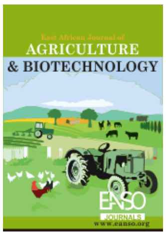

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Original Article

Effect of Mixing Ratio of Super Absorbent Materials on the Growth and Yield of Bell Pepper in the Ferric Luvisols of Mogotio, Kenya

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Crop Growth, Pumice, Super Absorbent Polymer, Soil Additives, Soil Properties, Yield.

ABSTRACT

Agriculture in arid and semi-arid regions (ASALs) faces challenges due to limited water and problematic soils. This study investigates the potential of superabsorbent materials like Super Absorbent Polymers (SAPs) and pumice to enhance water retention and agricultural productivity in Ngubreti in Mogotio Sub-County, Kenya, representing ASALs. Using a randomized design with different material ratios and a control group, the research analysed soil parameters and plant growth indicators. Incorporating superabsorbent materials increased soil porosity, reduced bulk density, and improved water retention. Bell pepper production notably increased by 53.4%, with the SAP Pumice Double Half (SPDH) treatment showing the highest yield. This research underscores superabsorbent materials' ability to enhance ASAL soil conditions and agricultural output, particularly SPDH treatment. Precise material concentration control and consideration of their impact on soil penetration rates are crucial for optimal results. The study contributes to sustainable agriculture in water-scarce regions, emphasizing soil management's role in crop productivity. Further research and region-specific experiments are needed for broader applicability. Farmers are advised to assess their soil characteristics and consider a recommended median soil-additives mixing ratio of 1:833. Long-term effectiveness warrants additional investigation.

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INTRODUCTION

Agriculture is a global industry that relies heavily on water, which is an essential resource for the production of food and the raising of livestock. In spite of the fact that the Earth has an abundance of water resources, only 2.5% of it is freshwater, while the remaining 97.5% is saltwater (Abobatta, 2018). This already limited supply of fresh water is further restricted by difficulties in gaining access to it. The consumption of water resources by agriculture is significant, accounting for approximately 70 percent of all water withdrawals worldwide. This pattern is most pronounced in the ASAL areas of Africa, which are characterised by their arid and semi-arid landscapes. Rainfall is the primary source of water for agricultural production in this region, which results in lower water withdrawals for agricultural purposes (Mekonnen & Hoekstra, 2016; Rosa et al., 2020; UNEP, 2008). Irrigation is not the primary source of water for agricultural production in this region. In addition to satisfying the requirements of the crops themselves, the allocation of water for agriculture must also compete with the needs of other sectors, including industry, households, and the environment.

Rainfall is the primary source of water for agricultural production in ASAL countries and regions, such as Kenya. However, because of the unpredictable patterns of rainfall, which are made even worse by climate change, rain-fed agriculture is particularly unreliable. The alternation between dry and wet seasons creates a level of variability that has never been seen before, and it frequently results in extended periods of each condition. In ASALs, dry seasons typically last longer than wet periods, which magnifies the impact of drought and the negative effects it has on food production (Gobarah et al., 2015; Karuku, 2018)

The development of a robust root system is an essential component in order to attain the highest possible levels of plant health and performance. According to Linn et al. (2018), the complex root network has a significant impact on a plant's health because it ensures the plant is securely rooted in the soil while also ensuring that it receives adequate amounts of water and nutrients. There is a wide variety of soil types found within ASALs, ranging from clay to sandy compositions. Problems can arise when dealing with heavy clay soils, which are characterised by poor water-holding capacities and inadequate drainage. These soils become waterlogged after it rains, which makes it difficult for air to circulate and for nutrients to be exchanged. In addition, they condense and harden into a crust, which prevents tillage and water infiltration into the soil.

Clay particles expand and contract as a result of wetting and drying, which contributes to these challenges. The intensity and duration of rainfall determine the effects of clay particles expanding and contracting. Rainfall of any intensity leads to waterlogging, while rain of a lesser intensity forms a solid crust. The effects on plants are significant: waterlogged soils inhibit root respiration, which slows plant growth; crusted surfaces prevent germination and oxygen flow, which lowers crop productivity overall (Szejba, 2020).

On the other hand, sandy soils have weak structures, which results in the loss of nutrients through leaching and minimal activity from microorganisms. Because of their larger particle size, they allow water to infiltrate and drain more quickly. Because of this, sandy soils quickly become saturated during periods of rainfall but have a difficult time retaining water during dry periods, which results in significant evaporation losses. As a direct consequence of this, these soils frequently lack fertility, which leads to decreased plant productivity. According to Benites & Castellanos-Navarrete (2003), waterlogged or water-stressed sandy soils don't support a lot of thriving vegetation.

