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ARTICLE

Superabsorbent Polymer and Rabbit Manure Improve Soil Moisture, Growth and Yield of Eggplant (*Solanum melongena L.*)

Annah Wanjala Mnyika[1,2] **Simon Muti Mbuvi**[1] **Elisha Otieno Gogo**[1*]

1. Pwani University, Department of Crop Sciences, P.O. Box 195, 80108, Kilifi, Kenya
2 . Taita Taveta County Government, Taita Sub-county, P.O. 1142, 80304, Wundanyi, Kenya

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ABSTRACT

Production of eggplant (*Solanum melongena* L.) is influenced by limited soil water and fertility conditions that affect its growth and yield. The use of superabsorbent polymer (SAP), also known as slush powder and rabbit manure are among the strategies that can improve soil conditions, hence growth and yield of crops. The objective of the study was to evaluate the effects of SAP and rabbit manure on soil moisture, growth and yield of eggplant. The study was conducted at Pwani University, Kilifi, Kenya. A randomized complete block design with three replications was used. The treatments were SAP, rabbit manure, SAP plus rabbit manure and control (without SAP or rabbit manure). Soil moisture, growth and yield parameters were determined. Superabsorbent polymer and/or rabbit manure improved soil moisture, growth and yield of eggplant compared with the control. Use of SAP had a better soil moisture retention, growth and yield comparable to SAP combined with rabbit manure. The finding demonstrates that use of SAP and/or rabbit manure may help in better soil water and nutrient management, particularly in arid and semi-arid areas to improve growth and yield of eggplant.

1. Introduction

Eggplant (*Solanum melongena* L.) also known as aubergine is one of the important vegetables grown in Kenya for export and local demand. It is grown as an annual plant and is one of the most consumed fruit vegetables in tropical Africa; probably the third after tomato (*Solanum lycopersicum* L.) and onion (*Allium cepa* L.), and before okra [*Abelmoschus esculentus* (L.) *Moench*] [12]. Eggplant fruit is associated with high nutritional value and for its therapeutic properties [7]. Ripe mature eggplant vegetables contain high amounts of vitamin C, whose concentration increases progressively as the plant advances in maturity [7]. Eggplant production tends to be confined to warm and semi-arid areas where water is more often a limiting factor in production [10]. Therefore, there is a need to optimize water and nutrient management for eggplant production. Eggplant has also been reported to be amongst the most sensitive horticultural plants to drought stress because of its high transpiration rates aided by large leaf surface area, high stomatal conductance and a shallow root system[10]. The negative effects of soil moisture stress on both yield and quality such as reduced leaf size, photosynthetic area, fruit size and yields of eggplant

**Corresponding Author:*
Elisha Otieno Gogo,
Pwani University, Department of Crop Sciences, P.O. Box 195, 80108, Kilifi, Kenya;
Email: e.gogo@pu.ac.ke

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fruits have been reported by Díaz-Pérez and Eaton [10].

Kilifi County is a hot and dry area for most parts of the year with most regions being arid and semi-arid, due to low annual rainfall [17]. The spatial and temporal distribution of this rainfall is inadequate and insufficient for commercial eggplant production. Thus, soil moisture conservation and nutrient management are essential practices; if sustainable vegetable production is to be realized in the region. One method of water conservation and reduction of irrigation costs is the use of superabsorbent polymer (SAP), also known as slush powder as soil improvement strategies. Superabsorbent polymer (SAP) is a group of new water-saving materials and soil conditioners that have been widely adopted in agriculture [8]. They are hydro-gels that can absorb and hold considerable amounts of water and slowly release them on demand around the root zone [8]. Superabsorbent polymer (SAP) has been considered as water-managing materials for horticultural purposes in the desert and drought-prone areas[24]. Use of SAP has been shown to increase soil water retention capacity, aeration in the soil, reduce soil bulk density, improve soil structure and increase crop production [8,11].

