EFFECTS OF HYDROGELS ON SOIL MOISTURE, NUTRIENTS AND GROWTH OF SOME AGROFORESTRY TREES IN WEST POKOT COUNTY, KENYA

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DECLARATION

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DEDICATION

This work is dedicated to my father Mr. Elijah C. Birir, my wife (Gillian), my son (Kiprop) and our entire family members for their inspiration and financial support.

ABSTRACT

Studies on the effects of hydrogels on soil amendments, moisture conservation, nutrients release, availability and growth of *Sesbania sesban, Cajanus cajan* and *Leucaena pallida* in arid and semi-arid lands (ASALs) was carried out. Hydrogels are hydrophilic in nature and highly absorbent to water molecules. This property helps to establish seedlings in ASALs. The effects of hydrogels on the growth of seedlings, nutrients and amount of moisture released have not yet studied and documented. The study was carried out in Kongelai in West Pokot County. Seedlings of *S. sesban, C. cajan* and *L. pallida* were established both in the nursery and in the field with and without hydrogels. Field experiment was carried out in split plot design under hedgerow intercropping system with three replications and three concentration hydrogels levels (7g, 11g and 15g) and control seedlings established in soils without hydrogels. In the nursery, root collar diameter and heights for each seedlings were measured every two weeks upto eight weeks. Seedlings established without hydrogels in the nursery were transplanted into field soils with none, 7g, 11g and 15g level of hydrogels. Root collar diameter and height were again measured every month for three months. In addition, soil was collected randomly once every month from the base of each seedling and analyzed for soil moisture and nutrient content using standard laboratory procedures. All data were subjected to analysis of variance using Analysis Toolpak. Results show that there was a significant difference in the height and RCD among the three species and at different level of hydrogels $F_{\text{calculated (0.05)}} = 10.3431 > F_{\text{tabular (critical)}}$ 3.4903. This suggests that use of hydrogels in the nursery soils retards plant growth but improves growth in the field. Hydrogels increased soil moisture volume from 5.7, 8.3 and 5.3% to 11.7, 13 and 10% in H_{15g} level of hydrogels in *S. sesban, C. cajan* and *L. pallida* respectively after transplanting. Analysis of variance of nutrients release into the soil shows that $F_{\text{calculated (0.05)}} = 5.4270 > F_{\text{tabular (critical)}}$ 2.9011 implying that hydrogels has an effect on the nutrients. Nutrient increased from 0.95, 0.07 and 0.12% in the pre-test analysis to 4.48, 3.81 and 0.42% after analysis in potassium, nitrogen and phosphorus respectively in the soil after transplanting. It was concluded that hydrogels does not contribute to growth of seedlings in the nursery but it does so after transplanting. Hydrogels increase soil moisture and nutrients in the soil therefore recommended for use in semi arid lands to boost the survival and growth of seedlings. Hydrogels level at 15g is highly recommended to be used in the transplanted seedlings in ASALs

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LIST OF ABBREVIATIONS

ASALs - Arid and Semi Arid Lands

CBO’s – Community Based Organization

Cm – Centimeters

FAO – Food and Agriculture Organization

G – Grams

GoK – Government of Kenya

H – Height

IFS – Integrated Farming System

IPCC – Intergovernmental Panel on Climate Change

K - Potassium

Kg – Kilogram’s

KEFRI – Kenya Forestry Research Institute

KFS – Kenya Forest Service

KVDA – Kerio Valley Development Authority

L – Litres

LSD - Least Significant Difference

M – Meters

Mg - Milligram’s

Mm – Millimeters

N – Nitrogen

NGO’s – Non Governmental Organization

nm – micrometers

P – Phosphorus

pH – Potential of Hydrogen

Ppm – Part per million

RCD – Root Collar Diameter

USDA – United States Department of Agriculture

Ca^{2+} - calcium ions

Cl^{-} - Chlorine ion

Na^{+} - Sodium ions

H_0 – Null Hypothesis

^{0}C – Degrees Celsius

% - Percentage

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CHAPTER ONE

INTRODUCTION

1.1 Background

Kenya is a developing country striving to achieve vision 2030 (Muchiri *et al*., 2009). Forest cover in the country currently stands at 6.1% below the internationally accepted minimum of 10% (FAO, 2010). One way of achieving vision 2030 is to support development of forestry practices to increase forest cover towards the required minimum percentage and to improve the livelihoods of people living in arid and semi arid lands (ASALs) through introduction of appropriate agroforestry technologies and practices to mitigate aridity (Okorie, 2003). Based on moisture availability for plant growth, Kenya is classified as 88% ASAL supporting a population of over 10 million many of whom are pastoralists and agro-pastoralists (GoK, 2010a). Arid and Semi-arid Lands are water deficient and unable to support primary production and nutrient cycling for agroforestry (Ajayi, 2007; Endrias *et al.,* 2013). In addition, crop production is limited while the rangeland supports cattle, sheep, goats and camels (Muchiri *et al*., 2009). Indeed ASAL areas are characterized by irregularities and shortages of rainfall, prolonged dry seasons, high temperatures and high evapotranspiration rates (Muchiri *et al*., 2009). Such climatic characteristics make ASALs fragile and prone to land degradation, desertification and severe soil water deficits and probably loss of valuable top soil (through erosion) leading to depletion of nutrients. This is reported to induce stress on plants, animals and human population (Lal, 2004).

Despite their high development potential, ASALs have the lowest development indicators and the highest poverty incidences amongst all areas in Kenya. More than 60 percent of ASALs inhabitants live in conditions of abject poverty (Okorie, 2003). Indeed, poverty level in West Pokot County is 68.5% (Pratt, 1999; Yazan *et al.*, 2012). This is associated with lack of a clear understanding by both policy makers and practitioners, about their ecological uniqueness (FAO, 2007b). In the past ASAL development plans were biased towards the cultivation of crops which inevitably failed hence the region was perceived as unproductive (IPCC, 2008). Although aridity is a major contributory factor to the special development challenges, innovative technologies can put Kenya's arid regions into other land uses (FAO, 2007a).

Agroforestry, a sustainable land use system and optimal production of any agroforestry practice, is influenced by the combination of tree and agricultural crops, amount of soil nutrients, moisture conditions and rate of organic matter decomposition (Bruno *et al.,* 2013). One of the main tenets of agroforestry tree species is its ability to maintain soil fertility. This hypothesis is based partially on the efficient transfer of nutrients from litter of trees to intercropped plants (Christopher *et al.,* 2013). Similarly, moisture retention in the soil is fundamental in the growth of agroforestry tree species. Soil water affects plant growth directly because it influences aeration, temperature, nutrient transport, uptake and transformation. Under unfavorable conditions of ASALs, seedling mortality rates are expected to be low following transplanting. It is therefore important to increase the water holding capacity of the growing media of tree seedlings in the nursery and during early establishment in the field through use of soil modifying agents such as hydrogels (Zhongkui *et al.,* 2011).

Hydrogels are networks of polymer chains that are hydrophilic and highly absorbent to water molecules (Abedi-Koupai *et al.,* 2008). The relative effectiveness of the hydrophilic polymers depend upon the chemical properties, such as molecular weight. The hydrophilic polymer properties tend to have differing effects on various soil properties. The addition of hydrogels to soil can improve not only its water holding capacity, but also the supply of plant available nutrients. It has a potential to influence infiltration rates, bulk density, soil structure, compaction, soil texture, aggregate stability, crust hardness and evaporation rates. Specht and Harvey-Jones (2000) found that less drought tolerant tree species had a much more favorable response to the incorporation of hydrogels. Hydrogels usually have some effects on plant establishment, with the greatest benefit for hydrophilic plants planted in drier conditions where the lack of water availability could be attributed to the amounts of soluble salts in the medium (Sabine *et al.,* 2013). The amount of soil water is usually measured in terms of percentage by volume or mass or as soil water potential (Glaser, 2013). Hydrogels amend soil relation to increase its water holding capacity, decrease evapotranspiration and allow plants to mitigate drought stress (Leciejewski *et al.,* 2008; Bartnik, 2008). This innovative method is known to be easy, cheap and ecological desirable hence are used commonly in horticulture and agriculture, where they precipitate growth, rooting and leafing of many species cultivated around the world. Hydrogels have been found to improve nutrients into the soil. According to Saha *et al*., (2013) massive losses of soil carbon, nitrogen (N), phosphorus (P), potassium (K), calcium, magnesium, manganese and zinc due to aridity will result in poor crop yields and trees establishment in arid environments and the reduction in soil fertility would consequently prevent sustained agricultural production.

Hydrogels application contributes to addition of nutrients into the soil hence influencing crop productivity and growth (Kelly, 2012).

1.2 Problem statement

The potential and sustainability of agroforestry practices in the ASALs of Kenya are severely limited due to low and unreliable rains that lead to low soil water and nutrient availability and restricted plant growth and development (Yazan *et al.*, 2012). Water shortages for the growth of plants in ASALs are becoming an international issue and unfortunately it seems that rapid growth of population has led to technological innovation potentials (Genhua and Denise, 2006; Luo *et al.,* 2011). This is further distressed by inappropriate and ineffective water conservation technologies for trees establishment and growth (Endrias *et al.,* 2013). In order to improve food security in arid regions, appropriate technologies should be identified to boost the growth of plants. The use of hydrogels is reported to improve the water holding capacity of the soil and reduce post planting stress (Valdecantos *et al.,* 2006). The hydrophilic networks of the hydrogels are highly absorbent to water molecules and have been found to absorb water and nutrients and facilitate their absorption by plant roots and shoots during periods of water stress (Landis and Haase, 2012). Hydrogels induce mechanisms for drought resistance and ensure seedlings survival to aid plant establishment and growth in dry soils by increasing the water holding capacity of amended media (Vallejo *et al.*, 2006). However, the effectiveness of hydrogels on soil water conservation, nutrient release and growth of agroforestry tree species in the ASALs of Kenya has not been well studied and documented.

This study therefore investigated the effects of hydrogels on soil water availability and nutrient release by monitoring the growth of *Sesbania sesban, Cajanus cajan* and *Leucaena pallida* seedlings in the nursery and during their early establishment in the arid and semi arid lands of Kongelai, West Pokot County in Kenya.

1.3 Justification and significance of the study

The challenge for agriculture over the coming decades will be to meet the world's increasing demand for food in a sustainable way therefore appropriate technology is required to mitigate aridity and to improve food production. In order to reduce levels of poverty in ASAL areas, it is necessary to increase agricultural production both through irrigated agriculture and development of appropriate agroforestry technologies for soil water and nutrient management (Yazan *et al.*, 2012). Informed use of hydrogels in these areas is likely to improve soil water and nutrient relations, crop and tree growth and local community livelihoods. Furthermore, improved tree establishment, survival and growth in agroforestry practices will lead to improved vegetation cover, better management and conservation of tree based resources in these areas (Endrias *et al.,* 2013). Land degradation and decline in soil fertility have become serious threats to agricultural productivity in Sub-Saharan Africa (Endrias *et al.,* 2013). The use of hydrogels has been considered crucial to boost crop productivity since soils in most of the Sub-Saharan Africa have inherently low fertility and nutrients. Declining soil fertility and soil moisture in these regions is a problem (Amel and Sirelkhatim, 2012).

Kongelai area is characterized by arid and semi arid climate, which currently is not supporting any sustainable agriculture due to low soil fertility and moisture content. A technology to conserve soil moisture and nutrients in the soil should be identified (Desertification, 2006; Raja *et al.,* 2013). Questions concerning desertification are widely discussed because as much as 60 percent of agricultural soils in non-humid areas in the world are affected by desertification (Srapatka *et al.,* 2002; Endrias *et al.,* 2013). Soils in some parts of Kongelai are deficient in soil nitrogen (N), phosphorus (P), or both (Sanchez and Logan, 1992). Many of these soils are acid, infertile, and cannot support sustainable crop production without external inputs of inorganic fertilizers. It is also characterized by low moisture content, nutrient status and high temperatures (Friedel, 2000). In addition to this, arid and semi arid environments have irregular and unpredictable character of the rainfall determines the agricultural production. This has led to a challenge in the establishment and growth of plants due to low organic matter content (Chen *et al.,* 2010). Some soils which were once fertile have become depleted of nutrients and can no longer sustain crop production (Christopher, 2013). Small scale farmers in the Kongelai have limited access to inorganic fertilizers due to high costs. In these situations, agroforestry practices and technological innovation are considered to be viable and sustainable land use alternatives (Zhongkui *et al.,* 2011).

Despite successful application of hydrogels to manage availability of soil moisture and nutrients, and improve tree planting in agroforestry and other systems in other regions of the world, its potential for agroforestry practices in the ASALs of Kenya has not been studied and documented and therefore remains inconclusive. Integrated plant nutrient supply with hydrogels in the soil will results in higher crop productivity under intensive cropping systems in ASALs (Saha *et al.,* 2012; Endrias *et al.,* 2013).

1.4 Objectives of the study

1.4.1 General objective

The main objective of this research was to improve soil moisture availability, soil nutrient release and growth of newly planted agroforestry tree species in ASALs using conventional hydrogel amendments.

1.4.2 Specific objectives

1. To determine growth based on measurements of the root collar diameters and heights of *Sesbania sesban, Cajanus Cajan* and *Leucaena pallida* seedlings established using hydrogels in the nursery and in the field.
2. To determine the amount of soil moisture held by hydrogels after transplanting of agroforestry tree seedlings in the field.
3. To characterize major nutrients and the amounts released by hydrogels into the soil under different agroforestry tree species

1.5 Hypotheses

1. H_O: Hydrogels have no effect on the root collar diameters and heights of *Sesbania sesban, Cajanus Cajan* and *Leucaena pallida* seedlings in the nursery and in the field.

2. H_O: Hydrogels do not improve moisture holding capacity in the soil after transplanting of agroforestry tree seedlings in the field.

3. H_O: Hydrogels do not improve nutrients into the soil under different agroforestry tree species

1.6 Assumptions

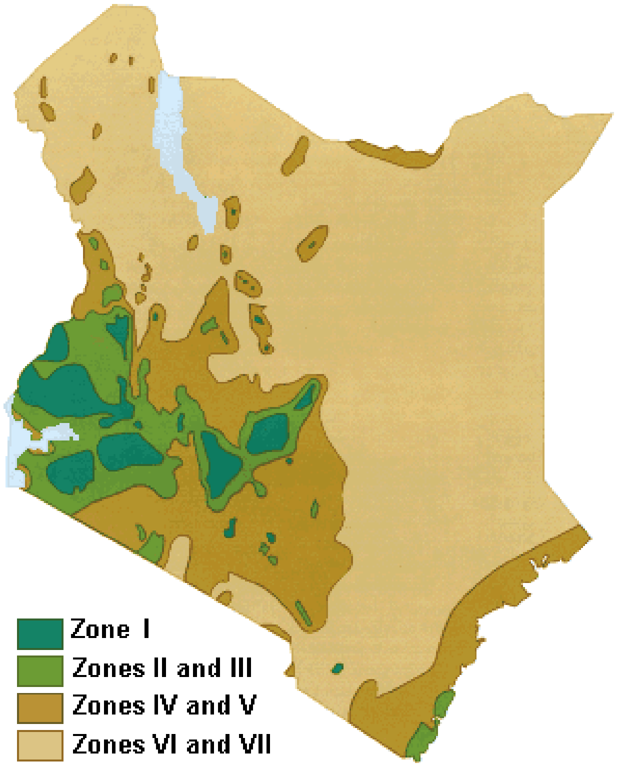
- Watering of seedlings was done evenly in all the seedlings regardless of whether treated with hydrogels (treatments) or not (control)
- Soil conditions were similar in all the nursery media and field plots.
- Light exposure to the seedlings considered to be similar.

CHAPTER TWO

LITERATURE REVIEW

2.1 Agro-climatic zones of Kenya

Kenya is classified into agro-climatic zones I – VII (Figure 1). Zone 1: has a mean annual rainfall above 2000 mm per annum. In zones II and III has a mean annual rainfall lie between 800 mm and 2000 mm per annum, while in zones IV and V and zone VI and VII lies between 400mm and 800mm, 200mm and 400mm per annum respectively (Braun *et al.,* 1982).



Zone 1 — High potential for production, some parts too cold and wet for optimum Production. Some forest land.

Zones II and III — Land suitable for crops where most food is grown.

Zones IV and V — Marginal, high risk areas but still some crops grown; rangelands in most parts of zone V.

Zones VI and VII — Marginal cropping, except under irrigation.

Figure 1: Map showing Agro-climatic zones of Kenya (Source: Braun *et al.*, 1982)

West Pokot is classified under zones V to VI (arid and semi arid zones) according to agro-climatic zones of Kenya (Figure 1). This is where agro-pastoralism are commonly practiced (GoK, 2003). These zones are recently settled to crop growing farmers (maize, cow pea, pigeon pea) as a result of in-migration from overpopulated better-watered areas. The zone is however suited for sorghum and millet, instead of maize. It is characterized from zone IV by a high crop failure due to frequent droughts, soil erosion and low soil fertility. Livestock especially goats are common. Other districts in Kenya that fall under this zone include parts of Keiyo, Marakwet, Tharaka, some parts of Kilifi and parts of Baringo (GoK, 2003; Yazan *et al.*, 2012). In these areas appropriate agroforestry interventions would increase the growth of plants to boost development of crops, agriculture, livestock, environmental rehabilitation and tree planting. Farmers in these areas are mostly agro-pastoralists as there source of livelihoods. Agroforestry is mainly practiced due to multipurpose nature of trees.

2.2 Agroforestry

Agroforestry has proved to be an important enterprise for small scale farmers in ASALs such as West Pokot. It has the potential of improving forest/tree cover and crop production. However, the decision to plant trees on farmers' land could be difficult due to low soil moisture and nutrients. Agroforestry in this area is emerging as an affordable and accessible science based solution to caring better for the land and increasing small scale food production (Vincent *et al.,* 2012). The area is characterized by water scarcity and is partially eroded (Macharia, 2012). West Pokot is characterized by high temperatures leading to high evapotranspiration with limited crops establishments. The inhabitants practice hedgerow intercropping for the purposes of fuel wood and pasture among other uses. Trees grown in these areas are mainly for the production of fodder. Frequent over grazing and increased population has led to a need for intensified and more productive land use, including growing crops and trees. It is believed that farm forestry promotes a more efficient cycling of nutrients than silvopastoral system in ASALs (Smiley and Kroschel, 2010).

Hedgerow intercropping is an agroforestry practice intended to place trees within agricultural cropland systems. In this system, arable crops are grown in between the hedges of woody shrubs and leguminous, that are regularly cut back to minimize tree crop competition for light, water and nutrients (Tossah *et al*., 1999). Nutrients, particularly nitrogen are added to the soil through leaf/root decomposition and nitrogen fixation in the roots hence use of nitrogen fertilizer to the soil may be saved (Christopher *et al.,* 2013). Subsistence farmers, who have little capacity to purchase high cost of inorganic inputs, could benefit by practicing hedgerow intercropping through saving in nitrogen fertilizer and improved soil productivity. Boosting the growth of agroforestry trees using hydrogels has been demonstrated to improve seedling survival rate and therefore boost livelihood of people in these areas (Saha *et al.,* 2012).

Interactions among tree species play an important role in determining the structure and the dynamics of plant communities in terms of moisture content and nutrients availability (Muyayabantu *et al.,* 2013; Endrias *et al.,* 2013). Intercropping is commonly practiced because of various advantages such as greater yield stability, greater land use efficiency and improvement of soil fertility due to the addition of N by fixation and some favorable exudates from legume species. Lithourgidis *et al.,* (2013) demonstrated that yield production under intercropping is higher than in sole cropping systems. This is because resources such as water, light and nutrients can be utilized more efficiently than in the respective sole cropping systems. Almost all reported intercropping combinations with a significant yield advantage involved non legume/legume combinations (Muyayabantu *et al.,* 2013). Interactions among species play an important role in determining the structure and the dynamics of plant communities in agriculture (Ghosh and Khushkhui, (2008).