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The purpose of irrigation, an essential part of agricultural practice, is to maximize the amount of water that is taken in by crops. However, the success of this endeavour is highly dependent on the type of soil and the weather in the area. The benefits of irrigation can be cancelled out by unsuitable soils and high temperatures, which will have a negative effect on crop growth. Crops frequently experience water stress in soils with limited water-holding capacities or poor water retention, which, when combined with high temperatures, can lead to premature withering of the plant before it reaches maturity. It is essential to have adequate soil moisture, particularly during the stages of germination and seedling growth. However, insufficient water storage in the root zone necessitates the application of frequent irrigation throughout the life cycle of the crop. To combat this issue, soil additives can improve water retention, which is especially important during the dry spells that are characteristic of ASALs (Brouwer et al., 2001; Sharma et al., 2012).

The use of soil amendments shows promise as a means of reducing hunger, particularly in ASALs. The need for increased food production is being exacerbated by both the rapid increase in the world's population and the effects of climate change. It is possible to significantly boost crop growth and yield by enhancing the water-holding capacity of the soil. According to Abd El-Rehim et al. (2004), the addition of soil amendments to land can help improve soil drainage, cut down on erosion, and enhance land and water management practices, ultimately leading to an increase in land productivity. Out of all of these modifications, superabsorbent materials stand out as particularly useful because of their capacity to take up and hold significant amounts of water. They correct deficiencies in clay soils that have a low water-holding capacity, as demonstrated by the superabsorbent polymer, Belsap®, and pumice, which were used in this study to maintain the moisture content of the root zone in clay soils.

Superabsorbent polymers, also known as hydrophilic three-dimensional networks, are distinguished by their extraordinary capacity to take in water. Because they can live for up to four years, they are extremely useful for the modification of soil. The biocompatibility and lack of toxicity of these polymers make them useful in a variety of contexts, including agriculture. Their ability to increase water retention in soils by 50–70%, gradually releasing moisture as it is required, enhancing soil aeration, texture, permeability, and microbial activity, and reducing water stress during dry spells (Bai et al., 2010; Dabhi et al., 2013) are all attributes that can be attributed to these microorganisms. Pumice is a natural superabsorbent that is derived from volcanic lava. It improves water availability, drainage, and aeration, which in turn encourages robust plant growth and reduces soil erosion (Nugraha et al., 2022).

The semi-arid conditions, high temperatures, and variable rainfall that characterise Baringo County are illustrative of the difficulties that can be encountered. Heavy clay soils reduce the amount of agricultural water that can be harvested in the Mogotio sub-county. Dry seasons cause soil to shrink, which limits the availability of water and air due to decreased porosity and infiltration. This makes it difficult for plants to thrive, and it frequently results in stunted growth or death. Root development is hindered further by wet seasons, which are characterised by waterlogged soils and limited aeration, both of which work against the plant's ability to grow.

This research investigated the efficacy of superabsorbent materials as soil amendments for water management in the context of increasing demand for agricultural water resources as a result of weather fluctuations and the water scarcity that exists in ASALs. The goal of determining the ideal additive mixing ratio is to improve crop water productivity in a manner that is specific to the conditions of the area. The significance of the study lies in the fact that it addresses the decreasing plant production that can be attributed to deteriorating soil quality and erratic weather patterns in ASAL areas.