Superabsorbent polymer (SAP) is credited for being inert and do not have adverse effects on humans, plants, soil and the general environment [21]. They have abilities to absorb about 200 to 500 times as much water as their weight, and in 5 to 12 years gradually biodegrading to water, carbon dioxide and ammonia due to the microbial activity or sunray effect [9,22]. Use of adequate amounts of SAP under irrigation and water stress conditions can compensate for its purchase costs, leading to profitable yield. Fernando et al. [11] found that addition of 3 g L^{-1} of SAP to tomato cultivation beds resulted in increased water storage by 35% and reduced leaching of nutrient elements by 15%, in addition to enhancing soil nutrient storage capacity.

Currently, in Kenya, there is declining soil fertility resulting from continuous cultivation of smallholder farms. On the other hand, the cost of synthetic fertilizers is escalating and therefore, unfordable to the majority of smallholder farmers. There is also a need to conserve and build natural resource capital and biodiversity, which has led to renewed interest in the use of locally available organic nutrient resources for soil fertility management. As a result of health risks associated with red meat, consumers are resorting to eating white meat. This has resulted in high demand for such meat from the rabbit. Therefore, many smallholder farmers are keeping rabbits. Besides, rabbit requires only a small farm area and are also reported to have excellent manure rich in nutrients, hence a good source of organic fertilizer for crop production [1]. Rabbit manure is reported to improve soil chemical properties by enhancing cation exchange capacity, and are also a source of micronutrients [1]. Uzun et al. [25] reported that when organic manure such as rabbit manure is incorporated into the soil, observed benefits to eggplant production have been attributed to improved soil physical properties, due to increased organic matter concentration as well as the increased nutrient availability. Unlike other manures which have to be well composted before they are used, rabbit manure can be immediately applied to the soil. It contains a much more considerable amount of nutrients compared with other animal manure [3]. Rabbit manure is rich in potassium, nitrogen, zinc, and calcium, and it's one of the most nitrogen-rich manures [5]. Studies have shown that rabbit manure is rich in potassium which resulted in better quality eggplant fruit [1]. Studies have shown that the effect of soil conditioners like SAP and rabbit manure on crops is dependent on various factors like prevailing weather conditions as well as nature and type of soil [2,4,8,11,23]. As such, this study seeks to evaluate the use of SAP and rabbit manure in managing soil water and nutrient requirement and assessing its effects on growth and yield of eggplant to improve farmer's productivity, especially in water-limited and poor soil conditions.

2. Materials and Methods

2.1 Site of the Study

The study was conducted in two seasons at Pwani University farm from April to July 2018 and 2019. Pwani University farm is located at about 30 m above sea level, and at latitude 3.6° S and longitude 39.8° E. The temperature in the region ranges between 21 °C and 32 °C and receives the bimodal type of rainfall, where long rains occur during March to July, and short rains in September to December, with annual totals of 1100 mm [15]. The soils in the region are predominantly sandy loam with pockets of clayey soil [19].

2.2 Plant Materials

Eggplant 'Black Beauty' (Amiran (K) Limited, Nairobi, Kenya) was used in the study. The variety was chosen because of its good adaptability to the study area. It is also widely grown and consumed in the region. 'Black Beauty' is an open-pollinated eggplant. It is a hardy crop that grows best in warm areas. The fruit is oval to heart-shaped glossy purple to almost black. Fruit size is about 10 x 8 cm. It has a meaty white flesh, big in size, an attractive purple colour. It also has a good shelf life [14].

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2.3 Superabsorbent Polymer

The SAP (Belsap®, Bell Industries Limited, P.O. Box 18603-00500 Nairobi, Kenya). The active ingredient includes 80% w/w cross-linked potassium acrylate polymer. The SAP used is non-tonic and environmentally safe. It has no residual toxicity in the soil. It biodegrades into base components parts of ammonia, carbon dioxide and water. Due to its potassium base structure, it does not increase salinity levels in the soil. It has a neutral pH (6-6.8) [22].

2.4. Rabbit Manure

Decomposed rabbit manure obtained from Pwani University farm, rabbitry section was used in the study.