Imbalanced nutrient application with low N and P content represents the major constraints that limit crop productivity in intercropping systems in many soils in temperate regions (Muyayabantu *et al.,* 2013). Other accounts of soil conservation in agroforestry include surface erosion control by planting various arid agroforestry tree species and tree crops along the boundaries of forest plantations and agricultural plantation crops (Macharia, 2012).

2.2.1 Agroforestry interventions to moisture availability in ASALs

Agroforestry practices with scattered trees in croplands have traditionally played a pivotal role in sustaining rural livelihoods in semi-arid zones of the world (Dhanya *et al.,* 2013). The interventions have been identified on the basis of resource base and livelihood systems in the ASALs (GoK, 2004). This ASALs agroforestry strategy takes advantage and builds on these resource bases (Zulfiia *et al.,* 2012; Audun, 2012). Agroforestry practices improve soil moisture since litter of the trees act as mulch to the crops at the same time provides nutrients to the crops. Audun, (2012), Dhanya *et al*., (2013) and Eni *et al.,* (2012) reported that soil and vegetation exhibit an integral relationship in that soil gives support (moisture, nutrient, and anchorage) to vegetation to grow effectively in arid environment.

Agroforestry interventions i.e. tree interactions and crops improve moisture availability for plant growth, soils, livestock and crop production potentials. The main economic activity of the arid lands (receiving an annual rainfall of 200 – 550 mm per annum) is livestock production by the nomadic pastoralists (Yazan *et al*., 2012). The types of livestock kept include camels, goats, sheep and donkeys. Between 70% and 80% of the

ASAL population is employed in the livestock industry (GoK, 2004; Yazan *et al.*, 2012). Economic activity of the semi-arid areas (receive an annual rainfall of 550 – 850 mm) comprise a combination of livestock and crop production agriculture (agro-pastoralism). The crops grown include maize, beans, cow-pea, pigeon pea, sorghum, millet, cotton, cattle, chicken (local varieties) and sheep (Mark Nijknik *et al.,* 2012). It represents the integration of agriculture and forestry to increase the productivity and sustainability of farming system.

Hedgerows alone reduced soil loss by 94% and run-off by 78%. When twigs and tender stem of hedge plants are used for mulch, it conserved 83% of the soil and 42% of rainfall (Saha *et al.,* 2012). Integrated farming system (IFS) has emerged as a well accepted, single window and sound strategy for harmonizing simultaneously joint management of land, water, vegetation, livestock and human resources. Besides these interventions having a tree crop with a high quality of leaf litter and root binding ability reduce erodibility of rainfall/runoff and improve the physicochemical conditions of the soil (Saha *et al.,* 2012). These agroforestry practices are affected by climate change hence appropriate technologies is required to mitigate the impacts.

2.3 Climate change and water scarcity

Sub-Saharan Africa is one of the most vulnerable regions in the world to climate change because of widespread poverty and limited adaptive capacity. The future climate change is likely to present an additional challenge to the agricultural sector. Therefore, the effects of climate change on the current agronomic management practices will boost the growth of plants in ASALs (Tumbo *et al.,* 2012) who reported that future climate change may present an additional challenge to agricultural production in these regions because it is the most vulnerable to climate change due to widespread poverty which limits its adaptive capacity. However, in all theoretical and experimental scenarios challenges arise as to how precipitation regimes translate into variation in soil moisture. Thus, there are growing number of experimental sites all over the world involved in analyzing the effects of more extreme precipitation regimes on biogeochemical cycles, ecological interactions and ecosystem functions (Bruno *et al.,* 2013). Soil moisture dynamics and other soil related properties integrate biological systems to respond to climate change variables. Soil moisture storage or soil hydrological properties will improve agroforestry in arid and semi arid lands (Tumbo *et al.,* 2012).

Water security is increasingly becoming problematic in ASALs as a result of climate change. Populations living in dry regions already face severe problems of water scarcity but climate change scenarios show that rainfall will become even more sporadic making the situation worse. Due to rain variability in semi arid regions, on average the risk of losing a substantial portion of crops is higher than 70% (IPCC, 2008). These have led to low survival rate of seedlings therefore use of innovative technology will improve the growth of plants in arid environment. Water is essential for all socio-economic development and for maintaining healthy ecosystems. As population increases leads to utilization of these areas to improve the livelihoods of people but water scarcity is the major challenge (Underwood *et al.*, 2009).

The reduced ecological resilience from land degradation and drought can strengthen social and environmental vulnerability leading to the loss of livelihood and creating conflicts concerning freshwater and food, particularly in semi-arid regions where the lack of water is a constant challenge. The key challenge of water managers is to optimize ecosystem resilience. Global development must embrace not only the interests of humanity but also of the interests of natural ecosystems (Underwood *et al.*, 2009).

2.3.1 Mitigation approaches to water scarcity

Control of drought stress in plant is not only very complex but also highly influenced by other environmental factors and developmental stages of the plant (Muhammad *et al.,* 2011). Water deficits under field conditions are required when considering a crop's response to drought. Drought is ultimately defined in terms of its effects on yield since this is the relevant issue when addressing the improvement of crop production under water limited environments (Pinheiron and Chaves, 2011). Drought is the most significant limiting factor for plant agriculture worldwide as it can cause serious losses of yields and productivity in most crop plants in arid and sub-arid regions. Technological innovations are required to mitigate the effects of aridity on the growth of crops in these ASALs areas (Pinheiron and Chaves 2011; Endrias *et al.,* 2013). Macharia, (2012) reported that successful implementation of precision farming technologies for managing agricultural fields would improve growth of plants in ASALs.

2.4 Soil water and its effects on plant growth in ASALs

Water is the most important physical factor that affects plant growth and development in ASALs (Unger *et al.*, 2006). Soil water influences aeration, temperature, nutrient transport, uptake and transformation in plants. Improved use of limited natural resources sustainably such as use of soil and water conservation measures to prevent land degradation, conserve soil fertility and improve use of the water resources through rainfall harvesting. The degree of soil degradation depends on soil's susceptibility to degradative processes, land use, the duration of degradative land use and the management (Saha *et al.,* 2012).

In ASALs, sustainable water management has been identified as one of the greatest challenges facing food security and poverty reduction (Unger *et al.*, 2006). Two recent developments have lead to an increased attention to efficient dry land agriculture and management in general (Unger *et al.*, 2006). The potential for irrigation of those lands has become more and more restricted due to a decreasing availability of fresh water reserves (Lin, 2004). Challenges related to the soils are either due to low nutrient content, presence of alkaline, saline or acidic soils. The majority of semi-arid soils are prone to salinity and this poses a major constraint to crop production (Unger *et al.*, 2006). Soil and nutrient loss is one of the major factors controlling net productivity. Therefore assessing the effect of erosion on soil properties in relation to soil characteristics is critical for predicting strategy for restoration of crop productivity of the eroded lands. For the best management of the soil resources of the area, it is very important to have information about the fertility status of that area (Khan *et al.,* 2012).

Plants obtain nutrients from the soil moisture. Both the ratios and concentrations of nutrients in this solution influence uptake rates and efficiencies, impacting plant health (Curtis *et al.,* 2013). Slow release of fertilizers will improve the growth of plants and improves soil fertility (Curtis *et al.,* 2013). In acidic soils, aluminium toxicity has been implicated in reducing crop growth (Saha *et al.,* 2012). All these constraints present a huge challenge to increasing agricultural productivity in semi-arid areas. Agricultural researchers, policy makers and other key stakeholders that are actively involved in promoting or increasing agricultural productivity in semi-arid areas all seem to agree that the solution to this challenge lies in agricultural production (Gunes, 2007). This concept of sustainable agricultural production entails improved management of the available and limited resources and use of improved crop production technologies that can enhance sustainable production in semi-arid areas.

2.5 What are hydrogels?

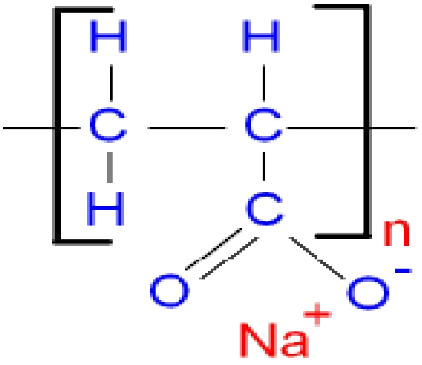
A gel (from the latin word '*gelu'* means freezing, cold, ice or *gelatos* meaning frozen, immobile) is a solid, jelly-like material that can have properties ranging from soft and weak to hard and tough (Kumar and Katere*,* 2005). Gels are defined as substantially dilute cross-linked systems, which exhibit no flow when in the steady state. By weight, gels are mostly liquid, yet they behave like solids due to a three dimensional cross-linked network within the liquid. It is the cross linking within the fluid that gives gels their structure and contribute to the adhesive stick. In this way gels are a dispersion of molecules of a liquid within a solid in which the solid is the continuous phase and the liquid is the discontinuous phase (Kumar and Katere*,* 2005). Gels consist of a solid three dimensional network that spans the volume of a liquid medium and ensnares it through surface tension effects. This internal network structure may result from physical bonds (physical gels) or chemical bonds (chemical gels), as well as crystallites or other junctions that remain intact within the extending fluid. Virtually any fluid can be used as an extender including water (hydrogels), oil and air (aerogel). Both by weight and volume, gels are mostly fluid in composition and thus exhibit densities similar to those of their constituent liquids. Edible jelly is a common example of hydrogel and has approximately the density of water (Eileen *et al*., 2010).

Hydrophilic gels, or "hydrogels" which are commonly known as super absorbents are cross linked polymers that can absorb 400 to 1500 times their dry weight in water (Evans and Bowman 1999). They are made from petrochemicals and polyacrylamides (PAMs). Such hydrogels are one of the most popular polymers that are chemically linked to prevent them from dissolving in solution. Special hydrogels i.e. superabsorbents absorb and store water hundreds of times their own weights (Tan and Osada 2013). Hydrogels are a network of polymer chains that are hydrophilic, sometimes found as a colloidal gel in which water is the dispersion medium. They are highly absorbent (they can contain over 99.9% water) natural or synthetic polymers. They also possess a degree of flexibility very similar to natural tissue due to their significant water content (Princeton, 2012). Their performance is determined by the chemistry and formation conditions of hydrophilic polymer and the chemical composition of the soil solution such as molecular weight (Princeton, 2012).

Linear chain polyacrylamides are used for erosion control, canal sealing and water clarification whereas cross linked polyacrylamide hydrogels are most commonly used in agriculture (Peterson, 2002). Hydrophilic polymers have been prepared by grafting synthetic monomers on starch, a naturally occurring polysaccharide polymer for improving water absorption and retention. Some polymers based on carboxymethyl cellulose developed recently have shown nearly 33000% m/m water absorption (Abedi-Koupai *et al.,* 2008). These hydrogels can be used in diverse areas of agriculture such as dry land/ rain fed agriculture, hi-tech horticulture and floriculture, nursery raising in soil less media, soil reclamation, agroforestry, landscapes, terrace gardening etc.

2.5.1 Structure of a Hydrogel

Hydrogels are cross linked polymers that have hydrophilic groups. The chemical name for this polymer is poly (sodium propenoate). The repeat unit for the structure is shown below.



(http://www.greenprophet.com)

The polymer chains usually exist in the shape of randomly coiled molecules.

In this state the hydrogel can absorb over five hundred times its own weight of pure water but less salty water. This ability to absorb so much water makes the hydrogels useful for agricultural use in moisture stress areas.

2.5.2 Hydrogels and the growing substrate (soils)

Substrate is a medium which permits root growth. Viero *et al*. (2000) found that hydrogels amendments in sandy soils promoted seedlings survival and growth under arid conditions, while under similar conditions found only an increase in seedling growth. Hydrogels application in sandy soils promotes an increase in water retention capacity and plant water potential (Sohrab, 2004), while in loamy and clay soils the effect may be negligible. Chen *et al*. (2010) found that addition of 0.6% hydrogels to saline soil improved seedling growth during a period of 2 years. The authors further reported that hydrogels treatment enhanced calcium ions uptake and increased capacity to exclude salt i.e. reduces contact with sodium ions and chlorine ions.

The soil media have varying influence on the performance of various trees. Some media induce rapid growth while others slow down growth rate or hardly influence growth depending on the nutrient level in the soil (Kimondo, 2000). Another application which has been widely tested is the incorporation of hydrogels into growing media prior to sowing as a means to hold more water and reduce moisture stress (Kimondo, 2000). In addition to increasing water holding capacity, hydrogels have been shown to retain nutrient ions against leaching especially in growing media with low cation exchange capacities. To help plants and trees grow in extremely dry areas, hydrogels granulate can be buried into the soil surrounding a plant's roots. Once there, it absorbs water and minerals and stores it, releasing it back to the plant when needed e.g. during the dry season (Kimondo, 2000). The gel particles in the earth store rain water or irrigation water providing a "reservoir" when it is needed at the plant's roots. Thus plants have much more water available than they normally would have. These results in an optimal supply of water, so plants' roots can grow strong quickly. That means long-term protection against dry stress (Zulfiia *et al.,* 2012). The authors in addition reported that hydrogels is cost effective and it can be used in plant seedlings in dry areas. Due to the increased water holding capacity of root zones, especially those high in sand, hydrogels promotes better establishment and survival of landscape plants and modify soils, assisting in buffering the periodic failure of seasonal rainfall.

2.5.3 How do hydrogels work in soils

Hydrogels increase the utilizable water holding capacity of soils by decreasing water and nutrient losses due to seepage, evaporation and surface runoff. In the soil hydrogels swells to form gel particles and store water as well as plant nutrients dissolved in the water (Landis and Haase, 2012). Thus hydrogels act as reservoirs of water and nutrients available to young plants on demand. Water and nutrients are taken up directly by the fine root hairs growing into the gel particles or they are slowly released to the surrounding soil. Hydrogels support the capillary flow of water into the root zone by releasing water to the surrounding soil due to the moisture gradient. Thus, the soil moisture potential is kept for a longer period of time at the highest level (Landis and Haase, 2012). Hydrogels amendments may improve seedling growth and establishment by increasing water retention capacity of soils and regulating the plants available water supplies, particularly under arid environments.

2.5.4 The potential of hydrogels

Hydrogels have been reported to be effective tools in increasing water holding capacity, reducing infiltration rate and cumulative evaporation and improving water conservation of sandy soils, particularly under arid environments (Gehring, 2010). They have the potential to absorb water many times their weight, retain it and supply it to plant roots during water stress, thereby enhancing plant survival and growth. The plant available water storage capacity of a soil provides a buffer which determines a plant's ability to withstand dry spells, hence its survival and growth (Abedi-Koupai, 2010). Hydrogels maintain conducive soil environment that facilitates water and nutrient absorption for plant root and shoot growth in periods of water stress. It is also known that water sorbents help to re-cultivate the degraded areas where flora has been absolutely devastated, they provide the re-vegetation (Paluszek and Zembrowski, 2006). The authors suggest that using hydrogels could be successful in areas where drought is frequent.

Hydrogels have a variety of potential uses including application to plants in the nursery and at the time of out planting during a period of moisture stress. Absorptive capacity of these gels is influenced by their chemical and physical composition as well as the ion concentration of the liquid being absorbed. The most common uses for hydrogels in nurseries or during out planting are incorporation in root dips. Research results are mixed regarding hydrogels influences on plant water uptake and vary by product and environmental conditions (Landis and Haase, 2012). It is recommended that growers or planters conduct small trials to determine whether there are benefits of using hydrogels under their specific conditions (Landis and Haase, 2012). Hydrogels have been used to establish tree seedlings and transplants in the arid regions of Africa and Australia to increase plant survival (Specht *et al.,* 2000). In these regions, water soluble polymeric conditioners improved soil physical properties thereby improving root penetration, infiltration, aeration, erosion resistance and drainage. These physical improvements usually increased rooting volume and plant interception of nutrients and water, indirectly improving plant nutrition (Akhter *et al.,* 2004). Hydrogels retain moisture around the germinating seeds and improve establishment either in a nursery or on an out planting site.

2.5.5 How do hydrogels affect soil moisture?

Hydrogels store water and dissolved plant nutrients against gravity thereby increasing soil moisture content and availability to. By applying 3g hydrogels per kg of soil the amount of plant available water is increased by 30-50% (Leciejewski *et al.,* 2008). Thus, the time period until plants reach the permanent wilting point under normal growing conditions is doubled. For example, in one study through the addition of hydrogels properties of a sandy soil as regards water retention capacity and water availability, changed to such an extent that they become similar to those of a silt loamy soil (Leciejewski *et al.,* 2008).

One kilogram of hydrogels is able to absorb up to 250 liters of demineralised water and absorb upto 150 liters of salty soil solution. When hydrogels are incorporated into the soil at a depth of 20 cm one kilogram of the commodity still absorbs 100 liters of soil solution (Kumar, 2005). Salts and ions in the soil solution decrease the uptake of water by the plants since hydrogels are sensitive to salt solutions. In the soil, salts and divalent cations like Mg^{2+} and Ca^{2+} are absorbed by the hydrogels. Since the cations act as additional cross linking agents the polymer network becomes narrow. This results in a reduced absorption capacity (Kumar, 2005). Hydrogels achieve their maximum swelling capacity even against the natural pressure of soils, substrates and compost (Kumar, 2005).

Hydrogels minimize water and nutrient losses through seepage, evaporation and surface runoff. By increasing the water use efficiency, more biomass is produced with less water while labor and maintenance costs associated with irrigation are significantly reduced (Raja *et al.,* 2013). Due to a more uniform water supply, hydrogels grant improved and faster germination and plant establishment and hydrogels allow for plant growth in extremely hot and dry climatic conditions. They increase the safety margin in plant production and plant quality and create optimum conditions for plant growth. Hydrogels have a positive effect on the water and nutrient supply, as well as on the porosity and permeability of soils and potting mixes (Zulfiia *et al.,* 2012). A particular feature of hydrogels is their very quick rewetting ability whilst in the soil even after completely drying out. They retain the ability of water absorption and release over a long period of time. They are also environmentally safe and compatible (Raja *et al.,* 2013).

Shim *et al.,* (2008) demonstrated that the residual amount of water in soil volume became more when blended with super absorbent material. It is estimated that the additional water associated with use of hydrogels reduces frequency of irrigation in plants and is thus cost effective. Mousavinia and Atapoor, (2006) and Karimi *et al*., (2008) reported that utilizing hydrogel absorbents in soil increased water holding capacity and available water and thereafter increased the water intervals. Increase in water intervals were about 30 to 130% in clay soils, 60 to 120% in loamy soil and up to 150 to 300 % in sandy soil. The water saved was 30, 40 and 70% in clay, loam and sandy soils, respectively.

Abedi-Koupai and Sohrab, (2004) in an experiment to evaluate water holding capacity and water potential of three kinds of soils concluded that on the whole, application of hydrogels in 6 to 8 grams per 1 kg of soil increased the amount of available moisture by 1.5 to 3 times respectively. Application of hydrogels in sandy soils results in more swelling grade, making the capillary porosity four times their controls. The effect of hydrogels increased the growth of plants 2 to 3 times water availability in the soils and saved in water consumption. Akhtar *et al*., (2004) reported that hydrogels work well in arid zones of transplanted seedlings and has a negative impact in the nursery due to frequent watering of seedlings.