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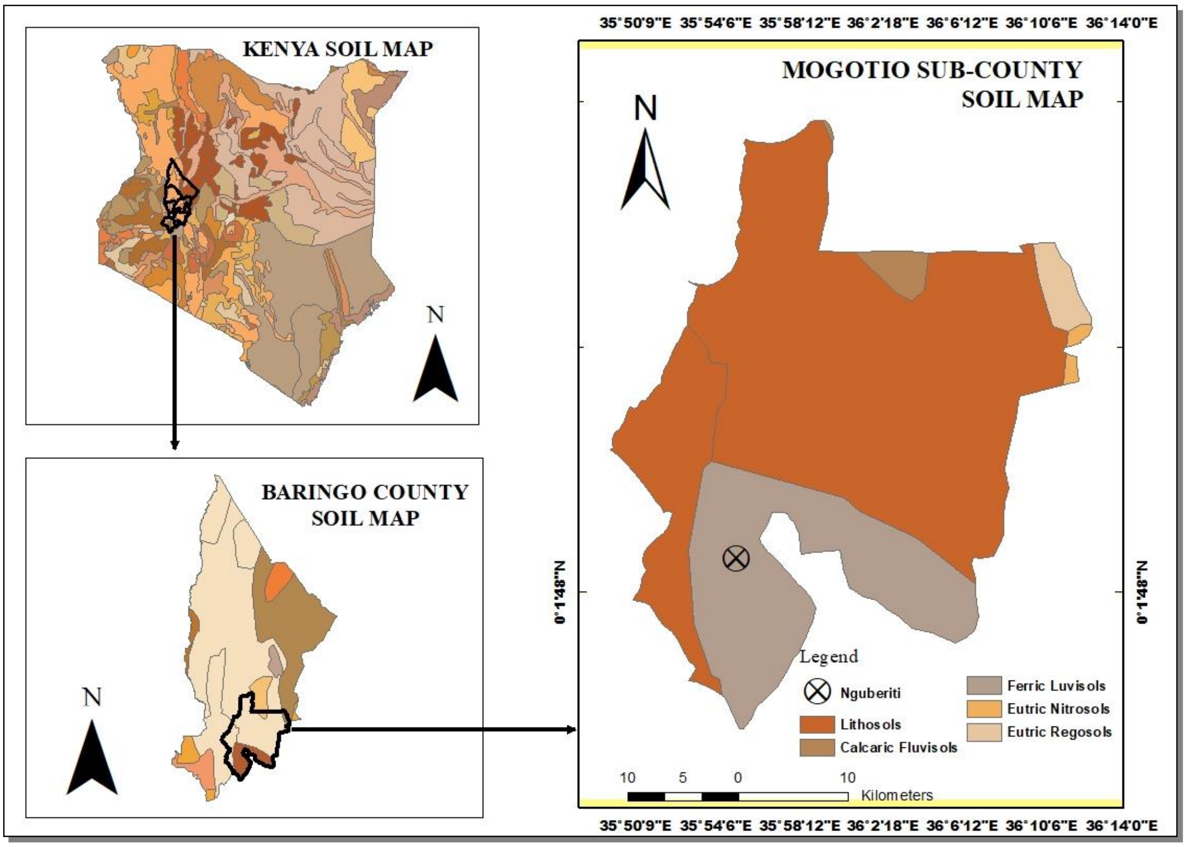
MATERIALS AND METHODS

Description of Study Area

The experiment was carried out on a farm in Ngubreti; Mogotio Sub-county, Baringo County, Kenya. Mogotio Sub-county covers an area of 1315 km2. It is located at 0.58315 N, 35.91746 E and 1590.10 m a.s.l. (c). Ngubreti, situated within this region, served as the study site.

Figure 1: Geographical location of experimental site



Source: Latitude (2024)

The average annual precipitation in the region is 531 millimetres, and the climate is defined as moderate and temperate. The rain falls in two distinct seasons. The region has a yearly average temperature of 27^0. The soils vary from well-drained to moderately deep to extremely deep, and their textures range from clay, loam, to sandy clay. The drainage classes of these soils are well-balanced. The terrain is mostly level, with a little rise in elevation here and there.

Treatments and Experimental Design

The experiment used a randomized design and contained three replicates, with each replicate containing a total of four plants. There were four plants placed in each of the thirty sub-plots that were prepared with a spacing of sixty centimetres by forty-five centimetres. The experimental factors are the amount of SAP at three levels (5, 10 and 15 kilograms per hectare), as per the manufacturer's recommendation, and pumice at three levels (6.25, 12.5 and 18.75 tonnes per hectare). Both additives were used at half, full, and 'double' their recommended weights in order to determine which combination produced the best results. A control was included. The choice of pumice test levels followed the recommendation of Tangolar et al., 2020, which stated that the application rate should be set at 50 tonnes per hectare per year. *Table 1* below shows the plot layout.

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Table 1: Experimental plots layout

SP_{HH}	CSP	SP_{FD}	SP_{HF}	SP_{DF}	SP_{FF}	SP_{FH}	SP_{HF}	SP_{DH}	SP_{HD}	CSP	SP_{HH}
SP_{DF}	SP_{FD}	SP_{DD}	SP_{HH}	SP_{DD}	CSP	SP_{DF}	SP_{FF}	SP_{DH}	SP_{DD}	SP_{FH}	SP_{FD}
SP_{HD}	SP_{FH}	SP_{DH}	SP_{HD}	SP_{HF}	SP_{FF}						