2.5 Experimental Design and Treatment Application

A randomized complete block design with three replications was used in the study. The treatments were SAP, rabbit manure, SAP plus rabbit manure and the control (no SAP or rabbit manure). The plot sizes were 3 m × 4.5 m. Each block measured 47 m × 4.5 m, separated by 1 m path. The entire plot measured 47 m × 15.5 m. Rabbit manure was applied at a rate of 1 kg per hole by mixing with the soil, two weeks before transplanting [14]. The superabsorbent polymer was applied at a rate of 5 g per hole (hill) or per plant during transplanting. This was done by mixing the SAP with soil [22].

2.6. Planting and Agronomic Practices

Nursery beds of 1 m by 2 m were prepared to a fine tilth. Eggplant ‘Black Beauty’ seeds were drilled at a spacing 10 cm between rows. Mulching was done using dry grass to conserve moisture and later removed after seedling emergence. Weeding was done manually every week. Watering was done manually in the evening using 10-litre watering can daily. Hardening-off seedlings were done two weeks before transplanting when the seedlings are 15 cm tall or had four true leaves by reducing watering to once after two days.

The field was prepared two weeks before transplanting to a fine tilth manually. Planting holes were dug up to 15 cm at, a spacing of 60 cm by 45 cm. One healthy seedling was transplanted in each hole. Gapping was done within the first week of transplanting. Three weedings were done during the first three weeks to maintain plots weed-free. All other acceptable agricultural practices were done when deemed necessary.

2.7 Data Collection and Methods of Their Determination

2.7.1 Rabbit Manure and Pre-plant Soil Analysis

Pre-plant samples of rabbit manure and soil were analyzed for total nitrogen contents using the Kjeldahl method as described by Okalebo et al. [18]. Phosphorus (P) was analyzed calorimetrically with a Jemway 6100 spectrophotometer following standard procedures [6]. Potassium (K) was analyzed by flame photometer following standard procedures [6]. The calcium (Ca), magnesium (Mg), Zinc (Zn) and iron (Fe) contents were analyzed after wet digestion with a mix of nitric, sulphuric and hydrochloric acids using atomic absorption spectro-photometer[18]. Organic matter and carbon (C) were analyzed by wet oxidation using a modified method of Walkley-Black [18]. Rabbit manure and soil pH content was determined in water using a pH meter (Hanna precision pH meter, Model pH 213, Merck KGaA, Darmstadt, Germany) [18]. Electrical conductivity (EC) was analyzed using an electrical conductivity meter (HI 993310, PCE Instrument, Southampton, UK). Moisture content was determined by the gravimetric method where a subsample of a fresh, sieved, composite sample of a soil or rabbit manure core was weighed, oven-dried until there was no further mass loss, and then reweighed [18]. The same method was also used to determine soil moisture in the experimental plots.

2.7.2 Weather Conditions

Weather data on rainfall, temperature, relative humidity and solar radiation were collected from Pwani University weather station. Data was collected during the entire production season and reported as a monthly average.

2.7.3 Growth and Yield Parameters

Data collection started two weeks after transplanting and continued on a weekly basis until harvesting. Ten plants in the middle rows were randomly selected and tagged for data collection. Growth parameters measured were; plant height, leaf number, stem thickness, number of branches, shoot fresh and dry weight, root fresh and dry weight, leaf area, leaf chlorophyll content, time to 50% flowering, fruit number, fruit length, fruit diameter, and fruit fresh and dry weight.

Plant height was measured from the ground to the tip of eggplant using a meter tape (5 m long with an accuracy of ± 1 mm). The number of leaves and branches was determined by counting. Vernier calipers was used to determine stem thickness of the main stem. Three plants were uprooted from each plot on a monthly basis and used to determine shoot fresh and dry weight. Fresh weight

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was determined by weighing the roots and shoots in a weighing machine and their weight recorded. Dry weight was determined by oven drying at 105 °C until constant weight. Leaf area was determined by measuring the length and width of leaves and their area computed. Leaf chlorophyll content was measured using chlorophyll meter (CCM-200, Opti-sciences, Inc. Tyngsboro, MA, USA) with a precision of ± 1.0 SPAD readings. Days to 50% flowering was determined based on days after transplanting. Mature fruit number was determined by counting. Mature fruit length and thickness was determined using a measuring tape and vernier calipers, respectively. Fruit fresh and dry weight was determined, applying a similar method for shoot and root.