In another experiment, *Conocarpus lancifolius* in warm and dry climate of Kuwait, applying hydrogels in 0.4% weight concentration led to 50% lesser irrigation need than that of control (Bhat *et al.,* 2009). Furthermore with a similar hydrogels concentration, available water capacity increased from 7.29 % (in control) and 18.75% respectively. Holding greater amount of water, clay soils give less than half of that of its weight. But as respects more than 90% of water absorbing by super absorbent are available to plant's roots (Abedi-Koupai, 2010). Abedi-Koupai and Sohrab, (2006) estimated that hydrogels in 2 to 8g levels per each kg of soil increased the moisture quantity 1 to 2.6 times respectively relative to control. In an experiment to evaluate effect of hydrogels on irrigation of seedlings of tree species: *Atriplex canescens*, *Pinus Eldarica* and *Populus euphratica* it was estimated that using 1% polymer result in three times more than controls. In general use of polymer is recommended to use polymer at planting time for the above mentioned species in order to reduce water for irrigation and to increase survival rate of seedlings transplanted in an arid environment (Poormeidany and Khakdaman, 2006).

2.5.6 Effects of hydrogels on nutrients

Hydrogels are produced in form of powder, charged with nutrients and mixed with soils near plant roots to increase survival and growth. They absorb water and swell, releasing water and nutrients and keeping the soil or the substrate humid over long periods of time (Amba *et al.,* 2011). According to Kelly, (2012) hydrogels improve nutrient uptake in the soil to a depth of 120 cm hence improving growth of plants in semi arid lands. Nutrients in the soil influence crop productivity and growth. Hydrogels application contributes to increase of nutrients in the soil since soil degradation is a major problem in Sub-Saharan Africa (Kelly, 2012). For example, Karimi *et al.* (2008) reported that hydrogels increased soil fertility and helped to improve plant growth during water stress periods. They observed that by using hydrogels, nutrient status in clay, loamy and sandy soil was increased in an application rate of 0.05, 0.1 and 0.3% respectively. They also investigated application of hydrogels to conserve water and nutrients release for agriculture and horticulture in arid and desert areas.

A ten-year research on steep land conservation, located in the Rocky Mountain (U.S.A), with estimated annual rainfall of 500 to 550 mm per annum indicated that using hydrogels could within this period control erosion rate by 65%. These materials, added to steep soils, established in a region with native plants increased organic material by 2.3% saving water amount in that region by 50% (Fertilizers Department, Sumitomo Chemical Company 2010). Hydrogels application into the soil controls erosion and improves nutrients which assist in growth of vegetation.

Shim *et al.* (2008) in a study on the effect of different hydrophilic polymers on nutrient uptake illustrated that magnesium and calcium uptake by plants in two kinds of polymer was as a result of better plant growth in those treatments. The authors further reported incorporation of hydrogels into growing media prior to sowing as a means to hold more water, nutrients addition and reduce moisture stress application which has been widely tested. In addition to increasing water holding capacity, hydrogels have been shown to retain nutrient ions against leaching especially in growing media with low cation exchange capacities. One trial found this to be true for cations ammonium and potassium cations, but not for the anionic nitrate which are one of the major causes of nutrient runoff from nurseries (Shim *et al.,* 2008; Tan, 2013).

2.5.7 Responses of agroforestry trees to hydrogels application

Application of hydrogels is an important practice to assist plant growth by increased water retention in sandy soils and its availability to plants in dry regions. The amendment with hydrogels is known to improve seed germination and seedling growth in several species. In addition they have been applied as a root dip; hydrogels coat fine roots and protect them against desiccation (Abedi-Koupai, 2010). One potential benefit is that hydrogels dips may function similarly to the natural polymeric mucilage's produced by healthy roots. Water held in the expanded hydrogels is intended as a soil reservoir for maximizing the efficiency of plant water uptake (Landis and Haase*,* 2012). Hydrophilic polymer networks have been reported to improve aeration and drainage of the medium. Hydrophilic polymers potentially influence infiltration rates, density, soil structure, compaction, soil texture, aggregate stability, crust hardness and evaporation rates. They have been used to establish tree seedlings and transplanted in the arid regions to increase plants survival (Abedi-Koupai, 2010).

One recent study demonstrated that mucilage weakens the drop in water potential at the root soil interface, increasing the conductivity of the flow path across soil and roots and reducing the energy needed to take up water (Carminati and Moradi, 2010). The main use of hydrogels has been to retain water for plant growth especially when irrigation isn't provided but new uses are continually being discovered. Hydrogels when applied to root dips could in addition to improving root to soil contact (Thomas, 2008), fill in air spaces around transplants or out planted seedlings. The concept of dipping plant roots before transplanting or out planting has been around for many years because it is intuitively attractive. Roots of nursery plants can dry as they are exposed to the atmosphere during handling and so it makes sense to apply a coating media to protect and increase their growth (Raja *et al.,* 2013).

Hydrogels amendments may improve seedling growth and establishment by increasing water retention capacity of soils and regulating the plant available water supplies, particularly under arid environments. Based on optimized conditions for root growth, the use of hydrogels activates sustainable root growth and results in faster development of seedlings, vigorous plant growth and increased crop yields particularly under difficult growing conditions such as drought stress due to low soil moisture and poor soil fertility. Hydrogels improve survival during plant establishment (Raja *et al.,* 2013).

Many studies have indicated that generally, super absorbent polymers cause improvement in plant growth by increasing water holding capacity in soils, delaying the duration to wilting point during drought stress. Water conservation by gel creates a buffered environment being effectiveness in short term drought tension and losses reduction in establishment phase in some plant species (Johnson and Leah, 1990). Proficiency in water consumption and dry matter production are positive plant reactions to super absorbent polymer application. Poly (ethylene oxide) hydrogels, polyacrylamide hydrogels and cross-linked poly (ethylene oxide)-copolyurethane hydrogels were attempted to alleviate the plant damage that resulted from salt-induced and water deficient stress (Shooshtarian *et al.,* 2012).

2.6 Factors affecting hydrogels performance

It is possible to reduce super absorbent performance by physical situation of soil and other factors. Bhat, (2009) reported that the water holding properties of this substance were significantly affected by the nature and dissolved salts concentration in water. In many studies, this reduction or lack of positive effectiveness was due to existence dissolved salts existence in water or fertilizers. Saline water reduces absorption and conservation of water. Akhtar *et al.,* (2004) evaluated effects of water on amount and rate of absorption and reported that the maximum time for absorption with distilled water, tap water and saline water were 7, 4 and 12 hours, respectively.

Naderi and Vasheghani, (2006) performed an experiment on three gel (Yellow, Aquasorb and White) properties and estimated that using tap water instead of distilled water reduced the degree of swelling. Furthermore the authors estimated that the ionic solution in water greatly decreased gel swelling and water absorption and the best pH is about neutral. They also suggested that regarding Iran's soil in most regions is above 7, it is better to apply ionic gels if they possess low quality of bivalent cations estimated that in general, the most favorable results associated with anionic polymers. However in another study no correlation was found between polymer size and growth of *Ardisia pusilla* (Shim *et al.,* 2008). Impact reduction of polymers with soil's salinity is because of absorption process in polymers happening on the basis of thermodynamic balance and the osmotic pressure differences between gel network and exterior solution decreased by increasing ionic power in saline solution. Thus, by growing plants in ionic power in saline solutions, swelling in solution media is declined (Eni and Offiong*,* 2012). In a study, application of super absorbent in loamy-sandy soils of Kuwait leads to an increase in water salinity caused by reduction in polymer effectiveness (Bhat, 2009).

Amendment of saline soil with 0.6% hydrogels improved seedling growth of *Populus euphratica* over a period of 2 years. However plant growth was reduced by salinity. Hydrogels treated plants had approximately 3.5 times higher root length and root surface area than their controls (Chen *et al.,* 2010). Tissue and cellular ion analysis showed that growth improvement may have been the result of increased capacity for salt exclusion and enhancement of Ca^{2+} uptake. Furthermore, root aggregation allows good contact of roots with a Ca^{2+} source and reduces contact with Na^{+} and Cl^{-}, which presumably plays a major role in enhancing salt tolerance (Chen *et al.,* 2010). There are large quantities of trace elements in polluted soils, particularly in mining regions, causing an interruption in plant growth and establishment (Walker *et al*., 2004; Celemente *et al.,* 2006). One way of treating polluted soils is by introducing hydrophilic polymers mixed with soil to enhance better establishment and growth. Pollution reduces effectiveness of hydrogels (Guiwei *et al.,* 2008).

In an experiment to evaluate establishment of *Spergularia purpurea* in a mine region, which has a great deal of trace elements and plant growth disturbed by the soil acidity, it was indicated that use of polymer could increase growth and establishment rate. Outcomes illustrated that area coverage and plant growth remarkably increased (4 to 5 times) toward control though affected by soil acidity and pollution (Qu and de Varennes, 2010). Furthermore, it is stated that concentrations of all elements apart from Na were lesser in plants treated with polymer than in those in controls in polluted soil. This is because of microcosm's existence produced by super absorbent polymer which filled with water and the little amount of trace elements was stored. Despite some limitations such as improper soil and severe lack of water, the tree losses were reported to be 6% when hydrogels were used during planting (Atieh and Anonymous, 2010). According to the authors hydrogels are frequently used for afforestation in semi-arid areas. The other factor influencing absorption rate is acidity of environment effecting on super absorbent's swollen degree illustrated that pH changes and electrolyte's concentration had great effect on swelling ionic group contained super absorbent. Hydrogels containing anionic and cationic groups in middle pH had maximum swollen and the gels containing both of which were more swollen in down or high soil pH.

Many earlier studies showed that hydrogels definitely increased the water holding capacity of the growing medium; this was not always reflected in increased plant growth. For example, *Douglas fir* containerized seedlings grown in hydrogels amended medium averaged lower moisture stress than those in the unamended control media when subjected to desiccation following lifting. However, no differences were found among treatments for height, stem diameter, root volume, and shoot volume (Nursery Technology Cooperative, 2009). The hydrogels treatment reduced germination percentage in some of the species in the nursery (Sijacic-Nikolic, 2010). The authors considered that the improved seedling growth after 2 years in the bare root nursery justified the use of hydrogels in future trials. He reported that gel seeding has little application in forest and native plant nurseries. The amount of hydrogels required is 0, 3.0, 6.0, 9.0, 12.0g thoroughly mixed with 2 kg of soil but depend on environmental conditions, season of the year and the type of soil in a particular region (USDA, 1996).

2.7 Soil amendments during out planting

The final application for hydrogels is to amend soils on the out planting site, especially on droughty (ASALs) or severely disturbed sites with the objective of retaining water that would normally be lost to evaporation or leaching. It has also been shown that hydrogels retain nutrient ions that could be leached out of the root zone (Sarvas *et al.*, 2007). When 8 grams of hydrogels were applied per kilogram of three different soil textures, the available water content increased 1.8 times that of the unamended control for the clay, 2.2 times for the loam and 3.2 times for the sandy loam soil (Abedi-Koupai *et al.*, 2008).

Soils physically support plants and act as reservoirs for the water and nutrients needed by plants. Soils are complex mixtures of mineral particles of various shapes and sizes; living and dead organic materials including microorganisms, roots and plant and animal residues; air and water. In the soil physical, chemical and biological reactions occur constantly and are closely interrelated (Mark *et al.,* 2012).

Hydrogel amendments are considered most effective on sandy soils and in drought environments. When a sandy soil was amended with a range of hydrogel treatments and planted with *Pinus halepensis* water retention of the soil increased exponentially with increasing additions of hydrogels. When the seedlings were subjected to controlled desiccation, those in soils with the highest amount of hydrogels survived twice as long as those in the control soils (Endrias *et al.,* 2013). Water potential measurements showed that seedlings in the amended soils had considerably less moisture stress than the controls.

Shoot growth and root growth were also significantly increased with the hydrogel amendments, (Sarvas *et al.*, 2007). The authors reported that the efficacy of hydrogels to increase seedling survival after out planting is dependent upon soil particle size and availability of soil moisture and recommended its use primarily as a root dip to protect roots from desiccation during the planting process (Starkey *et al.*, 2012).

2.8 Knowledge gap

Hydrogels have been found to be successful in establishing seedlings in the arid and semi arid areas. However the effects on the growth of seedlings, amount of moisture content conserved and amount of nutrients released into the soil by hydrogels have not yet been studied and documented. This study therefore involves use of hydrogels for establishment of seedlings in these regions to boost their growth and ensures survival in arid and semi arid lands.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Location and climate of study area

This study was carried out at Kongelai location, West Pokot County (Latitude: $1.47^0$71'S; Longitude: $35.02^0$07'E), bordering Uganda to the West, Trans Nzoia and Elgeiyo-Marakwet Counties to the South, Turkana County to the North and Baringo County to the South East (www.wikipedia.org/Counties_of_Kenya). The study area lies between 1500 to 2100 metres above sea level, characterized by bimodal type of rainfall with the long rains between April to August and short rains between October and February. The flat lowlands generally receive 600mm rainfall and the highlands 1600mm per annum. The study area is characterized by great variations in temperature with 30 °C in the lowlands and 15 °C the highlands. High temperatures in the lowlands cause high evapotranspiration which makes it is unfavorable for crop production in comparison with high altitude areas which receive moderate temperatures, high rainfall and hence low evapotranspiration (Evans, 2001). Soils in the study area are developed from sedimentary rocks. The soils are generally eutric cambisols partly with lithic phase, while some are eutric regosols and in some places have rock outcrops. The soils are shallow and well drained; hence retain optimum amounts of soil water for plant growth after rain. Natural fertility is moderate, while erosion susceptibility is high. The top soil is harden and sealed while infiltration rate is low hence runoff accompanied by severe erosion on the gentle slope (Gachene, 2003).

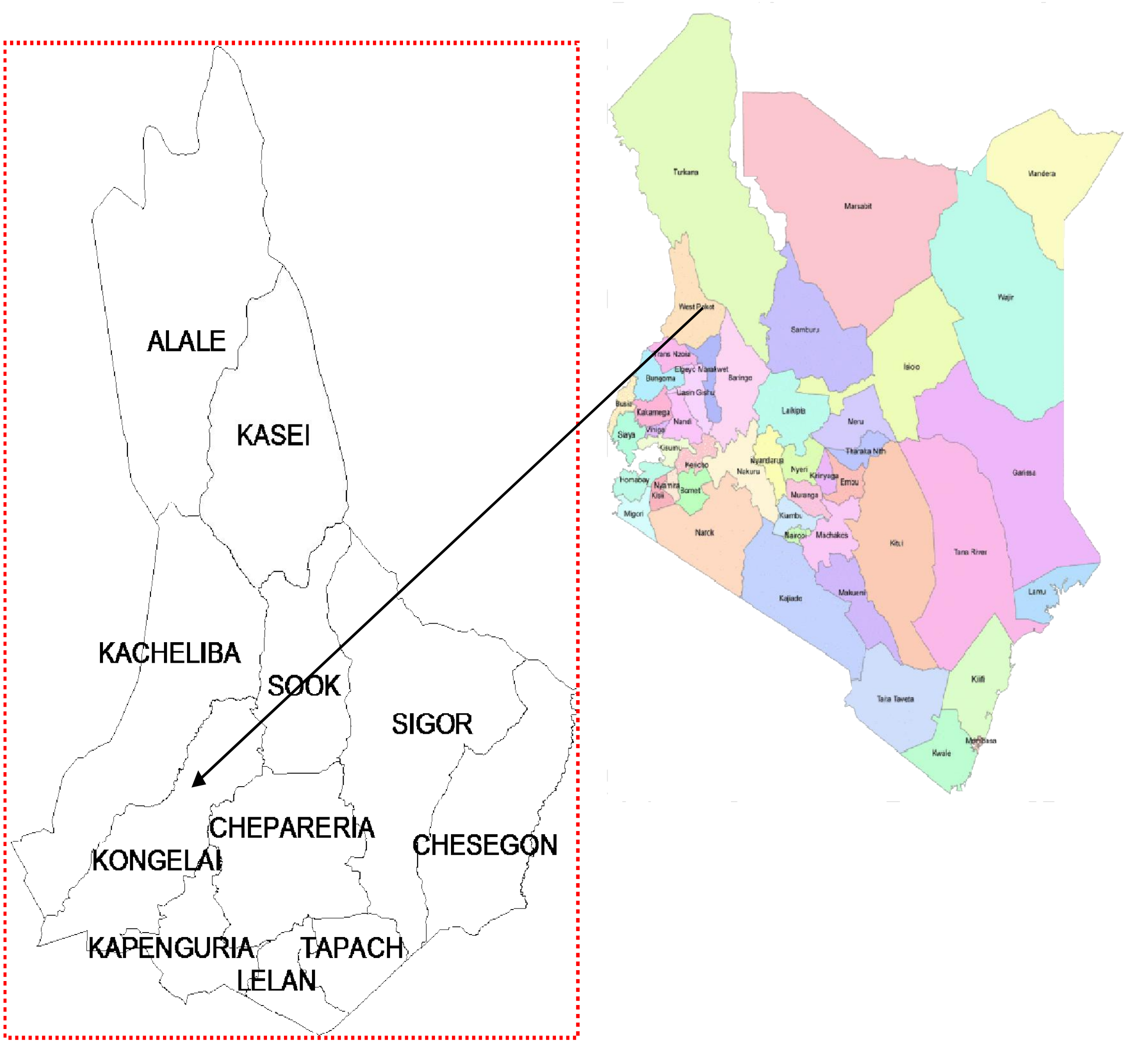


Figure 2: Map of study area, West Pokot County (Source: County Commissioner's Office, 2013)

3.2 Experimental tree species

Three agroforestry species namely *Sesbania sesban, Cajanus cajan* and *Leucaena pallida* were used in the study.

Sesbania sesban is a short shrub up to 8 m tall, it belongs to a family of *Fabaceae,* native to; Chad, Egypt, Kenya and Uganda but it has spread to other parts of the world. It grows in a wide range of soils from loose sands to heavy clays, improves soil fertility and tolerates saline soils and high temperatures. It does well in a range of 500-2000mm annual rainfall (Fuller and Harvey*,* 2009).

Cajanus cajan also known as pigeon pea belongs to a family of *Fabaceae* native to India, Australia and Africa. It is an important legume crop of rain fed agriculture in the semi arid tropics. It usually takes 3–5 months to yield seeds and is a drought resistant plant therefore grown in areas with less than 650 mm annual rainfall. It can be grown on a wide range of soil textures, from sands to heavy black clays but needs free drainage. Pigeon pea is tolerant to hot conditions and does well in temperatures of 18–30ºC. www.springerlink.com

Leucaena pallida is a small deciduous multiple-stemmed tree 3-7 m tall originated from Mexico and Central America. It belongs to a family the *Fabaceae*. Tolerate marginally more acidic soils and requires 500-1000mm annual rainfall, with a 5-7 month dry season and average annual temperatures ranging from 16-21 °C. The species requires shallow soils while it can be used as a starter of N and P therefore may be used when establishing depleted soils on cropping lands as nitrogen fixing (Specht and Harvey-Jones, 2000).

3.3 Hydrogels

Hydrogels used were obtained from Kenya Agricultural Research Institute Kitale in Trans Nzoia County. Hydrogels used goes by the common name Belsap (Plate 3.0) and its trade names were; natural polymers, water absorber and synthetic hydrophilic polymers manufactured by Bell Industries limited- a Member of Agrochemical Association of Kenya (Nairobi). It characteristics are solid and are hydrophilic in nature.

Plate 3.0 Hydrogels used in the study (Source: Author, 2015)

Potting soil was obtained from Kapolet Forest Station Cheragany Hills and polythene tubes obtained from VI Agroforestry Kitale.