Abbreviations
SPHH - SAP Pumice half half; SPHF - SAP pumice half full; SPHD - SAP pumice half double; SPFF - SAP pumice full full; SPFH - SAP pumice full half; SPFD - SAP pumice full double; SPDD - SAP pumice double double; SPDH - SAP pumice double half; SPDF - SAP pumice double full; CSP - control

Land Preparation and Cultivation of Crops

The land was tilled, then organic manure was spread on it, and finally the entire field was subdivided into thirty separate plots of equal size. At a distance of 60 by 45 centimetres between each of the sub-plots, four seedlings of the bell pepper cultivar known as Super bell were transplanted. During the course of the experiment, weeding, pruning, the application of chemical fertilizers, the control of pests and diseases, and irrigation were carried out.

Irrigation

A nearby earth pond on the property provided the water for the irrigation system. The water emitters were spaced 45 centimetres apart and an application rate of 1.2 litres per hour was used for the drip irrigation system that was installed on the farm. The wetting area and the net depth of irrigation were used in the calculation to determine the volume of irrigation needed to meet a demand of 100%. The following formula was used.

$$\theta_{V_{FC}} = \frac{\theta_{G_{FC}} \times \rho_b}{\rho_w} \quad [1]$$

$$d_n = (\theta_{V_{FC}} - \theta_{V_{PWP}}) \times d_{rz} \quad [2]$$

$$V = d_n \times A \quad [3]$$

$$Runtime_{in\ mins} = \frac{Volume\ of\ water \times 60}{Application\ rate} \quad [4]$$

Where: $\theta_{V_{FC}}$; is the percentage volumetric moisture content at field capacity; $\theta_{G_{FC}}$; is the percentage gravimetric moisture content at field capacity; $\theta_{V_{PWP}}$; is the percentage gravimetric moisture content at the permanent wilting point; ρ_b; is the bulk density of soil in gcm^{-3}; ρ_w; is the density of water in gcm^{-3}; d_n; is the net depth of irrigation in cm; d_{rz}; is the root zone depth in cm; A; is the wetted area in cm^2; V; is the volume of water in cm

Data Collection

To assess the soil properties comprehensively, the study employed guidance from two practical manuals on soil analysis by El-Nahhal et al. (2018) and Garcia et al. (2019). The initial characterization encompassed a range of vital parameters, including infiltration rate, field capacity, hydraulic conductivity, available water, permanent wilting point, texture, bulk density, soil salinity, and moisture content. Following the harvest, an extensive analysis of the soil's hydraulic properties, along with other soil attributes influencing these properties was conducted subsequent to the application of soil additives. This thorough examination aimed to provide a comprehensive understanding of how the introduced additives impacted the soil properties, particularly concerning its hydraulic behaviour and its ability to retain and manage

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moisture effectively. The evaluation of these properties is critical for assessing the potential improvements in soil quality and fertility, which directly influence crop growth and yield.

Soil Texture

To determine the soil texture, two distinct methodologies were employed: the mechanical sieving method and the hygrometer method. These techniques are recognized for their effectiveness in characterizing soil texture. The mechanical sieving method involved a systematic process of sieving, effectively separating soil particles based on their size. Through this process, the soil sample was categorized into sand, silt, and clay fractions, providing precise measurements of the percentage composition of each particle type within the soil.

Simultaneously, the hygrometer method was utilized to assess soil texture by evaluating its water-retention capacity at varying moisture levels. The combination of these well-established methods provided comprehensive insights into the soil's composition. Understanding the soil's texture was imperative for assessing its suitability for agricultural purposes, as it significantly influences its capacity to support plant growth and, consequently, crop yield.

Bulk Density

A soil sample was placed in an oven and allowed to dry out in the laboratory before bulk density measurements were taken. Before the land was prepared, a soil core ring was pounded into the undisturbed soil, and then it was removed carefully and the excess soil on both ends was trimmed with a sharp flat knife. This process occurred during the harvesting period. The value was arrived at by computing it using the following formula:

$$\rho_b = M_s/V \quad [5]$$

$$V = \pi r^2 h \quad [6]$$

Where, ρ_b is the bulk density, gcm^{-3}, M_s is the mass of dry soil, g, and V is the Volume of soil, cm^3; π=3.14 cm, h is the thickness of soil on ring and r^2 is the radius^2.

Soil Moisture Content

The weight of the damp soil samples was measured, and then the soil was dried in an oven to assess its moisture content using the gravimetric technique. This approach involves measuring the weight of the soil after it has been moist. This was calculated using the following formula:

$$\theta_g = \frac{M_{wet} - M_{dry}}{M_{dry}} \quad [7]$$

Where θ_g is the gravimetric soil water content, M_{wet} is the mass of the moist soil sample, and M_{dry} is the mass of dry soil.