2.8. Data Analysis

The data collected were subjected to analysis of variance (ANOVA) using SAS software (version 10), and significant means at F-test compared using Tukey's test, at 5% level of significance. Data for the two seasons were pooled and presented in tables and graphs.

3. Results

3.1. Weather Conditions during Production of Eggplant

Mean monthly temperature ranged between 24.9 to 28.8 °C in season one and 27.5 to 29.8 °C in season two. The temperature was higher in season two except in May compared with season one (Figure 1A). Mean monthly relative humidity ranged between 78.5 to 88.9% in season one and between 76.3 to 80.9% in season season two (Figure1B). Relative humidity was higher in season one than in season two except in July. Rainfall ranged between 59.5 to 516.4 mm/month in season one and 22.4 to 292.6 mm/month in season two (Figure 1C). Rainfall was higher in season one than in season two throughout the study. Mean monthly solar radiation ranged between 16.7 t0 20.5 MJ m^{-2} and 28.4 to 39.2 MJ m^{-2} in the first and the second season respectively. Solar radiation was higher in season two than season one throughout the study (Figure 1D).

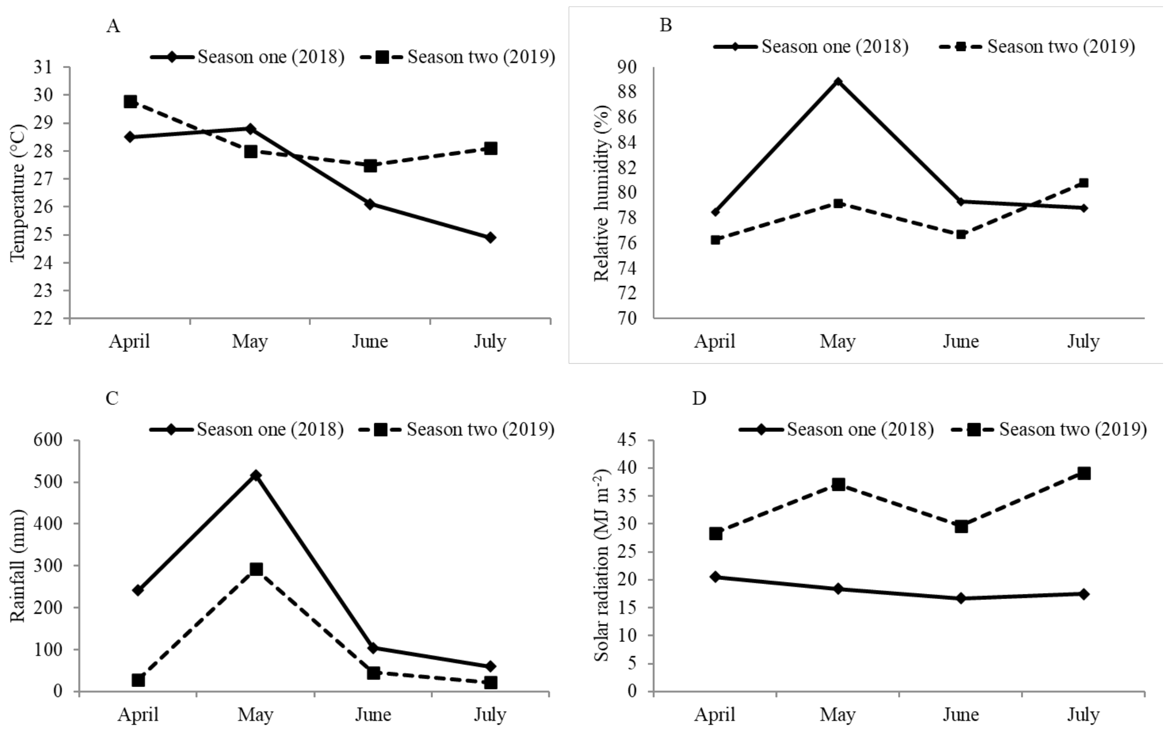

Figure 1. Mean monthly weather conditions during the production period of eggplant

3.2 Physico-chemical Properties of Rabbit Manure and Pre-plant Soil

Rabbit manure had higher electrical conductivity (7.9%), organic matter (4.6%), C (6.7%), moisture (78.2%), N (63.2%), P (20%), K (50%), Ca (37.5%), Mg (60%), Fe (64.5%), and Zn (72.1%) than pre-plant soil. Pre-plant soil on the other hand had only higher pH content (6.9) than rabbit manure (6.1) (Table 1).