3.4 Experimental procedures in the nursery

Seeds of *Sesbania sesban, Cajanus cajan* and *Leucaena pallida* were directly sown on 5th October, 2012 into polythene tubes measuring (4 x 6 inches) containing 800g of forest soil and at different levels of hydrogels or without hydrogels (control). A total of 3 treatments were prepared for each species. The total number of seedlings established were (42x12x3) 1512 consisting of 504 *S. sesban*, 504 *C. cajan* and 504 *L. pallida.* Each treatment consisted of 42 seedlings of the respective tree species at 0, 7, 11 and 15g hydrogels levels replicated thrice. Treatments were randomized within the blocks. Controls were sown in soil with no hydrogels. In the nursery watering periods, amount of water and sunlight were regulated in order to get appropriate results. All polythene tubes were labeled for identification purposes. Once germinated, root collar diameter and height were measured every two weeks for two months.

3.5 Experimental layout

Split plot design was used in this experiment, all the three species was in one block replicated thrice as shown in figure 3 below. The main plot contain are all tree species: *S. sesban*, *C. cajan* and *L. pallida*, while the sub-plots were a control and three levels of hydrogels: $H_{0\ (\mathrm{control})}$, $H_{7g,}$ H_{11g} and H_{15g}. Corresponding to the level of hydrogels; none, H7g, H11g and H15g respectively in each polythene tubes. The layout is shown in the figure 3.

TREATMENT 1

SSH$_{15}$	SSH$_{7}$	SSH$_{0}$	SSH$_{11}$
SSH$_{0}$	SSH$_{15}$	SSH$_{7}$	SSH$_{11}$
SSH$_{11}$	SSH$_{15}$	SSH$_{0}$	SSH$_{7}$

TREATMENT 2

CCH$_{7}$	CCH$_{11}$	CCH$_{15}$	CCH$_{0}$
CCH$_{7}$	CCH$_{0}$	CCH$_{11}$	CCH$_{15}$
CCH$_{0}$	CCH$_{11}$	CCH$_{7}$	CCH$_{15}$

TREATMENT 3

LPH$_{11}$	LPH$_{0}$	LPH$_{15}$	LPH$_{7}$
LPH$_{0}$	LPH$_{11}$	LPH$_{15}$	LPH$_{7}$
LPH$_{15}$	LPH$_{11}$	LPH$_{0}$	LPH$_{7}$

Figure 3: Experimental layout in the nursery

KEY

LP – *Leucaena pallida*

CC – *Cajanus cajan*

SS – *Sesbania sesban*

H_0 – No hydrogels (control)

H_7 – 7 g hydrogels

H_{11} – 11g hydrogels

H_{15} – 15 g hydrogels

3.6 Experimental procedures in the field

After two months, on 10th December, 2012, seedlings without hydrogels in the nursery were transplanted into pre-tested soil samples in a field within the same region. All seedlings treated with hydrogels in the nursery were not transplanted. This is due to the fact that it will not give appropriate result since they were not uniform in growth and many of them were subjected to scorching effect. In the field, the same levels of hydrogels (0, H_{7g}, H_{11g} and H_{15g}) as in the nursery were applied in the planting holes i.e. 30cm x 40cm deep and mixed with soil. The spacing was 5m between the rows and 30cm within rows. *C. cajan* was established between *L. pallida* and *S. sesban.* Thirty (30) seedlings were used for each tree species (treatment) and hydrogels levels replicated thrice. Control plots were not treated with hydrogels. Seedlings were labeled for identification during data collection. Once a month for three months, root collar diameter and height of seedlings were measured. In addition soil samples were collected from the base of each growing seedling for moisture and nutrient release analysis. With the exception of hedgerows in the field, experimental design remained as in the nursery i.e. *C. cajan* was established between *L. pallida* and *S. sesban.*

Plate 3.1 a: One month old *Cajanus cajan* seedlings intercropped with *Leucaena pallida* after transplanting. 3.1 b: Measuring RCD and height on one month *Cajanus cajan* (Source: Author, 2015)

3.7 Determination of soil moisture

Fifty grams (50g) soil from 0-10cm horizons was collected in the field using a soil auger under: *Sesbania sesban*, *Cajanus cajan* and *Leucaena pallida* seedlings. Initial weight (w1) was determined and the sample oven dried at 100 °C. Oven dry weight (w2) was determined and soil moisture content (mc) determined by the formulae below;

$$\text{Moisture content \%} = \frac{\text{Initial soil moisture content} - \text{final weight (oven dry weight)}}{\text{Initial soil moisture content}} \times 100$$

Soil was then stored ready for digestion in the laboratory for chemical analyses.

3.8 Determination of soil pH

Acidity, neutrality or alkalinity of the soil is expressed as the inverse log of hydrogen ion concentration (Okalebo *et al.,* 2002). Oven dried soil weighing 0.1g was mixed with 50ml of distilled water then stirred for 10 minutes. The mixture was allowed to stand for 10min then the pH was measured from the soil suspension using an electrical pH meter. The meter was inserted into the glass containing soil solution and the readings recorded.

Large particles of oven dried soil were crushed in a pestle and mortar to pass 2mm sieve. The soil was then digested in the laboratory using a block digester for 24 hours and nutrients in each soil sample determined as follows. Nitrogen and Phosphorous was tested by treating. Khedhal procedure was used analyze total nitrogen. Selenium powder of 0.21g was added to 7.0g of lithium sulfate then to 175 ml of 30 % hydrogen peroxide and mixed well. Concentrated sulfuric acid weighing 210ml was added with care while cooling in an ice-bath. This was then stored at 2^{o}C for stability purposes.

3.9 Soil analysis

3.9.1 Block digestion

Soil sample were treated with hydrogen peroxide + Sulphuric acid + selenium + salicylic acid. The principle took into account the possible omission of nitrates by coupling them with salicylic acid in an acid media to form 3-nitrosalicylic and or 4-nitrosalicylic. The hydrogen peroxide is known to oxidize the organic matter while the selenium compounds act as catalyst for the process. Hydrogen peroxide completes the digestion at elevated temperatures (Okalebo *et al.*, 2002).

3.9.2 Procedure for digestion

Finely grounded dried soil samples of 0.3g was weighed and put into labeled dry, clean digestion tubes. Digestion mixture weighing 2.5ml was added to each tube and also to reagents blanks for each batch of samples. The tubes were heated in a block digester at 350^0C for 2 hours. The digestion was completed when the digest became colourless. The tubes were removed from the digester and cooled to room temperature. Distilled water i.e. 25ml was then added, mixed well and made up to 50ml with 35ml distilled water (Okalebo *et al.*, 2002). The contents were then transferred into a 50ml volumetric flask and allowed to settle so that the clean solution was used for analysis of nitrogen, phosphorous and sodium.

3.10 Analysis of nutrients

3.10.1 Analysis of potassium

Potassium standard stock solution was prepared by dissolving 0.95g of potassium chloride in distilled water using 500ml volumetric flask and the solution was made to the mark with distilled water. The resulting solution was equivalent to 1.0mg per m of stock solution. The stock solution was diluted to give standard solutions of 0, 1.0, 2.0, 4.0, 6.0, 8.0 and 10.0ppm of potassium. The solutions were aspirated starting with blank, standards and samples directly into the flame photometer. The absorbance against the concentration of the standards was used to obtain the calibration curve measured at 766.5nm (Okalebo *et al*., 2002). Percentage of K was calculated as follows;

$$\text{Potasium } (\%) = \frac{\text{concetration } \times 100}{300}$$

3.10.2 Analysis of phosphorus

Colorimetric procedure was used to analyze phosphorus. The supernatant clear wet-ashed digest solution of 5ml was pipetted into 50ml volumetric flask. Distilled water of 20ml was added to each flask. Ascorbic acid (reducing agent) of 10ml was added to each flask beginning with distilled water stopped and shaken well. The solution was left to stand for 1 hour to permit full color development. The standards and sample absorbance (blue color) were measured at 880nm wavelength setting in a colorimeter (Okalebo *et al*., 2002).

Calibration curve was used to calculate the concentration of phosphorus in the sample as follows.

$$\text{Phosphorus (\%)} = \frac{(a - b) \times v \times f}{1000 \times w} \times 1000$$

a = the concentration of P in the sample, b = the concentration of P in the blank, v = volume of extracting solution, f = dilution factor, w = weight of the sample

3.10.3 Analysis of total nitrogen in soils

Khedhal procedure was used analyze total nitrogen. The entire digest and the blanks were diluted to a ratio of 1:9 (v/v) with distilled water to match the standards. Samples of 0.1ml and the blanks were taken with a micropipette into clearly labeled test tubes. The samples and the blanks were allowed to stand for 2 hours after which the absorbency was measured at 650nm (Okalebo *et al*., 2002). A calibration curve was plotted to read off the concentration of nitrogen and calculated as follows.

$$\text{Nitrogen (\%)} = \frac{(a - b) \times v \times 100}{1000 \times w \times al \times 100}$$

Where a = concentration of N in the solution, b = concentration of N in the blank, v = total volume at the end of analysis procedure, w = weight of the dried sample and al = aliquot of the solution taken.

3.11 Data analysis and interpretation

Data was analyzed using Microsoft Excel Analysis Toolpak. Two way ANOVA was used to analyze the effect of hydrogels on the height and RCD growth of tree seedlings both in the nursery and in the field. F-test was performed to test the level of significance. However, post hoc test (mean separation) to verify the difference among treatments was carried done.

CHAPTER FOUR

RESULTS

4.1 Effects of hydrogels on growth of seedlings

4.1.1 Effects of hydrogels on seedling height growth in the nursery

Sesbania sesban established in soils with no hydrogels (H_0) gave higher seedling height growth than those in soils treated with different levels of hydrogels ($H_{7g,}$ H_{11g} and H_{15g}) (Figure 4). Soils treated with the higher amount of hydrogels (H_{15g}) gave the least growth in height. Analysis of variance for the height of *S. sesban* after 8 weeks (Appendix I) showed that $F_{\text{calculated (0.05)}} = 10.3431$, $F_{\text{tabulated (critical)}} = 3.4903$. This implied that hydrogels application had a significant (p= 0.001) negative influence on the height of *S. sesban*. Hence, use of hydrogels in nursery soils had a significant negative effect on seedlings seedling height growth.

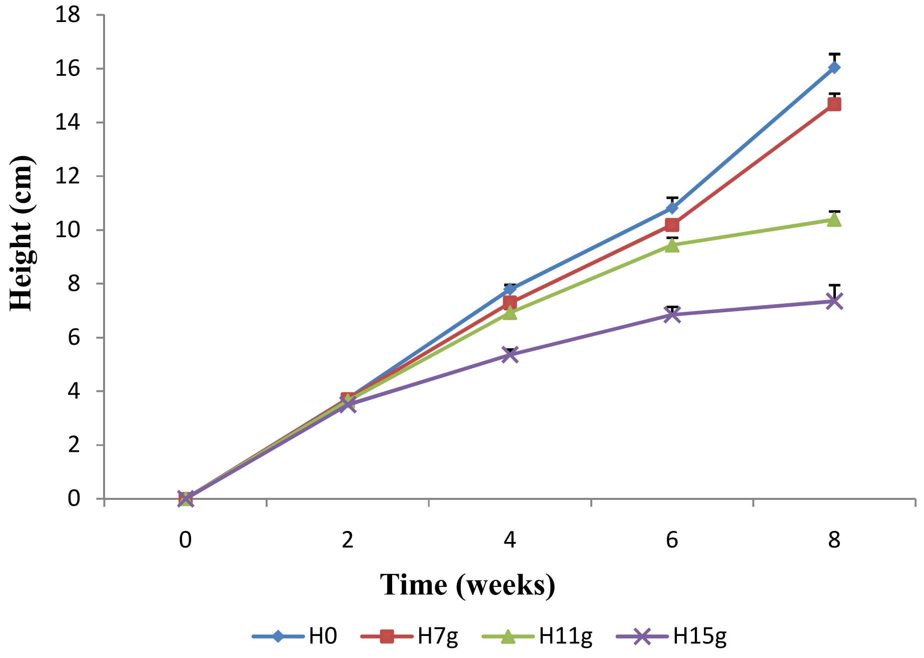


Figure 4: Height of *Sesbania sesban* seedlings in the nursery

Similar trends in height growth were observed in *Cajanus cajan* $F_{\text{calculated }(0.05)} = 3.6182$, $F_{\text{tabulated (critical)}} = 3.4903$ and *Leucaena pallida* $F_{\text{calculated }(0.05)} = 3.4967$, $F_{\text{tabulated (critical)}} = 3.1903$ established under similar conditions as shown in Figures 5 and 6, respectively.

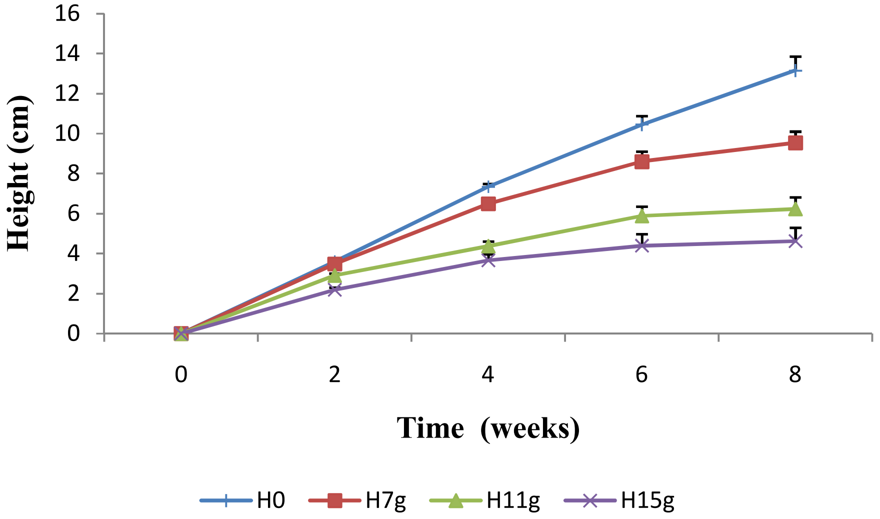


Figure 5: Height of *Cajanus cajan* seedlings in the nursery

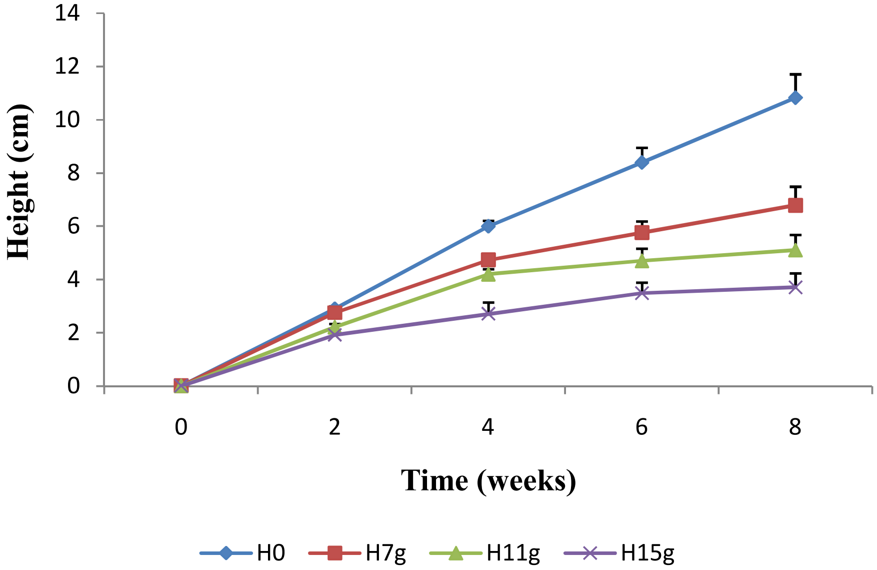


Figure 6: Height of *Leucaena pallida* seedlings in the nursery

4.1.2 Post hoc analysis of height in the nursery

The table below shows summary of means in height after 8 weeks in the nursery

Table 1: Mean Height (cm) after 8 weeks in the Nursery

HYDROGEL LEVEL	**H_{15g}**	**H_{11g}**	**H_{7g}**	**H_0**
Sesbania sesban	3.64	6.84	9.34	12.11
Cajanus cajan	3.04	5.21	7.26	8.39
Leucaena pallida	2.44	4.40	5.58	6.60

Analysis of variance shows that there is a significant difference (p=0.008) among the species and at different levels of hydrogels (Appendix I).

Post Hoc analysis or mean separation was carried out to determine if there is significance difference among the species and at different levels of hydrogels as shown below;

Significance level was 0.05, df was 6 (appendix II). From T table the value is 1.943

LCD = 1.943√(0.9097) * 2/4 (Appendix II) = 0.9609

If the difference between H_{15g} and $H_{11g} \geq$ LSD then you can reject the null hypothesis that the means are the same ($H_0{:}\mu_1 = \mu_2$). For this case the value 3.2 is larger than 0.9609 so we can reject the null hypothesis. This applies to the other hydrogels levels and between the species.

4.1.3 Effects on seedling root collar diameter in the nursery

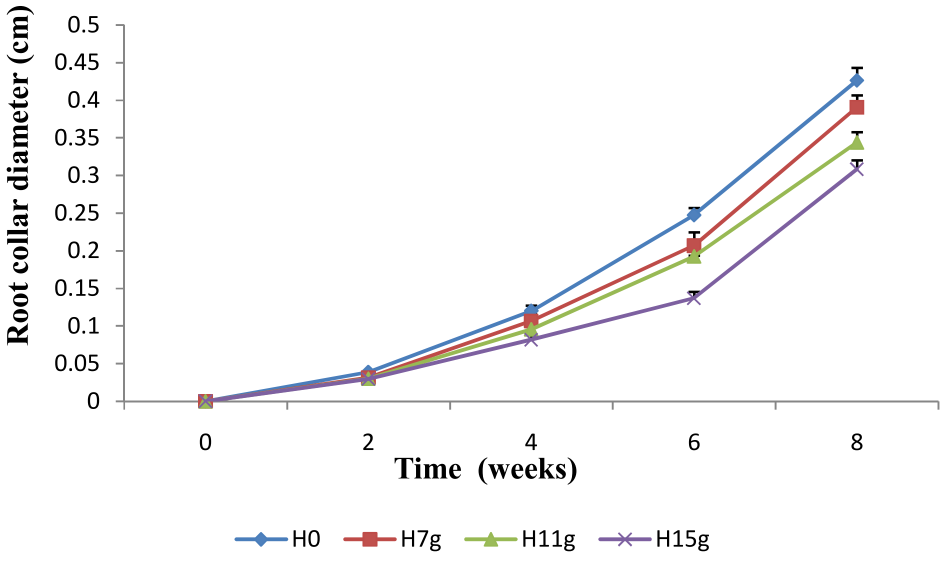


Figure 7: RCD of *Sesbania sesban* seedlings in the nursery

Sesbania sesban seedlings established in soils with no hydrogels (H_0) gave higher root collar diameter (RCD) growth as compared to seedlings established in soils treated with hydrogels ($H_{7g,}$ H_{11g} and H_{15g}). At higher levels of hydrogels (H_{15g}), low RCD growth was achieved as compared to lower levels (H_{11g} and $H_{7g)}$.

Analysis of variance (appendix I) showed that $F_{calculated\ (0.05)} = 7.5909$, $F_{tabulated\ (critical)} = 3.4903$. This implied that hydrogels application had a significant (0.004) influence on the growth of S. *sesban* and retarded growth of seedlings RCD in the nursery.

Similar trends in RCD were observed in *Cajanus cajan* $F_{calculated\ (0.05)} = 6.9127$, $F_{tabulated\ (critical)} = 6.2913$ and *Leucaena pallida* $F_{calculated\ (0.05)} = 4.6504$, $F_{tabulated\ (critical)} = 3.4903$ treated with similar levels of hydrogels as shown in Figures 9 and 10, respectively.