Soil Infiltration

A comprehensive on-site evaluation of the soil's infiltration rate was conducted using a double-ring infiltrometer, following the procedure outlined by Pal (2018). Throughout the experiment, the water level within the inner ring was consistently maintained at 20 centimetres, and the precise amount of water required for replenishment was meticulously recorded.

The experiments were thoughtfully designed to encompass a range of wheel traffic pathways, and three distinct loads were systematically applied to each pathway. Subsequently, the rate at which water penetrated the soil was calculated based on the data collected during the experiments. This rigorous methodology ensured a thorough assessment of the soil's infiltration characteristics and its response to different load conditions.

Field Capacity and Permanent Wilting Point

In the controlled environment of the laboratory, the field capacity and permanent wilting point of the soil samples were ascertained. This involved employing a precision pressure plate apparatus, which enabled the application of various suction pressures, specifically 10 kPa, 20 kPa, 30 kPa, 500 kPa, and 1500 kPa.

These selected suction pressures allowed for a comprehensive exploration of the soil's water-

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holding capacity at varying levels of moisture stress, ranging from field capacity to the permanent wilting point. This in-depth analysis provided valuable insights into the soil's ability to retain water across a spectrum of conditions, which is crucial for understanding its suitability for agricultural use.

Hydraulic Conductivity

The determination of hydraulic conductivity necessitated the implementation of the constant head approach, which was selected for its capacity to provide highly precise measurements of this critical soil parameter.

Statistical Data Analysis

Starting on the day when the transplants were performed, data was gathered and documented every two weeks. In order to calculate the overall yield in kilogrammes per plant, the entire quantity of fruits harvested from each plant was weighed. The findings of the soil analysis as well as the development of the bell peppers were utilized in calculating the optimal application rate and mixing ratio of additives. Quantitative data was analyzed via the use of Microsoft Excel 2016, Data Analysis Tool Pak, and Statistical Analysis Software (SAS) through descriptive statistics. The findings of the research were presented in the form of tables and figures, and the growth curves of the plants were plotted throughout the course of the full growing season. The optimal treatment ratio was determined by correlating the results of the growth rate and the total yield based on different application rates of additives.

RESULTS AND DISCUSSION

Initial Soil Properties

The results for the selected soil properties are summarized in *Table 2* below. The soil properties considered include the soil's bulk density, porosity, infiltration rate, moisture retention, and hydraulic conductivity. These properties are related to the water retention ability of soil, and that is why they are isolated for the initial investigation.

The soil texture analysis showed that the soil was clay soil, as indicated by more than 40% clay particles. The soil pH analysis showed that the soil was medium acidic, thus tolerable by most plants (Plant Production Directorate, 2013). The values of the other soil properties would be used later in the analysis to compare the effects of adding super-absorbent materials to the soil.

Table 2: Table of results of initial soil properties

Property	Units	Result
Texture	-	Clay soil -Sand 24% Clay 50% Silt 26%
Moisture content	%	4.73
Bulk density	gcm^{-3}	1.05
Field capacity	%	34.8
Permanent wilting point	%	20.9
Saturation	%	46.6
Available water	%	13.9
Hydraulic conductivity	cm/hr	0.17
Infiltration	cm/hr	1.5
pH	-	5.09

Porosity

Porosity is useful in determining the hydraulic properties of the soil because of its significant effect on water and nutrient flow, water retention, and overall plant growth. This study found that the use of SPDH and SPFF led to a 0.93% and 0.32% increase in soil porosity, respectively. However, the other treatments lowered soil porosity (*Figure 3*).