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Table 1. Soil and rabbit manure composition used during production of eggplant

Variables	Rabbit manure	Pre-plant soil
pH	6.1 ± 0.3*	6.9 ± 0.4
Electrical conductivity (mS m^{-1})	210.1 ± 5.7	194.8 ± 6.0
Organic matter (mg kg^{-1})	120.7 ± 2.4	115.4 ± 3.5
Moisture (%)	23.7 ± 2.9	12.4 ± 0.3
C (mg kg^{-1})	213.6 ± 6.4	200.2 ± 6.9
N (g kg^{-1})	28.4 ± 3.2	17.4 ± 1.4
P (g kg^{-1})	0.6 ± 0.0	0.5 ± 0.0
K (g kg^{-1})	0.2 ± 0.0	0.1 ± 0.0
Ca (g kg^{-1})	2.2 ± 0.1	1.6 ± 0.0
Mg (g kg^{-1})	0.8 ± 0.0	0.5 ± 0.0
Fe (µg kg^{-1})	10.2 ± 0.4	6.2 ± 0.0
Zn (µg kg^{-1})	7.4 ± 0.2	4.3 ± 0.0

Note:
** Values represent means ± standard deviations*

3.3 Summary Statistics of the Analysis of Growth and Yield Variables during Eggplant Production

Analysis of variance indicated that all measured variables were affected by the treatments (Table 2).

Table 2. Analysis of variance for effects of rabbit manure and superabsorbent polymer (treatment) on measured variables

Variables	Treatment (*p* value)	R^2	CV	Mean
Soil moisture (%)	<0.0001 *	80.9	13.2	28.8
Plant height (cm)	<0.0001 *	91.5	6.9	66.0
Leaf number/plant	<0.0001 *	75.5	8.1	98.1
Stem thickness (cm)	<0.0001 *	79.2	20.1	2.5
Branch number/plant	0.0012 *	80.8	16.7	7.3
Shoot fresh weight (g)	<0.0001 *	80.3	4.8	925.6
Root fresh weight (g)	<0.0001 *	68.6	4.4	127.1
Shoot dry weight (g)	<0.0001 *	89.1	2.2	298.5
Root dry weight (g)	<0.0001 *	80.7	9.9	41.0
Leaf area (cm^2)	<0.0001 *	87.6	11.5	954.3
Leaf chlorophyll (SPAD reading)	0.0056 *	65.2	9.5	51.3
Days to flowering	0.0017 *	63.4	16.4	39.8
Fruit number	<0.0001 *	86.2	16.3	21.2
Fruit length (cm)	<0.0001 *	73.3	4.7	12.3
Fruit diameter (cm)	<0.0001 *	83.8	5.2	10.9
Fruit fresh weight (kg/plant)	<0.0001 *	91.1	8.9	2.7
Fruit dry weight (g/plant)	<0.0001 *	92.0	10.3	529.3

Note:
*ns, * not significant or significant at p ≤ 0.05, ANOVA*

3.4 Effect of Superabsorbent Polymer and Rabbit Manure on Soil Moisture

Plots, where SAP or rabbit manure + SAP was applied, had the highest soil moisture content compared with where no SAP or rabbit manure was applied (control), which had the lowest soil moisture, followed by plots where rabbit manure was applied alone (Figure 2).