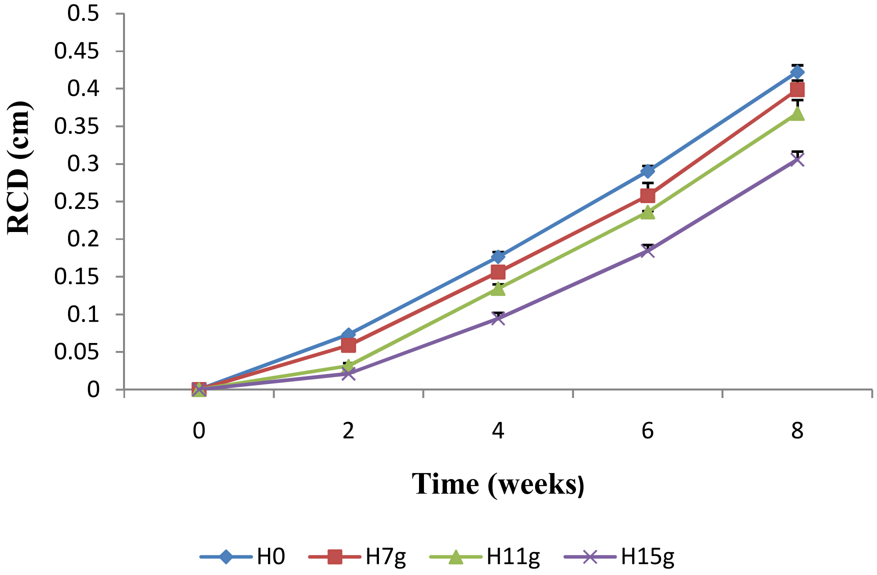


Figure 8: RCD of *Cajanus cajan* seedlings in the nursery

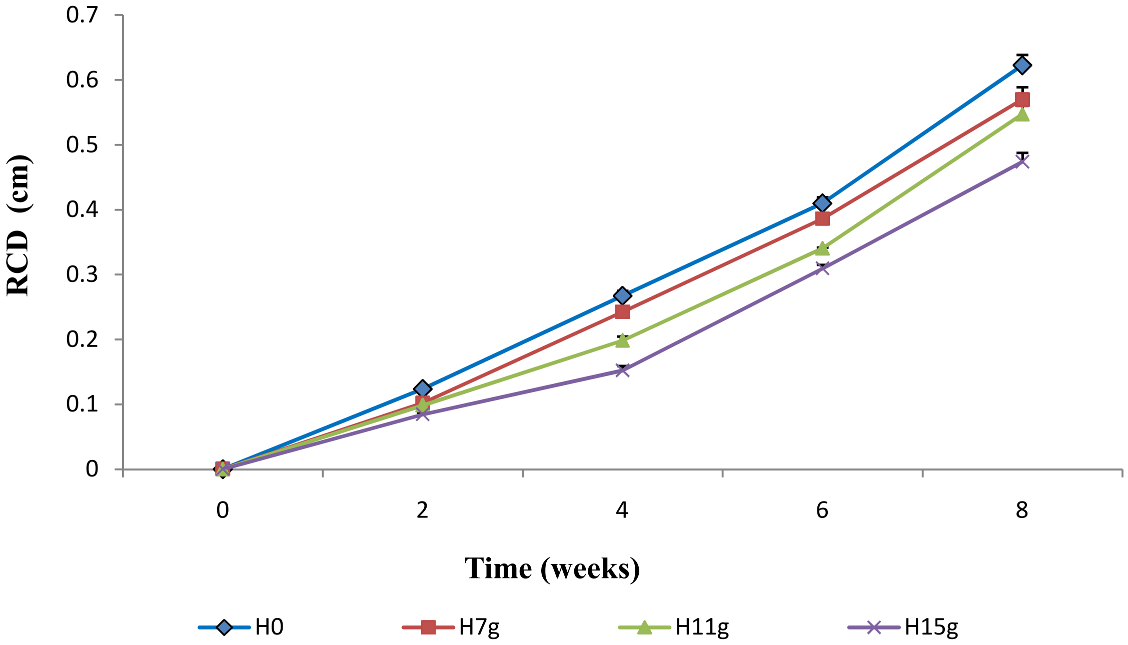


Figure 9: RCD of *Leucaena pallida* seedlings in the nursery

4.1.4 Post hoc analysis on RCD in the nursery

The table below shows summary of means in RCD after 8 weeks in the nursery

Table 2: Mean RCD (cm) after 8 weeks in the Nursery

HYDROGEL LEVEL	**H_{15g}**	**H_{11g}**	**H_{7g}**	**H_0**
Sesbania sesban	0.03	0.05	0.12	0.25
Cajanus cajan	0.02	0.05	0.09	0.10
Leucaena pallida	0.08	0.05	0.03	0.02

Analysis of variance shows that there was a significant difference (p=3.62) among the species and at different levels of hydrogels (Appendix I). Post Hoc analysis or mean separation was carried out to determine if there is significance difference among the species and at different levels of hydrogels as shown below;

Significance level was 0.05, df 6 (appendix II). From T table the value is 1.943

LCD = 1.943√(0.0039) * 2/4 (Appendix II) = 0.1971

If the difference between H_{15g} and $H_{11g} \geq$ LSD then you can reject the null hypothesis that the means are the same ($H_0{:}\mu_1 = \mu_2$). For this case the value 0.02 is less than 0.1971 so we can accept the null hypothesis. Between the S. *sesban* and *C. cajan* the value is 0.01 less than 0.1971 so we can accept the null hypothesis. This applies to the other hydrogels levels and between the species.

4.1.5 Effects of hydrogels on height of seedlings in the field

Sesbania sesban seedlings transplanted in the field and grown in soils with no hydrogels (H_0) gained least growth compared to those in soils treated with hydrogels (Figure 11). Seedlings in soils with highest level of hydrogels (H_{15g}) gained the highest height. Analysis of variance (Anova) for the height of this species at H_0, $H_{7g,}$ H_{11g} and H_{15g} (Appendix I) showed that $F_{\text{calculated (0.05)}} = 3.4903$, $F_{\text{tabulated (critical)}} = 0.0508$.

This showed that hydrogels had a significant influence on the growth of transplanted *Sesbania sesban* seedlings; hence use of hydrogels in soils in the field has a positive impact on height growth.

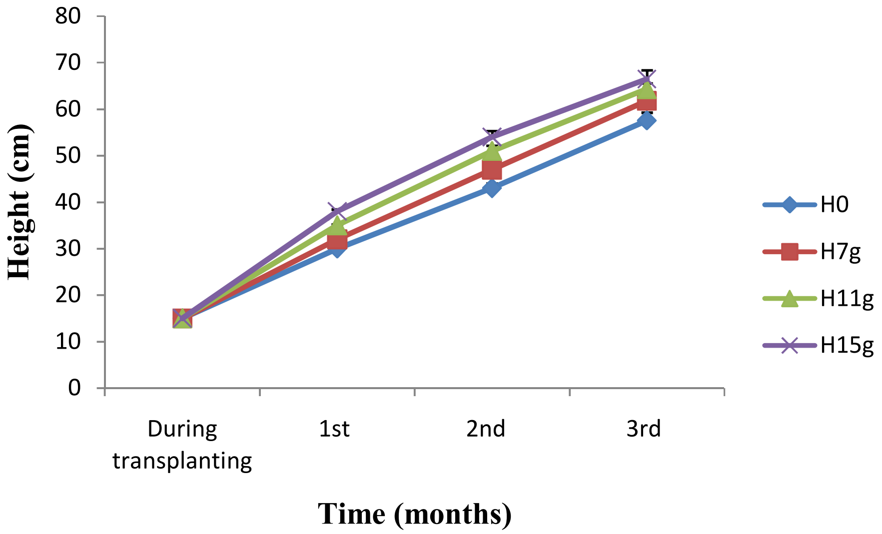


Figure 10: Height of transplanted *Sesbania sesban* seedlings

Similar trends of height increases were observed in *Cajanus cajan* F $_{\text{calculated (0.05)}}$ = 144.8962, F $_{\text{tabulated (critical)}}$ = 3.4903 and *Leucaena pallida* F $_{\text{calculated (0.05)}}$ = 91.6573, F $_{\text{tabulated (critical)}}$ = 3.4903 under the same conditions in the field (Figures 11 and 12, respectively).

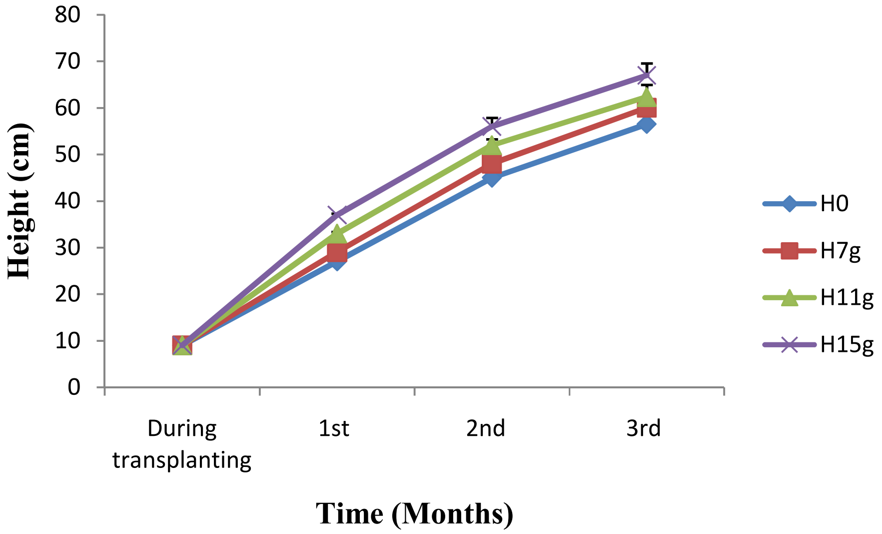


Figure 11: Height of *Cajanus cajan* seedlings after transplanting

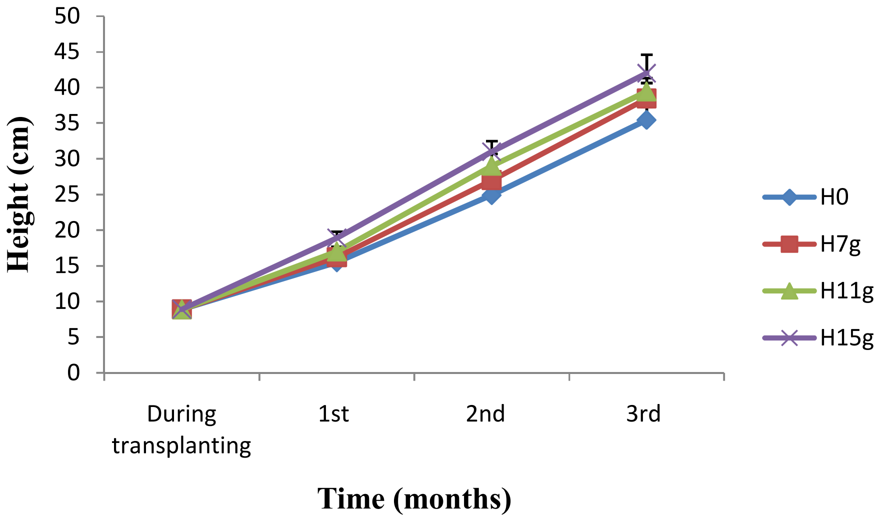


Figure 12: Height growth of transplanted *Leucaena pallida* seedlings

4.1.6 Post hoc analysis on height after transplanting

The table below shows summary of means in height after 3 months after transplanting.

Table 3: Mean Height (cm) after 3 months after transplanting

HYDROGEL LEVEL	**H_0**	**H_{7g}**	**H_{11g}**	**H_{15g}**
Sesbania sesban	37.67	39.88	41.53	43.16
Cajanus cajan	13.15	37.27	56.46	61.46
Leucaena pallida	10.82	25.65	34.27	38.71

Analysis of variance shows that there is a significant difference among the species and at different levels of hydrogels (Appendix I). Post Hoc analysis or mean separation was carried out to determine if there is significance difference among the species and at different levels of hydrogels as shown below;

Significance level was 0.05, df 6 (Appendix II). From T table the value is 1.943

LCD = 1.943√(96.62) * 2/4 (Appendix II) = 13.50

If the difference between H_{15g} and $H_{11g} \geq$ LSD then you can reject the null hypothesis that the means are the same (H_0:$\mu_1 = \mu_2$). For this case the value 1.63 is less than 13.50 so we can accept the null hypothesis. The same principles can apply to the other hydrogels levels and between the species.

4.1.7 Effects of hydrogels on root collar diameter after transplanting in the field

Sesbania sesban seedlings grown in soils with no hydrogels (H_0) gained least RCD growth as compared to seedlings treated with hydrogels. At the highest level of hydrogels (H_{15g}), highest growth in RCD was attained as compared to intermediate levels (H_{11g} and H_{7g}). Analysis of variance (appendix 1) showed that $F_{\text{calculated (0.05)}} = 7.9651$, $F_{\text{tabulated (critical)}} = 3.4903$, implying that hydrogels had a significant positive effect on the RCD growth of transplanted *Sesbania sesban* seedlings.

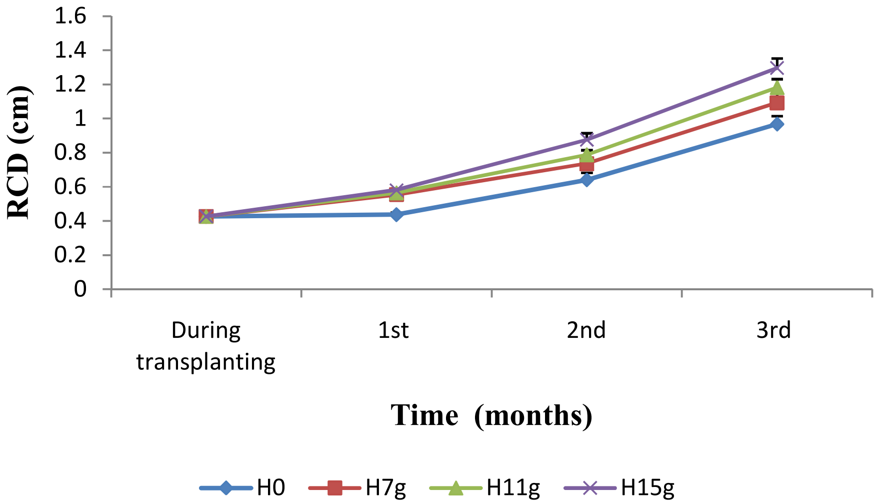


Figure 13: RCD of *Sesbania sesban* seedlings after transplanting

Similar trends in RCD were observed in *Cajanus cajan* F $_{\text{calculated (0.05)}}$ = 138.89, F $_{\text{tabulated (critical)}}$ = 3.4903 and *Leucaena pallida* F $_{\text{calculated (0.05)}}$ = 135.7926, F $_{\text{tabulated (critical)}}$ = 3.4903 treated with similar levels of hydrogels (Figures 14 and 15).

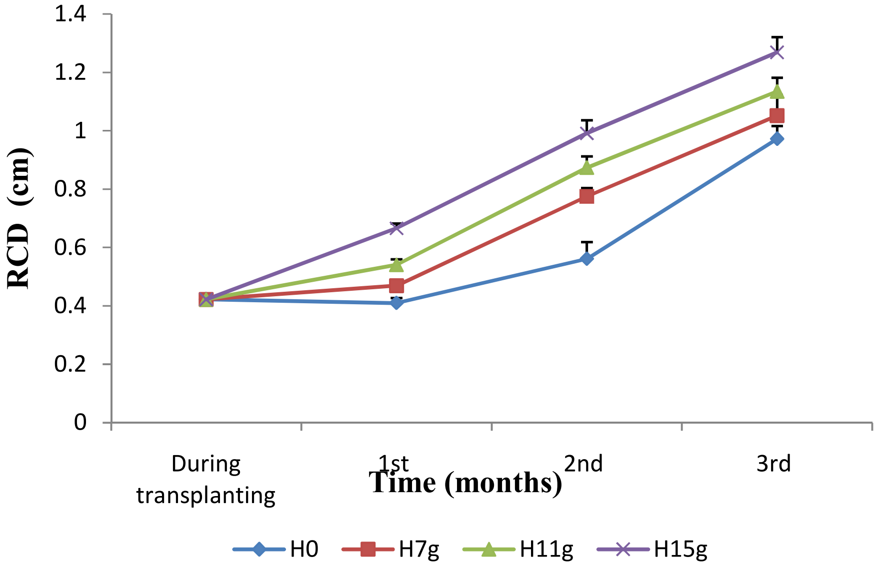


Figure 14: RCD of *Cajanus cajan* seedlings after transplanting.

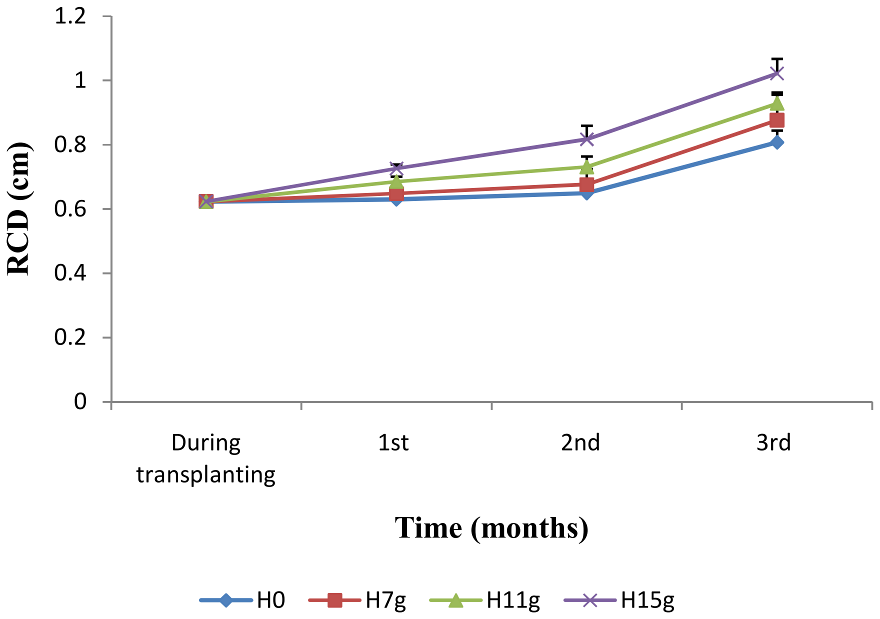


Figure 15: RCD of *Leucaena pallida* seedlings after transplanting.

4.1.8 Post hoc analysis on RCD after transplanting

The table below shows summary of means in RCD after 3months after transplanting.

Table 4: Mean RCD (cm) after 3 months after transplanting

HYDROGEL LEVEL	**H_0**	**H_{7g}**	**H_{11g}**	**H_{15g}**
Sesbania sesban	0.39	0.42	0.46	0.53
Cajanus cajan	0.12	0.28	0.45	0.52
Leucaena pallida	0.12	0.25	0.37	0.47

Analysis of variance shows that there is a significant difference among the species and at different levels of hydrogels (Appendix I). Post Hoc analysis or mean separation was carried out to determine if there is significance difference among the species and at different levels of hydrogels as shown below;

Significance level was 0.05, df 6 (Appendix II). From T table the value is 1.943

LCD = 1.943√(0.004) * 2/4 (Appendix II) = 0.0614

If the difference between H15g and H11g ≥ LSD then you can reject the null hypothesis that the means are the same ($H_0:\mu_1 = \mu_2$). For this case the value 0.07 is less than 0.0614 so we can accept the null hypothesis. The same principles can apply to the other hydrogels levels and between the species

Comparative bar graphs showing effects of hydrogels on the height and RCD growth of *Sesbania sesban, Cajanus cajan* and *Leucaena pallida* at 3 months after transplanting are shown in Figures 16 and 17 respectively.