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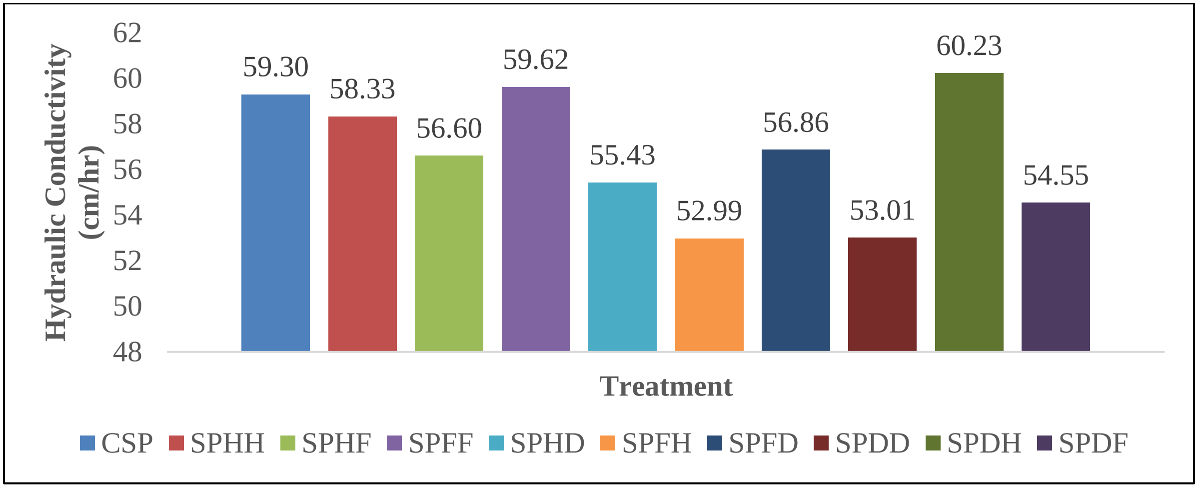
Figure 2: Effect of soil additives on porosity

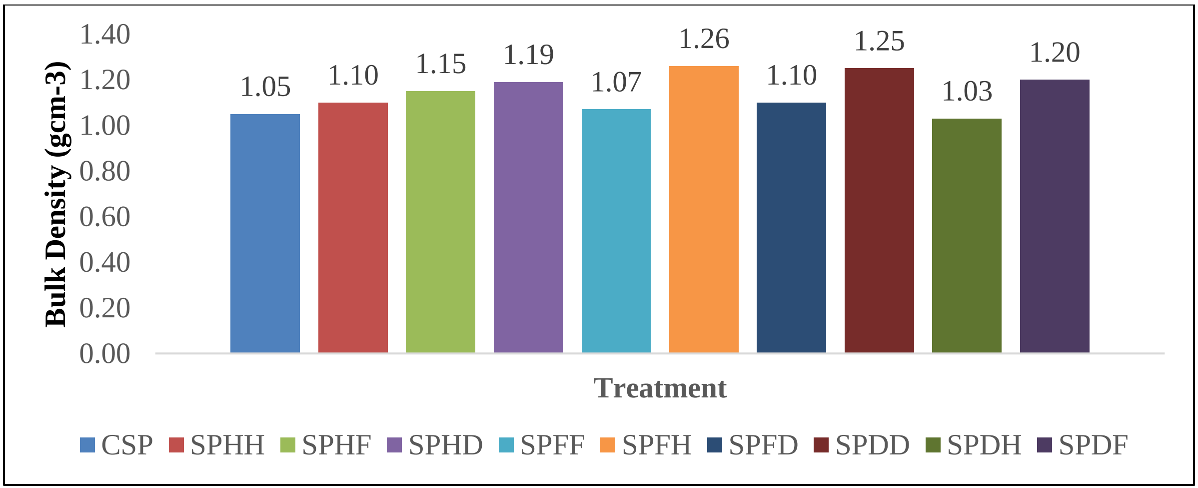


Ideally, soil porosity should be at least 50% of the soil volume to allow adequate movement and storage of dissolved nutrients and water (Gogo et al., 2020). Although the porosity in all treatments of this study was above 50%, the reduced porosity in most treatments meant that the additives reduced the soil's ability to provide space for water, and air. The varying effects of the additives on porosity confirmed that the effect of SAPs and pumice on soil porosity can vary depending on the dosage used, among other factors.

Bulk Density

Soil bulk density influences soil porosity and affects how water moves through the soil. The analysis revealed that bulk density was highest in SPFH at 1.26 gcm^{-3} whilst the control had a bulk density of 1.0 5 gcm^{-3}. SPDH had the least recorded bulk density at 1.03 gcm^{-3} (*Figure 3*). These findings confirmed that the use of SAPs and pumice generally increased soil bulk density by increasing the mass of soil per unit volume.

Figure 3: Effect of additives on soil bulk density



Moisture Content

The research findings unveil a notable surge of approximately 95% in soil moisture content due to the incorporation of superabsorbent materials. Among the treatment groups, the most significant increase was observed in SPFF, marking a substantial 9.21%, while the lowest increment was documented in CSP, registering at 4.733%.