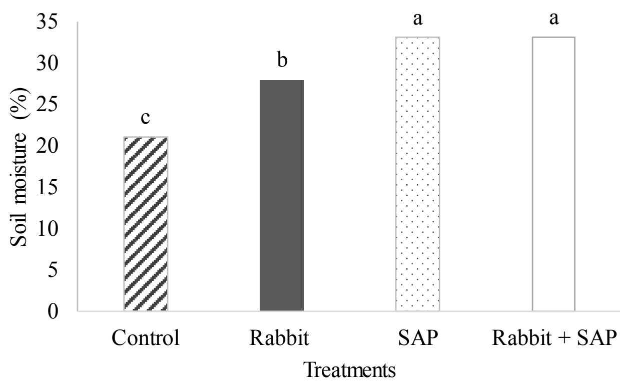

Figure 2. Effect of superabsorbent polymer and rabbit manure on soil moisture during production of eggplant. *Means followed by the same letter are not significantly different according to Tukey's honestly significant difference test at *p* ≤ 0.05. Rabbit = Rabbit manure, SAP = Superabsorbent polymer

3.5 Effect of Superabsorbent Polymer and Rabbit Manure on Growth and Yield of Eggplant

Use of SAP alone or in combination with rabbit manure resulted in tallest plants, most leaves, thickest stems and most branches. This was followed by the use of rabbit manure alone, while where no SAP or rabbit manure was applied had the shortest plants, fewest leaves, thinnest stems and most occasional branches (Table 3).

Table 3. Effect of superabsorbent polymer and rabbit manure on plant height, leaf number, stem diameter and number of branches of eggplant

Treatment	Plant height (cm)	Leaf number/plant	Stem diameter (cm)	Branch number/plant
Control	53.4 c*	82.3 c	1.7 c	5.9 c
Rabbit	62.4 b	97.4 b	2.3 bc	7.1 ab
SAP	72.3 a	104.5 ab	2.8 ab	7.4 ab
Rabbit + SAP	76.0 a	108.3 ab	3.1 a	8.6 a

Note:
**Means within a column followed by the same letter are not significantly different according to Tukey's honestly significant difference test at p ≤ 0.05. Rabbit = Rabbit manure, SAP = Superabsorbent polymer.*

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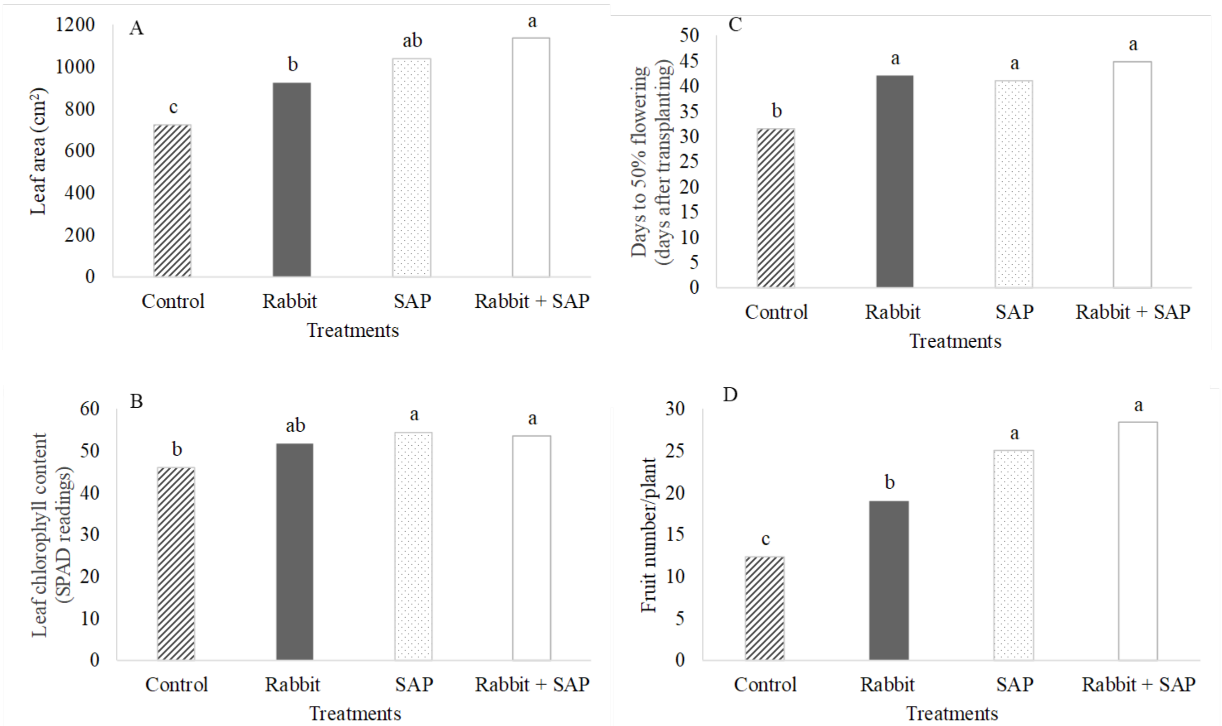

