths
alp
cal
1 0.3616450 0.9577679 1.420219e-06 5.174150
2 0.5311504 0.9984619 7.009460e-11 9.393815
3 0.5726885 0.9957072 9.872245e-12 10.264703
4 0.8517269 1.2164902 4.904085e-10 8.912657
5 0.3688409 0.9537400 4.231387e-07 5.667696
6 0.5295412 0.9711737 1.179888e-10 9.306017
7 0.6177164 1.0653004 3.626547e-11 9.681460
8 0.8084801 1.1935322 2.473110e-13 11.658880
9 0.3680932 0.9841849 6.363910e-07 5.564805
10 0.5174726 0.9663192 7.191725e-12 10.382099
11 0.6102571 1.0379852 9.195839e-08 7.671179
12 0.7742629 1.1483281 1.302763e-06 5.602607
13 0.3205046 0.8112147 9.961806e-05 3.368962
14 0.4823244 0.9115306 9.638995e-06 5.005897
15 0.4956457 0.9444136 4.662887e-09 8.044318
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18 0.4746361 0.9024799 1.365917e-06 5.869940
19 0.4713026 0.9020804 8.438047e-09 7.855901
20 0.5689467 0.9521561 1.101259e-07 6.687401
21 0.3347703 0.8517448 2.324035e-06 4.945722
22 0.4625815 0.8623069 2.251628e-12 10.813529
23 0.5208755 0.9193366 6.091821e-09 7.850738
24 0.5320299 0.9480814 6.182239e-08 7.003479
25 0.1271970 0.4321810 9.662650e-05 3.336614
26 0.3250795 0.7269020 1.568229e-02 1.613921
27 0.4744386 0.7750758 2.609251e-09 8.291712
28 0.5594840 0.9443632 2.471721e-05 4.581264
29 0.1673622 0.4318680 1.402803e-04 3.332027
30 0.3616421 0.5937281 3.057240e-08 7.221699
31 0.4188324 0.6458433 2.067465e-10 9.339529
32 0.6991877 1.0149670 3.370346e-07 6.078213
33 0.1331338 0.4279971 3.758717e-04 2.812658
34 0.3785070 0.6716025 9.023167e-06 4.982532
35 0.4256972 0.6810805 2.500563e-08 7.383192
36 0.6085577 0.8911741 2.209303e-09 8.292204

Degrees of freedom: 360 total; 216 residual
Residual standard error: 0.02476519

> plot(predicted(gard.lis))
> plot(predicted(gard.lis)-data2$y,ylab="Measured",xlab="Predicted",main="Measured vs Predicted Water Retention data at SAP=0-0.5",col=3,cex.main = 1,pch=18,cex.lab=0.8)
> cor(predicted(gard.lis),data2$y)^2=# squared [1] 0.9930201
> abline(lm(predicted(gard.lis)-data2$y))

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