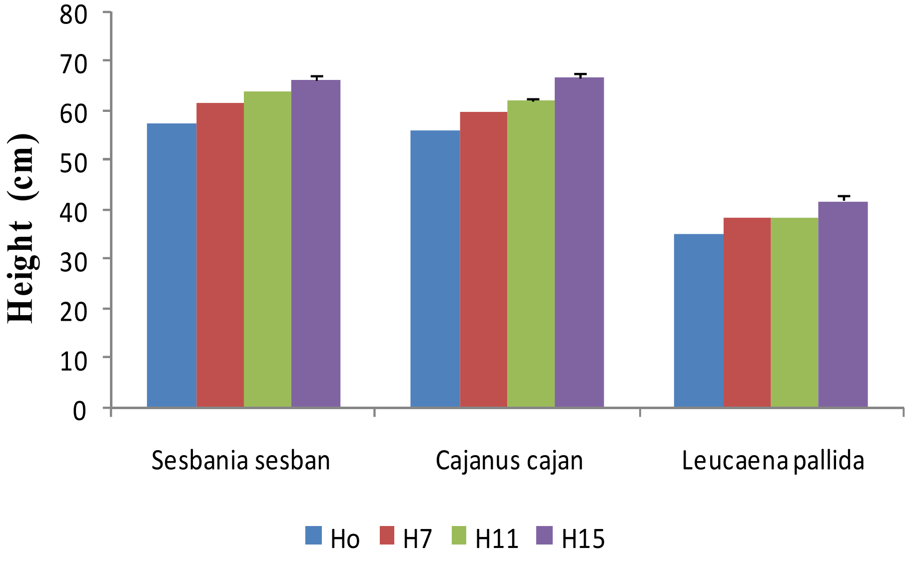


Figure 16: Height of seedlings three months after transplanting

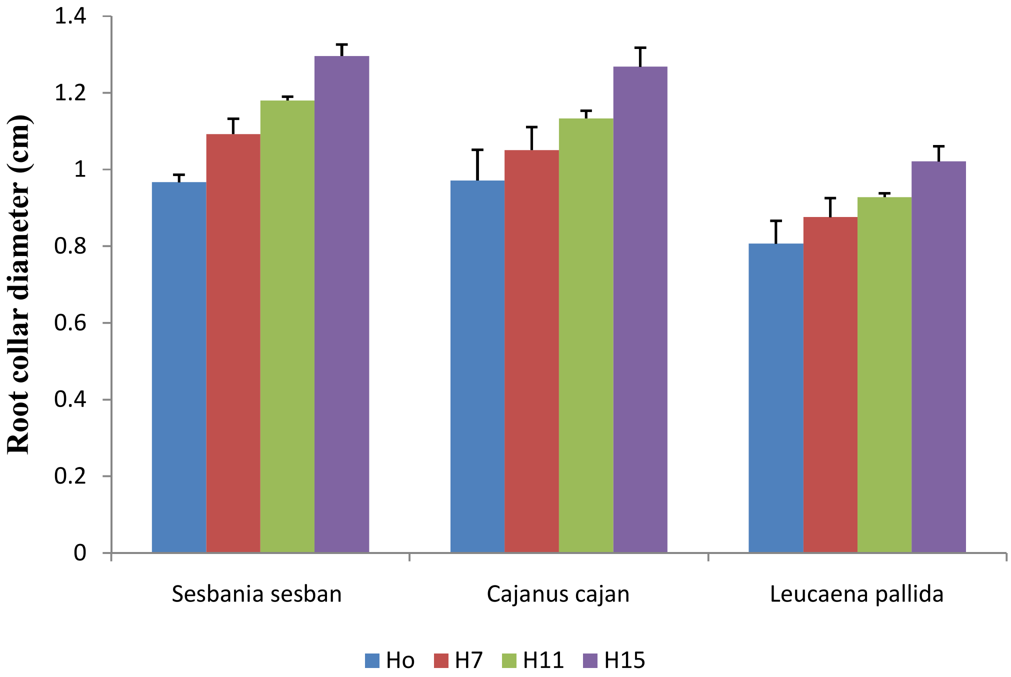


Figure 17: RCD of transplanted seedlings at 3 months.

4.1.9 Effects of hydrogels on soil moisture

Moisture content was determined after transplanting of seedlings as shown in figure 18 below.

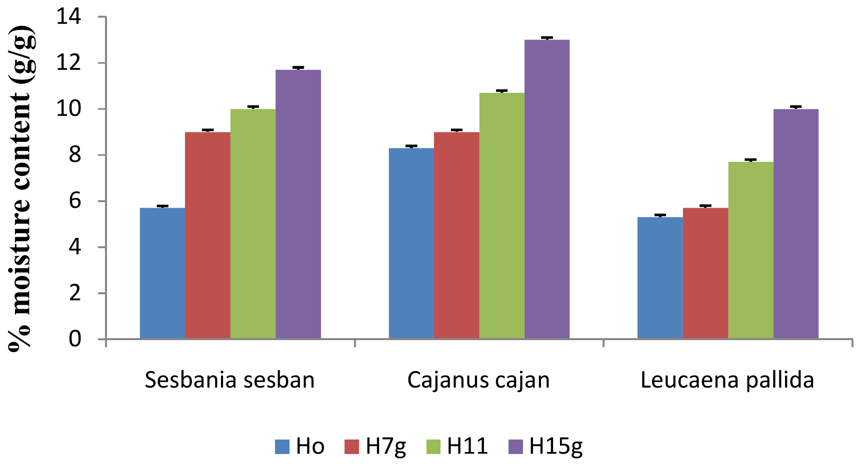


Figure 18: Soil moisture content after transplanting among the three species

Results showed that hydrogels has a significant impact on mean moisture content of soils collected from field sub-plots under transplanted seedlings among the different levels of hydrogels and a control in all the three tree species. Soils treated with 15g of hydrogels (H_{15g}) attained higher percentage moisture content than those that were and soils that was not treated with hydrogels attained least percentage moisture content (Figure 19 above). Analysis of variance (Appendix III) showed that $F_{calculated\ (0.05)} = 5.2690$, $F_{tabulated\ (critical)} = 4.0662$implying that hydrogels has a significant difference on the percentage moisture content within different levels of hydrogels and a control in all the species.

4.1.10 Soil pH

Table 5 below shows mean pH in all the treatment plots. Pure hydrogels had a pH of 9.84 while pure soils had a pH of 6.87. When agroforestry tree species were planted with hydrogels, soil pH was lowered from 9.84 (pure hydrogels) to 9.80, 9.71 and 9.76 under *Sesbania sesban, Cajanus cajan* and *Leucaena pallida,* respectively.

Table 5: Soil pH in plots with and without hydrogels amendments

Soil sample per species plot	**PH**
Pure hydrogels	9.84
Pure soils	6.87
S. sesban with hydrogels	9.80
S. sesban without hydrogels	6.05
C. cajan with hydrogels	9.71
C. cajan without hydrogels	6.53
L. pallida with hydrogels	9.76
L. pallida without hydrogels	6.69

When the agroforestry tree species were planted on pure soils without hydrogels, they lowered the soil pH from 6.87 (pure soil) to 6.05, 6.53 and 6.69 for *Sesbania sesban*, *Cajanus cajan* and *Leucaena pallida*, respectively. These results indicate that hydrogels are alkaline in nature (pH 9.84) and agroforestry tree species lower this alkalinity towards neutral. They suggest that they may be used to neutralize soils in areas with high soil pH and reduce it towards neutral for optimal growth of plants.

4.1.11 Soil nutrients

Soil nutrients released into the soil was analyzed in percentages and only major nutrients for plants growth was determined as shown in figure 19 below.

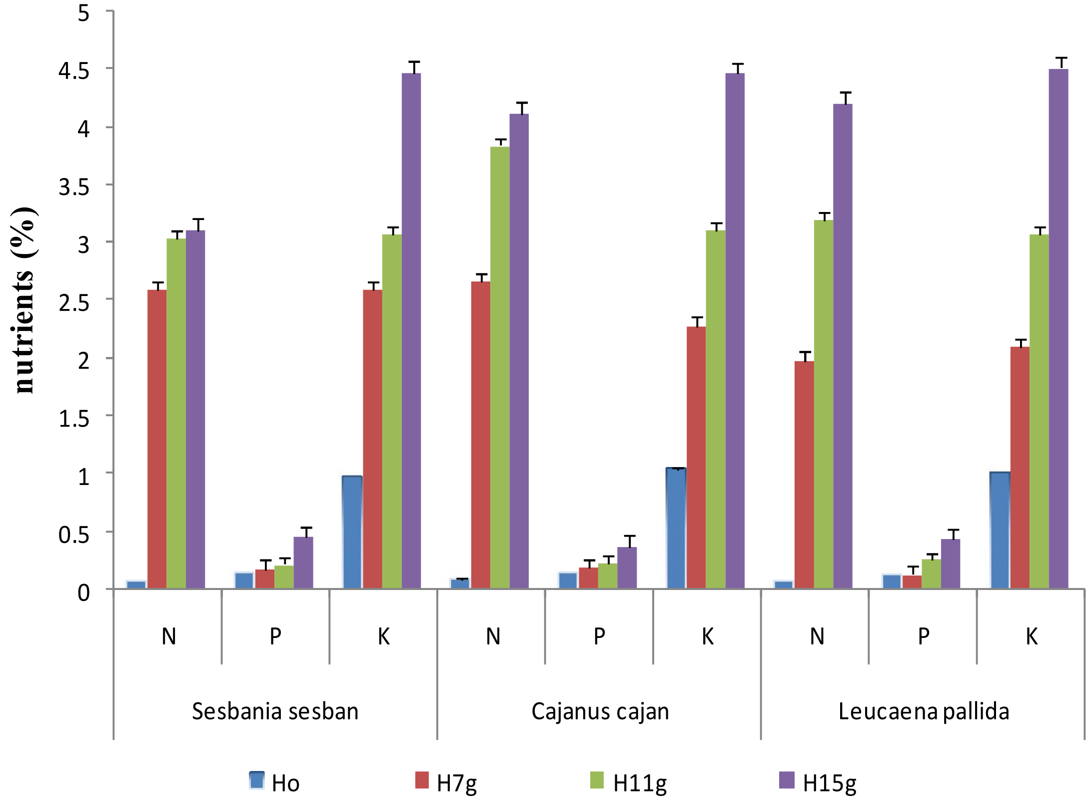


Figure 19: Nutrients released into the soil by agroforestry tree species after transplanting

Soils in the experimental site were poor in N and P but K is adequate (Figure 19) showing thresholds. However, analysis of the nutrient content of the hydrogels revealed that they were fortified with all macro elements (N, P and K). This could imply that the responses observed for the three agroforestry tree species (*S. sesban, C. Cajan and L. pallida*) could at least in part, due to the improved nutritional status of the soil in addition to the water availed by the hydrogels. Nutrients released into the soil for each of the species are shown in Figure 19 above. The major nutrients i.e. N, P & K were analyzed since seedlings require them for early growth. In all the species, seedlings treated with H_{15g} level of hydrogels gained higher percentages of nutrients as compared to other levels of hydrogels. In all the species, nutrients that were released into the soil at higher percentages were K, N and P in that descending order. This showed that soils in Kongelai were rich in potassium as compared to other nutrients apart from addition by the hydrogels.

Analysis of variance for nutrients released into the soil (appendix 4) showed that $F_{\text{calculated}\ (0.05)} = 5.4270$, $F_{\text{tabulated (critical)}} = 2.9011$. This implied that application of hydrogels in the soil had a significant effect on the growth of transplanted seedlings therefore, increasing soil nutrients released into the soil as compared to controls.

Table 6: Nutrients (%) released into the soil after transplanting of seedlings at three months

Hydrogels levels		H_o	H_{7g}	H_{11g}	H_{15g}
Pure hydrogels	N	-	2.0957	2.717	3.421
	P	-	0.012	0.018	0.023
	K	-	2.789	3.014	3.125
Pure soils	N	0.066	-	-	-
	P	0.129	-	-	-
	K	0.952	-	-	-
Sesbania sesban	N	0.087	2.592	3.043	3.107
	P	0.144	0.183	0.22	0.451
	K	0.984	2.591	3.078	4.468
Cajanus cajan	N	0.092	2.664	3.841	4.120
	P	0.144	0.192	0.231	0.378
	K	1.047	2.284	3.11	4.465
Leucaena pallida	N	0.088	1.984	3.193	4.208
	P	0.141	0.132	0.26	0.435
	K	1.015	2.095	3.078	4.513

Analysis of pure hydrogels in the laboratory (using 3 g samples), showed that hydrogels had 3.125% K, 0.023% P and 3.421% N at H_{15g} level of hydrogels (Table 3). When transplanted with agroforestry trees the level of nutrients increased in the soil to 4.468%

K, 0.451% P and 3.107% N, respectively at H_{15g} level of hydrogels on *Sesbania sesban* (Table 3). Higher levels of hydrogels released higher levels of nutrients into the soil. Similar results were obtained on *Cajanus cajan* and *Leucaena pallida*, showing that hydrogels improved soil nutrient content after transplanting together with agroforestry tree species.

CHAPTER 5

DISCUSSION

5.1 Effects of hydrogels on growth of seedlings

Hydrogels has negative impacts on the growth of seedlings in the nursery. Analysis of variance shows that there is a significant different on the growth of height and root collar diameter among the controls and at different levels of hydrogels. Similar results in which negative influences of hydrogels on the growth (height and root collar diameters) of seedlings in the nursery were observed have been reported from elsewhere. Landis and Haase (2012) in an experiment where leguminous tree seeds were coated with hydrogels before being sown in greenhouse or field soils showed mixed results between plant species with the larger seeded species surviving and growing better. Several hypotheses have been proposed with regard to possible explanations for this observation. One of these hypotheses was that coating seeds with hydrogels may have reduced germination and emergence by reducing aeration around the seeds. The other was related to the possible effect of excessive watering. In this case, the excess water filled the soil pores causing flooding in the polythene tubes therefore reducing growth of seedlings. Further lowering of seedling growth in treatment compared to control plots may have been due to the scorching effect of the nutrients supplied by the hydrogels in the polythene tubes. According to Antonio (2011) and Audun (2012), hydrogels would contribute to the scorching of seedlings during early growth in the polythene tubes in the nursery.

Another reason for the low growth of seedlings treated with hydrogels in the nursery may have been related to the state of soil water in the nursery at the time. Although hydrogels have capability to absorb water in the soil, effective watering of seedlings in the nursery may not have any impacts on the growth of seedlings unless under water deficit conditions (Alami, 2010). Bhat (2009) noted that the water holding properties of soil in the polythene tubes was affected by hydrogels when watering was done evenly in the nursery. Carminati and Moradi (2010) and Poormeidany and Khakdaman (2006) also reported similar observations on the impact of hydrogels on seedling growth in the nursery.

Soil water retention is important for the study of water availability to germinating seeds because it fills vacant spaces, causes gel swelling and reduces soil air. Excess water leads to negative impacts when interacted with hydrogels because of the later's capacity to swell and capacity to absorb water. The negative impacts of hydrogels on seedlings growth in the nursery were further ascertained by John *et al*. (2012). Naderi (2006) found out that hydrogels reduced swelling ability in polythene tubes in the nursery hence having negative impacts on the growth of seedlings. Celemente *et al.* (2006) and Sarvas *et al.* (2007) reported hydrogels to have nitrogen known to contribute positively to the growth of seedlings in the polythene tubes but also to have scotching effects on seedlings when applied in higher amounts during early growth. These authors reported that an overdose application of hydrogels can produce negative effects in some cases due to filling of pores in the soil reducing aeration due to the swelling ability of gel.

In a container, hydrogels addition into the soil medium has shown overall reduction in plant stress due to occupation of many vacant spaces of soil causing severe reduction in soil ventilation and the amount of water available in the plants (Abedi-Koupai, 2010). Alami (2010) stated that applying super absorbent on *Lolium pernne* in 6g/1kg of soil significantly enhanced performance of some characters, but application of a higher amount of 9g/1kg of soil lessened the performances in the nursery. Application of 7g per planting hole of hydrogels granules caused over-dosage and plant mortality. The application of hydrogels granules is simple but very complicated so as not to cause over-dose because of the very high swelling capacity of hydrogels (Alami, 2010; Kelly, 2012). Sarvas *et al.* (2007), in an experiment on *Pinus sylvestris* seedlings observed that by over-using super absorbent with applications of over 14 g/kg of soil, plants were more likely to be exposed to *Fusarium* diseases and mostly perished. They suggested that some investigations needed to be carried out to find out the most suitable amount of hydrogels in different situations and for different plant species. Results of another investigation (Sarvas *et al*., 2007) showed that addition of polymer up to 0.3% had a positive effect on plant growth, but concentration over 0.4% had negative effects.

According to authors' (Kelly, (2012); Audun, (2012) responses of moisture requiring plants to hydrogels in containers reduced their growth unless when moisture content was inadequate

5.2 Effects of hydrogels on height of seedlings in the field

Results shows that hydrogels has positive impacts on the growth of seedlings after transplanting. Analysis of variance shows that there is a significant different on the growth of height and root collar diameter among the controls and at different levels of hydrogels in all the three species.

Similar results in which positive influences of hydrogels on the growth (height and root collar diameter) of seedlings after transplanting in moisture stress areas have been reported from elsewhere. Michael (2010) and Amba *et al.* (2011) in an experiment on the effects of soil hydrogels amended media on the early establishment of seedlings in semi-arid areas showed that hydrogels absorbed water which improved seedling growth. In these cases, it was suggested the positive influence of hydrogels was a result of improved water holding capacity and supplying to the seedlings during water stress periods.

Other results have also been reported on the positive impacts of hydrogels on the growth of seedlings in arid environments. Specht (2000) and Raja *et al*. (2013) ascertained that super absorbent (gels) have been used to establish tree seedlings and transplants in the arid regions of Africa resulting in increased plant survival and higher height and RCD growth of seedlings treated with hydrogels as compared to controls. Gunes (2007); Moftah (2007) and Abedi-Koupai (2010) observed the ability of hydrogels to absorb water was used successfully in agriculture and forest restoration in dry areas to improve plant growth. Other authors' who achieved positive results in which soil media amended with hydrogels supported improved growth of transplanted seedlings under moisture stress environment include; Starkey *et al.,* (2012); Sarvas *et al.,* (2007); Saha *et al*. (2012) and Raja *et al.* (2013). These results are likely due to the fact that hydrogels have the capability of absorbing soil moisture and releasing it to the roots of the plants during dry seasons hence making it survive in semi-arid and arid areas.

Other observations on the positive effects of hydrogels after transplanting have been reported by Esler (2004) and Oyelade and Aduba (2012). These authors evaluated the effect of different cultivation methods with addition of either organic mulch or hydrogels on seedling emergence of indigenous plant species in South Africa. Seedling emergence was higher in areas where seed and hydrogels were sown together. Water retained per kilogram of polymer increased with an increase in polymer concentration in sand while undergoing desorption, but absorbed water decreased with polymer concentration during absorption, indicating an effect of hysteresis and absorption kinetics in the water absorption process. These could be the same reasons why hydrogels were able to absorb water in the transplanted seedlings as compared to their controls. Similar results were reported by Moftah *et al*. (2007) on the early growth of transplanted *Conocarpus erectus* under moisture stress in sandy soil amended with hydrogels at 0.6%. The young transplants treated with hydrogels showed 3 times higher survival than control plants.