Figure 3. Effect of rabbit manure (rabbit) and superabsorbent polymer (SAP) on leaf area, chlorophyll content, days to flowering and fruit number of eggplants. Means followed by the same letter within a production season are not significantly different according to Tukey's honestly significant difference test at $p \leq 0.05$. Rabbit = Rabbit manure, SAP = Superabsorbent polymer

Use of SAP alone or in combination with rabbit manure resulted in highest shoot fresh weight, root fresh weight, shoot dry weight and root dry weight of eggplant, followed by use of rabbit manure alone. Control treatments, where no SAP or rabbit manure was applied had the lowest shoot fresh weight, root fresh weight, shoot dry weight and root dry weight of eggplant (Table 4).

Table 4. Effect of superabsorbent polymer and rabbit manure on fresh and dry weight of eggplant during production in season one (2018) and two (2019)

	Fresh weight (g)		**Dry weight (g)**	
Treatment	Shoot	Root	Shoot	Root
Control	848.1 c*	118.4 c	281.0 c	31.4 c
Rabbit	919.0 b	124.2 bc	298.7 b	40.6 b
SAP	954.0 ab	131.1 ab	305.6 ab	45.5 ab
Rabbit + SAP	981.2 a	134.8 a	308.9 a	46.5 a

Note:
**Means within a column followed by the same letter are not significantly different according to Tukey's honestly significant difference test at p ≤ 0.05. Rabbit = Rabbit manure, SAP = Superabsorbent polymer.*

Superabsorbent polymer (SAP) and rabbit manure had effect on eggplant leaf area (Figure 3A), leaf chlorophyll content (Figure 3B), days to 50% flowering (Figure 3C), and fruit number (Figure 3D). Generally, use of SAP alone and/or rabbit manure had the highest leaf area, leaf chlorophyll content, days to 50% flowering, and fruit number compared with where no SAP or rabbit manure was used (control).

Superabsorbent polymer (SAP) and rabbit manure had effect on eggplant fruit length (Figure 4A), diameter (Figure 4B), fresh (Figure 4C) and dry weight (Figure 4D). Use of SAP alone or in combination with rabbit manure resulted in longest and thickest fruit as well as fruit the highest fresh and dry weight while the control, where no SAP and/or rabbit manure was used had the lowest of the mentioned parameters, followed by rabbit manure alone.

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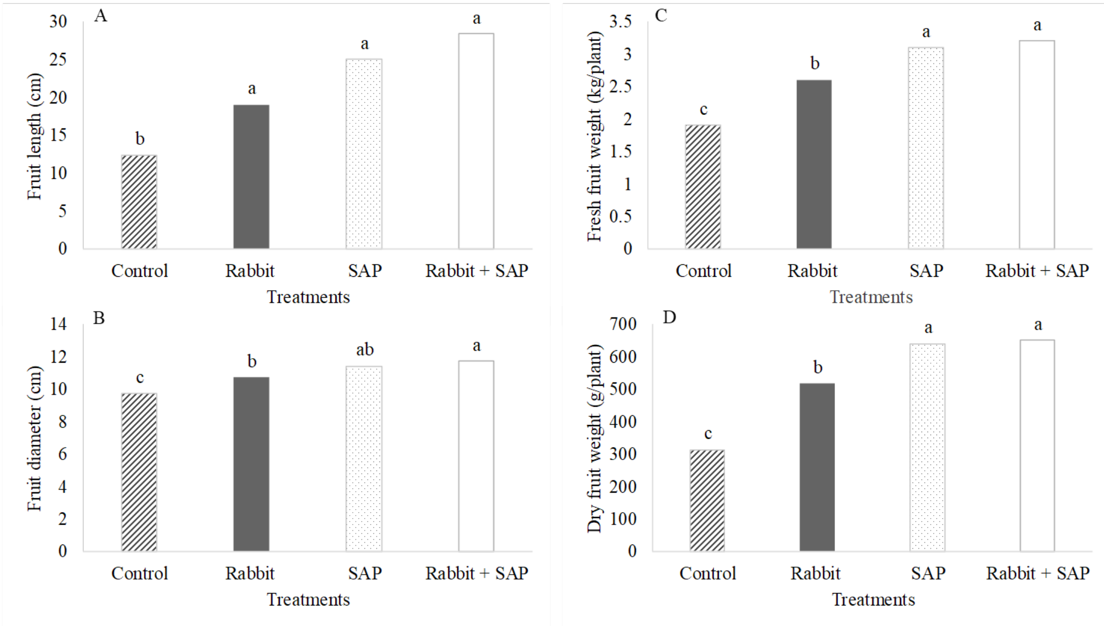