It's essential to recognize that soil compaction, porosity, bulk density, and permeability all intricately influence the distribution of water within the soil. This water can be broadly categorized into gravitational, capillary, and

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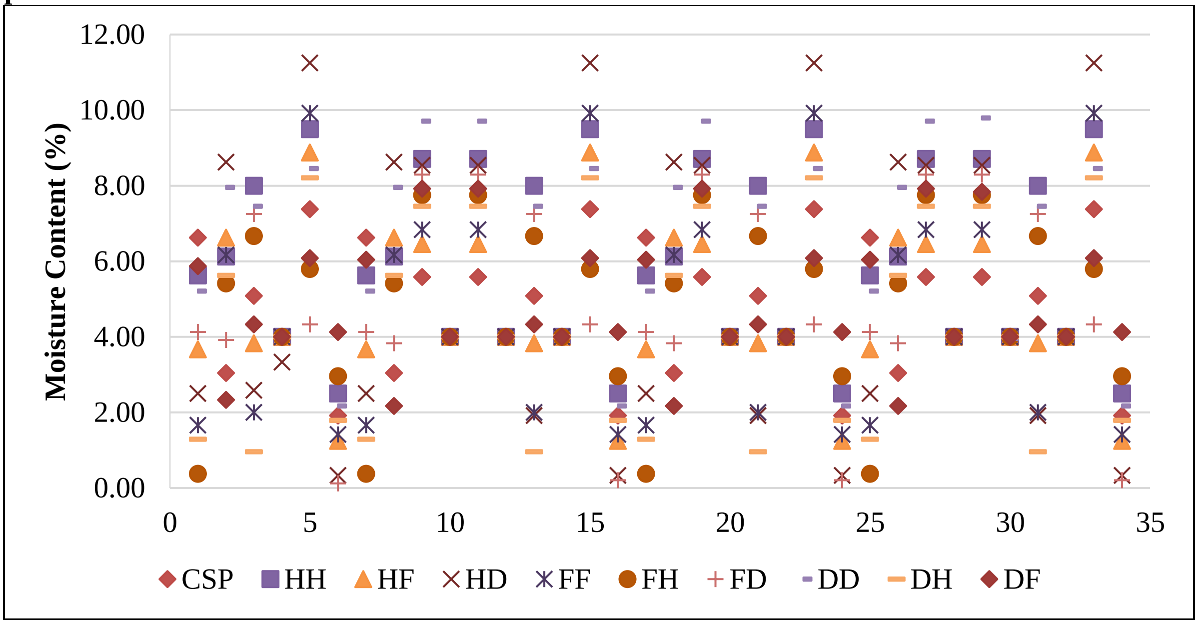
hygroscopic forms. The mean percentage moisture differential was most pronounced in SPDH, highlighting this treatment's superior performance in retaining soil moisture during the initial phases of bell pepper plant growth. Conversely, as the plants advanced into later stages of development and maturity, SPDH consistently outperformed others in its sustained ability to retain moisture.

The notable implications for plant productivity can be predominantly attributed to the unique additive combination found in SPDH. This blend exhibited a remarkable consistency in moisture retention throughout the entire growth season. These outcomes are in harmony with the findings of Milani et al. (2017), underscoring the substantial improvement in soil water retention resulting from the application of absorbents. The collective findings of this research emphasize the potential of superabsorbent materials in optimizing soil moisture content and subsequently enhancing plant productivity.

Figure 4: Effect of different treatments on soil moisture content in the early plant development period



The findings of the study reveal that SPHD consistently maintained higher daily moisture content throughout the period of study whereas the other treatments only recorded high averages during the second half of the study. In relation to the control, all the additives reduced fluctuations in moisture content within the study period (*Table 3*). This confirms that the proportion of additives determines the soil's capacity to maintain moisture storage for a prolonged period of time.

Table 3: Daily volumetric moisture content

	Mean diff early	Mean diff late	Mean diff all
CSP	2.68	9.05	6.02
SPHH	3.91	5.90	4.93
SPHF	2.98	5.85	4.55
SPHD	5.43	5.70	5.68
SPFF	4.10	4.70	4.48
SPFH	3.82	6.07	5.02
SPFD	3.05	8.14	5.67
SPDD	4.52	6.77	5.72
SPDH	4.13	8.33	6.33
SPDF	2.62	5.87	4.37