5.3 Effects of hydrogels on soil moisture

These results concur with those obtained from similar trials elsewhere. In an experiment conducted under semi-arid conditions to evaluate water holding capacity of hydrogels in three kinds of soil, hydrogels increased water holding capacity in the soil by 7.29 % and 1.5 times their control as reported by Sohrab (2004) and Bhat *et al*. (2009) respectively. This could be due to the fact the hydrogels are hydrophilic in nature, hence absorb moisture in the soil and later on release it to the plant during dry period. This property enables it for successful establishment and survival of seedlings in arid and semi-arid lands. Reporting similar results in experiments under soil moisture stress environments Kimondo (2000), Akhter (2004) and Landis and Haase (2012) found out that hydrogels improved soil moisture content in the soil and provided water to the plants during the dry season. In other experiments conducted by Mousavinia (2006), Karimi *et al.* (2008) and Raja *et al.* (2013) using hydrogels helped to improve water holding capacity in soils, thus providing plants with moisture during dry periods, thereby hastening plant growth in arid and semi arid lands. Varennes (2010) and Atieh (2010) stated that hydrogels would improve moisture content in the soil when used to boost growth of seedlings in arid zones. This implies that the use of hydrogel amendments as a cultural practice can be useful in increasing plant establishment in drought prone environments. Hydrogels have capability to absorb moisture forming a gel which acts as a water reservoir for transplanted seedlings during dry periods.

5.4 Soil Ph

These results indicate that hydrogels are alkaline in nature (pH 9.84) and agroforestry tree species lower this alkalinity towards neutral. They suggest that they may be used to neutralize soils in areas with high soil pH and reduce it towards neutral for optimal growth of plants.

5.5 Effects of hydrogels on soil nutrients

The nutrient status of pure soils in the pre-tested sample plots (using 3g samples) was: 0.952% K, 0.129% P and 0.066% N. After the introduction of agroforestry trees, the amount of nutrients rose i.e. to 0.984% K, 0.144% P and 0.087% N, respectively for *Sesbania sesban* at H_0 level of hydrogels. Similar results were observed in *Leucaena pallida* and *Cajanus cajan*. This showed that agroforestry tree species improved the amount of nutrients in the soil alongside the hydrogels. Therefore, they may be used for restoration of degraded lands in arid and semi arid areas.

According to the results, hydrogels had positive impacts on the nutrients released into the soil after transplanting of seedlings. Analysis of variance showed significant differences on the effects of hydrogels on nutrients released into the soil of transplanted seedlings among the controls and at different levels of hydrogels.

Similar results have been reported by other researchers. Akhter *et al.* (2004) and Antonio *et al.* (2011) in an experiment on the effects of hydrogels on plant nutrition ascertained that hydrogels application improved soil plant nutrition in arid and semi-arid lands, although they didn't give percentages on the particular level of hydrogels. This showed that when hydrogels were applied to the soil, the major nutrients: N, P & K increased (Table 2). This implied that hydrogels were rich in nutrients that helped to improve soil fertility in addition to absorbing soil moisture in water stressed environments. Several hypotheses have been proposed with regard to possible explanations for this observation. According to Kimondo (2000), Moftar (2007), Abedi-Koupai (2010) and Mark *et al.* (2012), whose conclusions agreed with the findings of this study, use of hydrogels increased not only moisture content but also nutrient availability to plants.

Furthermore, Antonio *et al.* (2011) found that application of hydrogels in soils during transplanting could improve potassium in higher percentages compared to other major nutrients required by the plant during early stages of growth. This could be due to the fact that arid lands have higher levels of potassium compared to other nutrients because of their salinity. Potassium was the major nutrient in ASALs as compared to nitrogen and phosphorus, respectively (Figure 20). This therefore confirms that arid lands are endowed with adequate levels of potassium compared to other nutrients

According to authors' of some literature, hydrogels contribute to the survival of transplanted seedlings in arid and semi-arid environments by providing plants with moisture and nutrients. Karimi *et al.* (2008) and Endrias (2013) ascertained that hydrogels increased uptake of nutrients (N, P & K) in a variety of soils to improve plant growth in arid and semi arid lands. Sohrab (2006), Bhat *et al.* (2009) and Qu, (2010) found out that hydrogels increased moisture content and major nutrients in soils to boost growth of plants in arid and semi arid lands, thus confirming that hydrogels increased soil nutrients release into the soil.

CHAPTER SIX

CONCLUSION AND RECOMMENDATION

6.1 CONCLUSION

The results of the study led to the following conclusions; hydrogels was found to retards height and root collar diameter growth of seedlings in the nursery but it had a positive impact after transplanting. The application of 7 g per 800g of soil in the polythene tube in the nursery led to over dosage because of high swelling capacity of hydrogels therefore leads to higher mortality of seedlings in the nursery. However hydrogels application in the nursery is done when water is inadequate. The higher level of hydrogels (H_{15g}) gained higher growth as compared to H_{11g} and H_{7g} respectively after transplanting (Figure 17 and 18). This implied that hydrogels work well in arid and semi arid areas when moisture content is inadequate. Hydrogels at 15g give optimum results.

Hydrogels when incorporated into growing media or soil absorbs moisture in the environment and retain water; therefore is suitable for use in arid and semi arid areas to increase plants survival after transplanting. Seedlings that were treated with H_{15g} level of hydrogels gained 10.9 % in moisture content as compared to H_{11g} (9.5%) and H_{7g} (7.9 %) respectively.

Hydrogels supplied the plant with major nutrients (N, P & K) apart from moisture content. When applied as a root dip, hydrogels can release nutrients into the soil. Potassium was the adequate nutrient that was supplied into the soil by hydrogels, nitrogen and phosphorus respectively (Figure 20). Higher amount of nutrients were experienced in seedlings treated with $H_{15}g$ level of hydrogels than $H_{11}g$ and H_7g respectively (Figure 20).

The hydrogels amendments improved seedling growth and establishment by increasing water retention capacity and supplying nutrients to the plants, hence increasing survival in arid environments.

6.2 RECOMMENDATION

The following recommends are made in reference to the conclusions above; hydrogels to be used in the transplanted seedlings to increase the growth of seedlings in arid and semi arid areas but it should not be used in the tree nurseries unless water scarcity is a problem. Hydrogels level of 15g is highly recommended to be used in the transplanted seedlings.

Further studies to be done on hydrogels effects on a range of soil types using a wide range of tree species and tree species suitable for growing in different soil type's under water stress conditions.

More research to be done on the influence of hydrogels addition on soil moisture retention properties and in the response of different species for specific hydrogels required by different soil types.

More research to be done on the need for a longer term experiment with hydrogels in the field.

REFERENCES

Abedi-Koupai, J. (2010). Effects of Superabsorbent polymer on water requirement and growth of Ficus Benjamina. *Journal of Plant Nutrition Volume 33, Issue 6, 2010.*

Abedi-Koupai, J. and Sohrab F. (2004). Effect evaluation of superabsorbent application on water retention capacity and water potential in three soil textures. *J. Sci. Technol. Polym.* 17(3), 163-173.

Abedi-Koupai, J. and Sohrab F. (2006). *Study of different soil usable water under addition of hydrogels and compost*. Isfahan University of Technology, Iran.

Abedi-Koupai, J. and Mesforoush, M. (2009). Evaluation of superabsorbent polymer application on yield, water and fertilizer use efficiency in cucumber (*Cucumis sativus*). *J. Irrigation and Drainage.* 2(3), 100-111.

Abedi-Koupai, J. Eslamian, S. and S. Asadkazemi (2008). Enhancing the available water content in unsaturated soil zone using hydrogels, to improve plant growth indices. *Ecohydro. Hydro.* 8(1), 67-75.

Abedi-Koupai, J. F. Sohrab and G. Swarbrick (2008). Evaluation of Hydrogels Application on Soil Water Retention Characteristics, *J. Plant Nutr.*2008, 31, 317.

Ajayi, O. C. (2007). User acceptability of sustainable soil fertility technologies lessons from farmer’s knowledge, attitude, and practice in Southern Africa. *Journal of Sustainable Agriculture*, 30: 21−40.

Akhter, J., Mahmood, K., Malik, K., A. Mardan, A. Ahmad, M. and Iqbal, M. M. (2004). Effects of hydrogels amendment on water storage of sandy loam and loam soils and seedling growth of barley, wheat and chickpea. *Plant Soil Environ.* 50, 463-469.

Amba, A. A., Agbo, E.B., Voncir, N. and Oyawoye, M.O. (2011). Effect of phosphorus fertilizer on some soil chemical properties and nitrogen fixation of legumes at Bauchi. *Continental J. Agricultural Science* 5 (1): 39 - 44, 2011 ISSN: 2141 – 4203.

Alami, M. (2010). *Study the effect of superabsorbent and Paclobutrazul on water requirement reduction of Lolium pernne.* L. Msc Thesis, Ferdowsi University of Mashhad. 46p.

Amel Idris, O. and Sirelkhatim Ahmed (2012). Phosphorus sorption capacity as a guide for phosphorus availability of selected Sudanese soil series. Land and Water Research Center, Agricultural Research Corporation, P. O. Box 126, WAD Medani, Sudan. *African Crop Science Journal, Vol. 20, Issue Supplement s1, pp.* 59 - 65 ISSN 1021-9730/2012.

Antonio, D. Del Campo, Javier Hermoso, Jaime Flors, Antonio Lidon and Rafael, M. Navarro-Cerrillo (2011). Nursery location and potassium enrichment in Aleppo pine stock 2. Performance under real and hydrogels-mediated drought conditions. *Forestry, Vol.* 84, No. 3, 2011. doi:10.1093/forestry/cpr009.

Arndt Schmidt, T. Richter, A. and Kuckling, D. (2004). High response smart gels. Synthesis and applications. *Macromol Symp* 207:257–268.

Atieh Energy Talash and Anonymous (2010). Using hydrogels application and guide. Published by St., Tehran, Iran No. 620 http://www.superjazeb.com/references.htm (accessed on 8th June, 2013).

Audun Korsaeth (2012). N*, P, and K Budgets and Changes in Selected Topsoil Nutrients over 10 Years in a Long-Term Experiment with Conventional and*

Organic Crop Rotations. Arable Crops Division, Norwegian Institute for Agricultural and Environmental Research, 2849 Kapp, Norway.

Bartnik, C. (2008). Wpływ hydrożelu Alscorb na przeżywalność siewek i sadzonek sosny pospolitej w warunkach suszy. [*The influence of hydrogels on the survival rate of seedlings and the plants of the Pinus Syvestris L. during drought*]. *Studia i Materiały Centrum Edukacji Przyrodniczo-Leśnej R. 10. Zeszyt* 2(18)/2008.

Bhat, N. R. Suleiman, M. K. Al-Menaie, H. Al-Ali, E.H. AL-Mulla, L. Christopher, A. Lekha, V. S. Clemente, R. Almela, C. and Bernal, M. P. (2009). A remediation strategy based on active phytoremediation followed by natural attenuation in a soil contaminated by pyrite waste. *Environ. Pollut.* 143, 397–406. The 1st National Congress of Irrigation and Drainage Networks Management. Ahwaz. 9p.

Braun, H. M., Sombroek, W. G. and Van Der Pouw, B. J. A. (1982). *Exploratory soil map and agro-climatic zone map of Kenya, 1980,* scale 1:1,000,000. Exploratory Soil Survey Report No. E1. Kenya Soil Survey, Nairobi.

Bruno Glaser, Anke Jentsch, Juergen Kreyling and Carl Beierkuhnlein (2013). Soil moisture change caused by experimental extreme summer drought is similar to natural inter-annual variation in loamy sand in Central Europe. *J. Plant Nutr. Soil Sci.* 2013, 176, 27–34 DOI: 10.1002/jpln.201200188 27.

Carminati, A. and Moradi, A. (2010). *How the soil root interface affects water availability to plants.* Geophysical Research Abstracts 12.1 p. URL: http://meetingorganizer.copernicus.org/EGU2010/ EGU2010-10677.pdf. (Accessed 19th May, 2013).

Celemente, N. and Sivapalan, S. (2006). Some benefits of treating a sandy soil with a cross- linked type polyacrylamide. *Aust. J. Exp. Agric.* 46, 579-584.

Chen, S., Zommorodi, M., Fritz, E., Wang, S. and Huttermann, A. (2010). Hydrogels modified uptake of salt ions and calcium in *Populus euphratica* under saline conditions. *Tree-Struc. Func.* 18(2), 175-183.

Christopher Brock, Uwe Franko, Hans-Rudolf Oberholzer, Katrin Kuka, Gunter Leithold, Hartmut Kolbe and Jurgen Reinhold (2013). Humus balancing in Central Europe concepts, state of the art, and further challenges. *J. Plant Nutr. Soil Sci.* 2013, 176, 3–11 DOI: 10.1002/jpln.201200137 3.

Curtis Adams, Jonathan Frantz and Bruce Bugbee (2013). Macro- and micronutrient release characteristics of three polymer-coated fertilizers: Theory and measurements. Department of Plants, Soils, and Climate, Utah State University, 4820 Old Main Hill, Logan, UT 84322, USA. *J. Plant Nutr. Soil Sci.* 2013, 176, 76–88.

Desertification (2006). GreenFacts Scientific Board. Retrieved November 24, 2010 from **http://www.greenfacts.org/en/desertification/l-2/6-prevention-desertification.htm** (accessed on 10th June, 2013).

Dhanya, B., Syam Viswanath and Seema Purushothaman (2013). Decomposition and Nutrient Release Dynamics of *Ficus benghalensis.* L. Litter in Traditional Agroforestry Systems of Karnataka, Southern India. *Hindawi Publishing Corporation ISRN Forestry Volume 2013,* Article ID 524679, http://dx.doi.org/10.1155/2013/524679.

Eileen May Dee, Mark McGinley and C. Michael Hogan (2010). *Long-finned pilot whale*. Encyclopedia of Earth. National Council for Science and the Environment. Washington DC.eds. Peter Saundry and Cutler Cleveland.

Endrias Geta, Ayalneh Bogale, Belay Kassa and Eyasu Elias (2013). Determinants of Farmers' Decision on Soil Fertility Management Options for Maize Production in Southern Ethiopia. *American Journal of Experimental Agriculture* 3(1): 226-239, 2013 SCIENCEDOMAIN international. www.sciencedomain.org

Eni, D. D., A. I. Iwara and R. A. Offiong (2012). Analysis of Soil Vegetation Interrelationships in a South-Southern Secondary Forest of Nigeria. *Hindawi Publishing Corporation International Journal of Forestry Research Volume 2012,* Article ID 469326, doi:10.1155/2012/469326.

Esler, K. (2004). Old Field Restoration: An Assessment of the influence of restoration techniques on the establishment of selected Karoospecies. *Elsenbugh Journal* 3-7.

Evans, D.O. (2001). *Sesbania sesban*: Widely distributed multipurpose NFT. In: Roshetko, J.M. (ed.) Agroforestry Species and Technologies. pp. 157-158. Winrock International, Morilton, USA.

Evans, R.Y. and Bowman, D. C. (1999). Calcium inhibition of polyacrylamide gel hydration is partially reversible by potassium. *Horticultural Science* 26, 1063-1065.

FAO. (2010): Forest Resources Assessment Report. Food and Agriculture Organization of the United Nations (FAO).

FAO (2007a). *Desertification, drought and their consequences*. Rome: Food and Agriculture Organization of the United Nations (FAO).

FAO (2007b). *Deforestation: Tropical forests in decline*. Rome: Food and Agriculture Organization of the United Nations (FAO).

Friedel, J. K. (2000). The effect of farming system on labile fractions of organic matter in Calcari-Epileptic Regosols. *J. Plant Nutr. Soil Sci.* 163*,* 41—45.

Fuller, D.Q. and Harvey, E. (2006). The archaeobotany of Indian Pulses: identification, processing and evidence for cultivation. *Environmental Archaeology* 11(2), 219-246.[1].

Gachene and Kimaru, G. (2003). *Soil Fertility and Land Productivity- A guide for Extension Workers in Eastern Africa region*. Technical Handbook No. 30. Regional Land Management Unit / Swedish International Development Cooperation Agency.

Gehring (2010). Effect of hydrophilic polymer on wilting and moisture stress of bedding plants, *J. Am. Soc. Horticul. Sci.,* 105, 511-513.

Genhua, N. and Denise, S. R. (2006). Relative salt tolerance of selected herbaceous perennials and groundcovers. *Hort Science.* 100, 218-305.

Ghosh, M. and Khushkhui, M. (2008). Effects of superabsorbent polymer on irrigation interval and growth and development of Chrysanthemum (Dendranthema × grandiflorum Kitam.). *J. Sci. Technol. Iran.* 8(2), 65-82. *Hort Science.* 110, 352-358.

Glaser Maria, I. E. Margarida M. Santana, Maria C. Portillo, and Juan M. Gonzalez (2013). Characterization of new soil thermophilic bacteria potentially involved in soil fertilization. Instituto de Ciências Agrárias e Ambientais

Mediterrânicas (ICAAM), *J. Plant Nutr. Soil Sci.* 2013, 176, 47–56 DOI: 10.1002/jpln.201100382 47.

GoK (2004). *National policy for the sustainable development of the arid and semi-arid lands of Kenya (Draft)*. Government of Kenya. Nairobi, Kenya.

GoK (2004). *Strategy for revitalizing agriculture 2004-14*. Government of Kenya. Nairobi, Kenya.

GoK (2010a). *National Climate Change Response Strategy*. Ministry of Environment and Mineral Resources. Government of Kenya. Nairobi, Kenya.

GoK (2003). *Draft national policy for the sustainable development of the arid and semi-arid lands of Kenya*. Government of Kenya. Nairobi, Kenya.

Guiwei, J. A. and Rosomoff, R. N. (2009). *In the Shadow of Slavery. Africa's Botanical legacy in the Atlantic World*. Berkeley: University of California Press

Gunes, T. (2007). Effect of polymer on seedlings survival and growth of transplanted tomato under water stress. *Asian J Chem* 19(4):3208–3214.

Haraguchi, K. and Takehisa, T. (2008). Nanocomposite hydrogels: a unique organic-inorganic network structure with extraordinary mechanical, optical and swelling/deswelling properties. *Adv Mat* 14:1120–1124.

http://www.greenprophet.com/2012/05/a-funturistic-hydrogels-to-grow-food-0n-desert-sand/4th may,2013.

http://www.fao.org/ag/AGP/AGPC/doc/Publicat/Gutt-shel/x5556e08.htm/12th April,2013.

http://www.icrisat.cgiar.org/text/research/grep/homepage/pigeonpea/pigeonpea.htm/1st June,2013.

http://www.springerlink.com/content/g78774q222672082/fulltext.pdf/23th April, 2013.

https://en.wikipedia.org/wiki/Counties_of_Kenya/9th September, 2015.

http://www.winrock.org/forestry/factpub/factsh/SESBAN.HTM/16th May 2013.

http://www.worldagroforestry.org/Sites/TreeDBS/AFT/SpeciesInfo.cfm?SpID=1753/4thJune ,2013.

John W. Bullied, Paul R. Bullock, Rene C. and Van Acker (2012). Modeling Soil Water Retention for Weed Seed Germination Sensitivity to Water Potential. *Hindawi Publishing Corporation Applied and Environmental Soil Science Volume 2012, Article ID* 812561, doi:10.1155/2012/812561.

Johnson H. and Leah K. (1990). Low-molecular weight organogelators. In: Robb ID, editor. Specialist surfactants. Glasgow: *Blackie Academic and Professional, p.* 208–268 (1997).