Figure 4. Effect of rabbit manure (rabbit) and superabsorbent polymer (SAP) on fresh and dry fruit weight of eggplant. Means followed by the same letter within a production season are not significantly different according to Tukey's honestly significant difference test at $p \leq 0.05$. Rabbit = Rabbit manure, SAP = Superabsorbent polymer

4. Discussion

Ideal soil condition is critical for the growth of crops such as eggplant. Water plays a vital role for the physiological development of eggplants [20]. Water is essential in maintaining cell turgidity, transportation of nutrients and organic compounds throughout the plant, serving as a raw material for various plant metabolic processes, including photosynthesis, and through transpiration, buffering the plant against wide temperature fluctuations as well as comprising much of the living protoplasm in the cells [16].

Use of superabsorbent polymer (SAP) and/or rabbit manure helped to conserve soil moisture compared with where they were not applied. Studies have shown that SAP is able to absorb large amounts of water during irrigation or rain to between 200 to 500 times their original weight or volume in relatively short periods[9, 22]. After irrigation or rain has stopped, SAP act as water reservoirs and gradually release water into the soil near the root zone and therefore helping to extend soil moisture availability[4]. Rabbit manure has also been shown to improve soil water holding capacity through changes in soil physical, chemical and biological properties[1]. Therefore, this explains why soil moisture content was higher, where SAP and/or rabbit manure was applied. Abrisham et al. [2] observed that SAP enhanced soil and plant properties, including soil water retention capacity. Abuarab et al. [3] observed that rabbit manure had a better water holding capacity than chicken, cow and compost manure.

Use of SAP and/or rabbit manure improved growth and yield of eggplant compared with when they were not applied. The effect was much better when SAP was used alone, similar to when it was combined with rabbit manure compared with rabbit manure alone. Superabsorbent polymers have been reported to act as water reservoirs by absorbing excess water during irrigation or rain and releasing it slowing into the root zone on demand [8]. Rop [22] observed that SAP upon biodegradation release nutrient to the soil making them available for plant uptake. Rabbit manure is reported to improve soil physical, chemical and biological properties which result in better plant nutrient uptake and therefore improved physiological growth and development. Rabbit manure was observed to improve vegetative growth and yield of pepper (*Capsicum annuum* L.) and eggplant (*Solanum melongena* L.) grown in pot culture [1]. This was attributed to enhanced water holding capacity and nutrients that were gradually released to the soil which resulted in better nutrient uptake and physiological development.

5. Conclusion

Soil water and nutrient management are essential for the growth of crops, including eggplant. This is even more

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critical in arid and semi-arid areas where water shortage is of great concern. SAP and/or rabbit manure helped to improve soil moisture, growth and yield of eggplant compared with the control. Use of SAP had a better soil moisture retention effect comparable to SAP combined with rabbit manure. The finding demonstrates that SAP and/or rabbit manure may help in better soil water and nutrient management, particularly in arid and semi-arid areas, thus improving growth and yield of eggplant.

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