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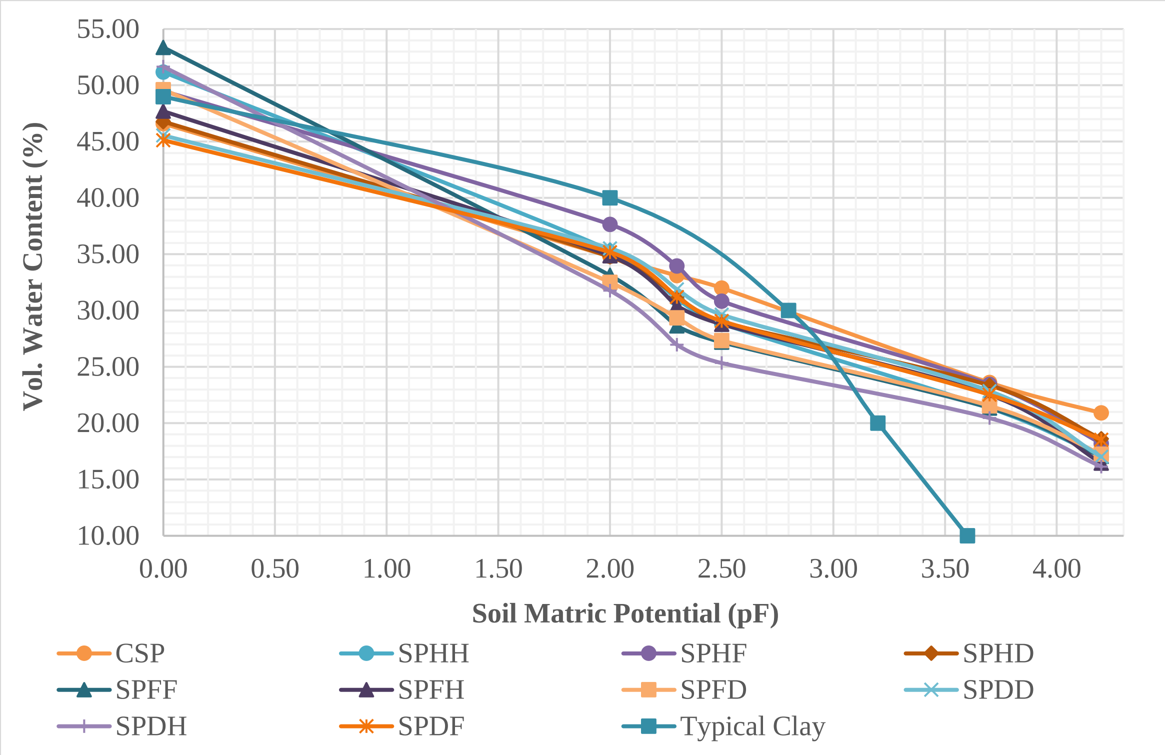
Moisture Retention Capacity

According to the findings of the research, the SPFF treatment had the greatest values for saturation, field capacity, and permanent wilting point, with percentages of 53.37 percent, 37.65 percent, and 33.95 percent, respectively. The SPDH therapy showed the lowest results, with percentages of 45.13%, 31.77%, and 26.96% respectively. These were the lowest values observed.

Figure 5: Water Retention Curves for Different Soil Treatments



These findings are in line with those found in earlier research on the water retention capabilities of sandy soils and the effect that super absorbent polymers have on the water retention capabilities of soils. Clay soils were found to have the highest water retention, although some of the treatments had greater moisture percentages than clay at saturation and near saturation levels, suggesting a more porous mix. This was discovered despite the fact that clay soils had the best water retention.

CONCLUSION AND RECOMMENDATIONS

This study investigated the potential of superabsorbent materials like Super Absorbent Polymers (SAPs) and pumice to enhance water retention and agricultural productivity in Ngubreti in Mogotio Sub-County, Kenya, representing arid and semi-arid areas. Using a randomized design with different material ratios and a control group, the research analyzed soil parameters and plant growth indicators. Incorporating superabsorbent materials increased soil porosity, reduced bulk density, and improved water retention. Bell pepper production notably increased by 53.4%, with the SAP Pumice Double Half (SPDH) treatment showing the highest yield. This research underscores superabsorbent materials' ability to enhance ASAL soil conditions and agricultural output, particularly SPDH treatment. Precise material concentration control and consideration of their impact on soil penetration rates are crucial for optimal results. The study contributes to sustainable agriculture in water-scarce regions, emphasizing soil management's role in crop productivity. Further research and region-specific experiments are needed for broader applicability. Farmers are advised to assess their soil characteristics and consider a recommended median soil-additives mixing ratio of 1:833.

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However, assessment of the long-term effectiveness of the additives in the area warrants additional investigation.

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