Johnson Jones, N. W. Blackhall, J. B. Power, M. R. Davey, Veltkamp E. C. Cocking and Hartman T. P. (2006). Helmut Guttenberger. ed. "Cytogenetics, Molecular Cytogenetics, and Genome Size in *Leucaena* (*Leguminosae*, *Mimosoideae*)". Cytogenetic Studies of Forest Trees and Shrubs: Review, Present Status, and Outlook on the Future: Proceedings of the Second IUFRO Cytogenetics Working Party S2.04.08 Symposium, September 6–12, 1998, Graz, Austria: 57–70

Karimi A., Noushadi M. and Ahmad Zadeh M. (2008). Effect of water superabsorbent (Igita) amendment material on water soil, plant growth and irrigation intervals. *J. Sci. Tech. Agric. Natural sour.* 46, 403-414.

Kelly J. M. and J. L. Kovar (2012). Modeling Phosphorus Capture by Plants Growing in A Multispecies Riparian Buffer. *Hindawi Publishing Corporation Applied and*

Environmental Soil Science Volume 2012, Article ID 838254, doi:10.1155/2012/838254.

Khan F., K. Ejaz, M. Ramzan, Z. Shah, Naveedulla, M. Sharif, M. Afzal and M. J. Khan (2012). Extent of nutrient deficiencies and degradation of selected soil properties in water eroded soils of district Muzaffarabad, Pakistan. Sarhad. *J. Agric.* 28(4): 571-578.

Kimondo, M. James and Kioko, M. Joseph (2000). *A Manual for Tree Nursery Management: A practical guide on Tree Nursery Practices*. A Kenya Forestry Institute (KEFRI)/Forest Department (FD) German Development Co-operation (GTZ) publication under the auspices of the Promotion of Sustainable Forest Management Project.

Kumar, R. and Katare, O. P. (2005). *Lecithin organogels* as a potential phospholipid-structured system for topical drug delivery: A review. American Association of Pharmaceutical Scientists. *Pharm Sci Tech 6,* E298–E310 (2005).

Lal, R. (2004). Soil carbon sequestration impacts on global climate change and food security. *Science, 304:* 1623−1629.

Landis, T.C. and Haase, D.L. (2012). *Applications of hydrogels in the nursery and during out planting.* In: Haase DL, Pinto JR, Riley LE, technical coordinators. National Proceedings: Forest and Conservation Nursery Associations 2011. Fort Collins (CO): USDA Forest Service, Rocky Mountain Research Station. Proceedings RMRS-P-68. 53-58.

Leciejewksi Chirino E., Vilagrosa A., Cortina J., Valdecantos A., Fuentes D., Trubat R., Luis VC., Puértolas J., Bautista S., Baeza J., Peñuelas J. and

Vallejo V. (2008). Ecological restoration in degraded drylands: the need to improve the seedling quality and site conditions in the field. In: Grossberg SP (ed) Forest management. *Nova Publisher, New York,* pp 85–158.

Lin, W. J. (2004). Effects of Hydrogels on the Growth of Seedlings and Their Physiological Properties under Drought Stress, *Arid Zone Res.* 2004, 21, 353.

Lithourgidis Tan and S. Liu (2013). Baseline-Dependent Responses of Soil Organic Carbon Dynamics to Climate and Land Disturbances. ARTS, US Geological Survey (USGS), Earth Resources Observation and Science (EROS) Center, 47914 252nd Street, Sioux Falls, SD 57198, USA. *Hindawi Publishing Corporation Applied and Environmental Soil Science. Article ID* 206758, http://dx.doi.org/10.1155/2013/206758.

Luo W.Y., Fox JED and Xu Z.F. (2011). Leaf litter decomposition of canopy trees, bamboo and moss in a montane moist evergreen broad-leaved forest on Ailao mountain, Yunnan, Southwest China. *Ecological Research,* 15:435−447.

Macharia P. N., Thuranira W. Ng'ang'a, J. Lugadiru and S. Wakori (2012). Perceptions and adaptation to climate change and variability by immigrant farmers in semi-arid regions of Kenya. *African Crop Science Journal, Vol. 20, Issue Supplement s2, pp.* 287 - 296 ISSN 1021-9730/2012.

Mark Nijnik, Arie Oskam and Anatoliy Nijnik (2012). Afforestation for the Provision of Multiple Ecosystem Services: A Ukrainian Case Study. *Hindawi Publishing Corporation International Journal of Forestry Research Volume 2012, Article ID* 295414, doi:10.1155/2012/295414.

Mark Watkins, Hayley Castlehouse, Murray Hannah and David M. Nash (2012). *Nitrogen and Phosphorus Changes in Soil and Soil Water after Cultivation. Future Farming Systems* Research Division, Department of Primary Industries, 1301 Hazeldean Road Ellinbank, VIC 3821, Australia.

Michael Shutao Chen, Yao Huang, Jianwen Zou, Qirong Shen, Zhenghua Hua, Yanmei Qin, Haishan Chen and Genxing Pan (2010). *Modeling Inter-annual Variability of Global Soil Respiration from Climate and Soil Properties*. College of Environmental Science and Engineering, Nanjing –China.

Mousavinia M. and AtaPoor A. (2006). *Study the effects of superabsorbent polymer (A200) on turf grass irrigation reduction*. The 3rd National Congress on Superabsorbent Hydrogels Agricultural Application. Iran Polymer & Petrochemical Inst.

Muchiri Kamondo, B. Ochieng, Tuwei P. and Wanjiku (ed) (2009). *Kenya Forestry Research Institute Proceedings' of the 4th KEFRI Scientific Conference.* Recent advances in Forestry Research for Environmental Conservation, Improved livelihood and Economic Development. Published by KEFRI 2009.

Muhammad Waseem, Asghar Ali, M. Tahir, Nadeem, M. Ayub, Asif Tanveer, R. Ahmad and M. Hussain (2011). Mechanism of drought tolerance in plant and its management through different methods. Department of Agronomy, University of Agriculture, Faisalabad, 38040, Pakistan. *Continental J. Agricultural Science* 5 (1): 10 - 25, 2011 ISSN: 2141 – 4203. http://www.wiloludjournal.com

Moftah, A.E. and Humaid, A.I. (2007). Effects of hydrophilic polymer on the survival of buttonwood seedlings grown under drought stress. *J Plant Nutr* 30:53–66. doi:10.1080/0190416060105497.

Muyayabantu G. M., B. D. Kadiata and K. K. Nkongolo (2013). Assessing the Effects of Integrated Soil Fertility Management on Biological Efficiency and Economic Advantages of Intercropped Maize (*Zea* Mays) and Soybean (*Glycine Max*) in DR Congo. *American Journal of Experimental Agriculture* 3(3): 520-541, 2013 SCIENCEDOMAIN international www.sciencedomain.org

Naderi F. and Vasheghani Farahani (2006). Increasing soil water holding capacity by hydrophillic polymers. *J. Sci. Wat. Soil. Iran.* 20(1), 64-72.

Nursery Technology Cooperative (NTC) (2009). Efficacy of Zeba to mitigate moisture stress in Douglas-fir seedlings. NTC Annual Report, Oregon State University, Department of Forest Science, Corvallis, OR: 21-22.

Okalebo R. J., Gathua K.W. and Woomer P.L. (2002). Laboratory methods of soil and Plant analysis. 2nd Ed. *A working manual.* 29-54.

Okay O. (2002). Macroporous copolymer networks. *Prog Polym Sci* 25:711–779.

Okay O. and Oppermann W. (2007). *Polyacrylamide clay nanocomposite hydrogels: rheological and light scattering characterization*. Macromolecules 40:3378–3387.

Okorie F.C. (2003): *Studies on Drought in the Sub-Saharan Region of Nigeria using Satelite Remote Sensing and Precipitation Data*; Department of Geography, of Lagos, Nigeria.

Oyelade O. A. and Aduba J. J. (2012). Effects of tillage operations on soil physical properties: a case study of sandy loam and clay loam soils. National Centre for Agricultural Mechanization (NCAM), PMB 1525, Ilorin, Kwara State, Nigeria. *Continental J. Environmental Sciences* 6 (2): 7 – 17, 2012 ISSN: 2141 – 4048 and doi:10.5707/cjenvsci.2012.6.2.7.17. http://www.wiloludjournal.com

Paluszek J., Zembrowski W. (2006). Wpływ hydrożelu Stockosorb na strukturę agregatową gleb erodowanych. [*The influence of Stockosorb hydrogels on aggregate structure of erodated soils*]. *Roczniki* Akademii Rolniczej w Poznaniu. Rolnictwo. *Zesz.* 65 (375): 115–122.

Peterson D. (2002). Hydrophilic polymers - effects and uses in the landscape. Restoration and Reclamation Review. *Vol 7S. 16 p. Plant Health Care.* Website: http://www.planthealthcare.com (Accessed 18 Nov 2010).

Pinheiro C. and M. Chaves (2011). Photosynthesis and drought: can we make metabolic connections from available data. *J. of Exp. Bot., Vol.* 62, No. 3,869–882.

Poormeidany A. and Khakdaman H. (2006). Study of Aquasorb polymer application on irrigation of *Pinus eldarica*, *Olea europea* and *Atriplex canescens* seedlings. *Iran. J. For. Invest .poplar.* 13(1), 79-92.

Pratt, D. (1999). *Notes on the economics of pastoralism and rangeland development in northern Kenya* (from the GoK National Policy for the Sustainable Development of the Arid and Semi-arid lands; 4th draft of March 2004).

Princeton.edu. (2012). *Acta Materialia*, 85(0), 199-206. ScholarID: 243364 | DOI:http://dx.doi.org/10.1016/j.actamat.2014.11.009.

Unger, N.B., D.T. Shindell, D.M. Koch, M. Amann, J. Cofala, and D.G. Streets, (2006). Influences of man-made emissions and climate changes on tropospheric ozone, methane and sulfate at 2030 from a broad range of possible futures. *J. Geophys. Res.*, **111**, D12313, doi:10.1029/2005JD006518.

Qu, G. and de Varennes, A. (2010). Use of hydrophilic polymers from diapers to aid the establishment of *Spergularia purpurea* in a mine soil. *J. Hazard. Mat.* 178(1-3), 956-962.

Raja Reddy K., W. Brien Henry, Ramdeo Seepaul, Suresh Lokhande, Bandara Gajanayake and David Brand (2013). Exogenous Application of Glycinebetaine Facilitates Maize (*Zea mays*) Growth under Water Deficit Conditions. *American Journal of Experimental Agriculture* 3(1): 1-13, 2013 SCIENCEDOMAIN international. www.sciencedomain.org

Sabine Heumann, David L. Rimmer, Andre Schlichting, Geoffrey D. Abbott, Peter Leinweber, and Jurgen Bottcher (2013). Effects of potentially inhibiting substances on C and net N mineralization of a sandy soil a case study in Institut für Bodenkunde. *J. Plant Nutr. Soil Sci.* 2013, 176, 35–39 DOI: 10.1002/jpln.201200353 35.

Saha R., R. S. Chaudhary and J. Somasundaram (2012). Soil Health Management under Hill Agroecosystem of North East India. *Hindawi Publishing Corporation Applied and Environmental Soil Science Volume 2012, Article* ID 696174, doi:10.1155/2012/696174.

Sanchez P.A. and Logan T.J. (1992). *Myth and science about the chemistry and fertility of soils in the tropics.* In: Lal R and Sanchez PA (eds) Myths and Science of Soils of the Tropics, pp 34–46. SSSA Spec Publ No. 29. ASA, CSSA, and SSSA, Madison, WI, USA.

Sarapatka B., Dlapa P. and Bedrna Z. (2002): (*Soil quality and degradation in Czech),* Palacký University Press, Olomouc, 246 pp.

Sarvas M., Pavlenda P. and Takacova E. (2007). Effect of hydrogels application on survival and growth of pine seedlings in reclamations. *Journal of Forest Science* 53:204–209.

Shim M. S., Choi S. Y. and Kwon O. K. (2008). Growth Responses of *Ardisia pusilla* to the Contents of Various Hydrophilic Polymers in the media. *Hort. Enviro.Biotecshnol.* 49(6), 365-370.

Shooshtarian Bot, Pernetti M., Floter E. and Malssen K.F. (2012). Structuring of edible oil by alternatives to crystalline fat. *Current Opinion in Colloid and Interface Science* 12, 221–231.

Sijacic-Nikolic M., Vilotic D., Milovanovic J., Veselinovic M. and Stankovic D. (2010). Application of superabsorbent polymers in the production of Scotch pine (*Pinus sylvestris*) and Austrian pine (*Pinus nigra*) seedlings. *Fresenius Environmental Bulletin* 19(6): 1180-1185.

Smiley G.L. and Kroschel J. (2010). Yield development and nutrient dynamics in cocoa-gliricidia agroforests of Central Sulawesi, Indonesia. *Agroforestry Systems,* 78: 97–114.

Sohrab, F. (2004). Evaluating the application of superabsorbent polymers on soil water capacity and potential on three soil textures. *Iranian Journal of Polymer Science and Technology* 17, 163-173.

Specht A. and Harvey-Jones J. (2000). Improving water delivery to the roots of recently transplanted seedlings trees: the use of hydrogels to reduce leaf and hasten root establishment. *Forest Research1,* 117-123.

S. Shooshtarian, J. Abedi-Kupai and A. TehraniFar (2012). Evaluation of Application of Superabsorbent Polymers in Green Space of Arid and Semi-Arid Regions with emphasis on Iran, *International Journal of Forest, Soil and Erosion,* 2 (1):24-36.

Starkey, T.E., Enebak S.A., South D.B. and Cross R.E. (2012). Particle size and composition of polymer root gels affect loblolly pine seedling survival. *Native Plants Journal* 13(1):19-26.

Tan, Gong J.P. and Osada Y. (2013). Novel hydrogels with excellent mechanical performance. *Prog Polym Sci* 30:1–9.

Thomas, D.S. (2008). Hydrogels applied to the root plug of subtropical eucalypt seedlings halves transplant death following planting. *Forest Ecology and Management* 255:1305-1314.

Tossah, B.K., Zamba D.K., Vanlauwe B., Sanginga N., Lyasse O., Diels J. and Merckx R. (1999). Alley cropping in the moist Savanna of West Africa: Impact on soil productivity in a North-to-South transects in Togo. *Agroforestry Systems* 42, 229-244

Tumbo, S. D., F.C. Kahimba, B.P. Mbilinyi, F.B. Rwehumbiza, H.F. Mahoo, W.B. Mbungu and E. Enfors (2012). Impact of projected climate change on agricultural production in semi-arid areas of Tanzania: a case of Same

District. *African Crop Science Journal, Vol. 20, Issue Supplement s2, pp.* 453 - 463 ISSN 1021-9730/2012.

Underwood, E., Viers J.H., Klausmeyer K.R., Cox R.L. and M.R. Shaw (2009). Threats and biodiversity in the mediterranean biome. *Diversity and Distributions* 15 (2): 188–197.

USDA, (1996). Official Methods of Soil Analysis, Washington D.C., USA, 1996

Valdecantos, A., Cortina J. and Vallejo R. (2006). Nutrient status and field performance of tree seedlings planted in Mediterranean degraded areas. *Annals of Forest Science,* 63,249-256.

Vallejo, R., Aronson J., Pausas J. G. and Cortina J. (2006). Restoration of Mediterranean Woodlands. In J. Van Andel and J. Aronson (Eds.), Restoration Ecology: The New Frontier. (pp: 193-207). Blackwell Science. Oxford, UK.

Vareness Ali S. I. and George P. (2010). Polyacrylamide polymer and salinity effects on water requirement of *Conocarpus lancifolius* and selected properties of sandy loam soil. *Euro. J. Sci. Res.* 25(4), 549-558.

Vincent Onguso Oeba, Samuel C. J. Otor, James B. Kung'u and M. N. Muchiri (2012). Modeling Determinants of Tree Planting and Retention on Farm for Improvement of Forest Cover in Central Kenya. *International Scholarly Research Network ISRN Forestry Volume 2012, Article ID* 867249, doi:10.5402/2012/867249.

Viero, P. W., Little, K. M. and Oscroft, D. G. (2000). The effect of a soil-amended hydrogels on the establishment of *Eucalyptus grandis* x *E. camaldulensis* clone grown on the sandy soils of Zululand. *South African Forestry Journal* 188, 21-28.

Walker, N., Galgal, K. K., Shelton, H. M. and Mullen, B. F. (2004). Animal production potential of some new *Leucaena* accessions in the Markham Valley. *Tropical Grasslands*,39 , (in press).

Yazan Elhadi A., D.M. Nyariki, V.O. Wasonga and W.N. Ekaya (2012). Factors influencing transient poverty among agro-pastoralists in semi-arid areas of Kenya. *African Crop Science Journal, Vol. 20, Issue Supplement s1, pp.* 113 - 122 ISSN 1021-9730/2012.

Zhongkui Luo, Enli Wanga, Osbert, J. Sunb, Chris, J. Smitha and Mervyn E. Probertc (2011). *Modeling long-term soil carbon dynamics and sequestration potential in semi-arid agro-ecosystems Land and Water*, GPO Box 1666, Canberra, ACT 2601, Australia.

Zulfiia Sakbaeva, Veronica Acosta-Martinez, JenniferMoore-Kucera, Wayne Hudnall and Karabaev Nuridin (2012). Interactions of Soil Order and Land Use Management on Soil Properties in the Kukart Watershed, Kyrgyzstan. *Hindawi Publishing Corporation Applied and Environmental Soil Science, Article ID* 130941, doi:10.1155/2012/130941.

APPENDICES

Appendix I

Summary of Anova Table on the effects of hydrogels on growth of seedlings

EFFECTS OF HYDROGELS ON HEIGHT IN THE NURSERY				
Species	**Df**	**F value**	**P value**	**F critical**
Sesbania sesban	12	10.343	0.001	3.490
Cajanus cajan	12	3.618	0.055	3.490
Leaucaena pallida	12	3.497	0.062	3.190
EFFECTS OF HYDROGELS ON RCD IN THE NURSERY				
Sesbania sesban	12	7.590	0.004	3.490
Cajanus cajan	12	6.912	0.052	6.291
Leaucaena pallida	12	4.650	0.022	3.490
EFFECTS OF HYDROGELS ON HEIGHT AFTER TRANSPLANTING				
Sesbania sesban	12	3,490	0.984	0.0507
Cajanus cajan	12	144.896	1.091	3.490
Leaucaena pallida	12	91.66	1.540	3.490
EFFECTS OF HYDROGELS ON RCD AFTER TRANSPLANTING				
Sesbania sesban	12	7.965	0.003	3.490
Cajanus cajan	12	138.885	1.394	3.490
Leaucaena pallida	12	134.972	1.66	3.490

Appendix II

Post Hoc analysis (Mean Separation)

POST HOC ANALYSIS IN THE NURSERY				
Treatments	**df**	**F value**	**P value**	**F critical**
Treatments (Height)	6	11.677	0.008	5.143
Treatments (RCD)	6	1.206	0.362	5.143
POST HOC ANALYSIS AFTER TRANSPLANTING				
Treatments (Height)	6	2.713	0.144	5.143
Treatments (RCD)	6	5.487	0.044	5.143

Appendix 111

Anova table on soil moisture analysis

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
H_0	3	19.3	6.433333	2.653333
H_{7g}	3	23.7	7.9	3.63
H_{11g}	3	28.4	9.466667	2.463333
H_{15g}	3	34.7	11.56667	2.263333

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	43.50917	3	14.50306	5.269048	0.026813	4.066181
Within Groups	22.02	8	2.7525			
Total	65.52917	11				

Appendix IV

Anova table for analysis of nutrients

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
H_0	9	3.742	0.415778	0.202997
H_{7g}	9	14.717	1.635222	1.261599
H_{11g}	9	20.054	2.228222	2.289155
H_{15g}	9	26.145	2.905	3.648227

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	30.12804	3	10.04268	5.427025	0.003924	2.90112
Within Groups	59.21582	32	1.850495			
Total	89.34386	35				