Effect of Hydrogel and Mulching on soil moisture, yield and economics on yellow passion fruit in Embu and Kiambu Counties, Kenya

ABSTRACT

Inadequate rainfall is a significant problem hindering the production of most crops in dryland regions. The current study was carried out to assess the effect of selected soil-water conserving interventions on soil moisture, growth, yield, quality, and profitability of yellow passion fruit. The experiment was laid in a randomized complete block design (RCBD) at Kenyatta University (Kiambu County) and Ugweri (Embu County). The treatments were: grass mulch, plastic mulch, hydrogel 10 g per plant (49 gm^{-2}) + plastic mulch, hydrogel 20 g per plant (98 gm^{-2}), hydrogel 10 g per plant + grass mulch, and a control (no hydrogel, no mulch). Results showed significant effects of treatments on soil moisture, growth, and yield of yellow passion fruit at both sites. Hydrogel 10 g per plant + plastic mulch treatment had significantly higher mean soil moisture than other treatments during all the sampling dates. The treatments: hydrogel 10 g per plant + plastic mulch, hydrogel 10 g per plant + grass mulch, and plastic mulch, recorded the highest average vine length. Hydrogel 10 g per plant + plastic mulch treatment had significantly higher yields than other treatments during 46, 48, 50, and 52 weeks after transplanting (WAT) at both sites. Treatments did not significantly affect the total soluble solids (TSS) of fruits. At Ugweri, hydrogel 10 g per plant + plastic mulch and hydrogel 10 g per plant + grass mulch had higher net benefits; 2599.00 USD ha^{-1} and 2455.10 USD ha^{-1}, respectively. At Kenyatta University, hydrogel 10 g per plant + plastic mulch provided significantly higher net benefit (3390.40 USD ha^{-1}) than other treatments. Based on the results, hydrogel 10 g per plant + plastic mulch and hydrogel 10 g per plant + grass mulch are recommended for yellow passion fruit growers in regions facing water scarcity.

Keywords: Mulch, hydrogel, soil-water conserving intervention, soil moisture, yellow passion fruit

1. Introduction

In Sub-Saharan Africa (SSA), rain-fed agriculture is the dominant source of food production practice by most smallholder farmers (Tesfaye *et al.,* 2017; Mwenda *et al.,* 2019). Droughts and dry spells are common in the tropics (Barrow, 2016). The reliance on erratic rainfall and exposure to climate risk illustrates smallholder farmers' livelihoods in the SSA region (Patt *et al.,* 2010). These constraints exacerbate efforts to sustainably increase agricultural production, reduce poverty, and enhance food security (Hansen *et al.,* 2011). Almost all (about 98 %) of agriculture in Kenya is rainfed; hence, extremely vulnerable to the increasing temperatures and droughts (WRI *et al.,* 2007). Kenyan agriculture is thus highly volatile, mainly due to extreme weather events, such as erratic rainfall, droughts, and rising mean temperatures, increasing in frequency and intensity with climate change. These together with other factors such as commodity price fluctuations, pests and diseases, and floods are significant causes of most crops' low yields.

The horticultural industry is one of the most important agricultural sectors and provides food and employment to a significant proportion of the Kenyan population. Over 5 million Kenyans in the rural areas, most of them women and youth, raise incomes from the sales of horticultural produce in the local markets and overseas (HCDA, 2017). Passion fruit production offers Kenyan farmers a viable venture for increasing household incomes vis-à-vis cereal crops such as maize. The passion fruit, primarily the yellow passion, is used to make juice, blend other juices, and sometimes consumed as fresh fruit. However, adverse consequences of climate change, including inadequate and unpredictable rainfall patterns in Kiambu and Embu counties, are a serious threat to optimizing passion yields. Yellow passion fruit is favored due to its high-quality fruits, but in smallholder farms, more than 80% of yellow passion yield losses are caused by erratic rainfall and diseases (Wangungu *et al.,* 2010; HCDA, 2017). Yellow passion fruit farming in Kenya produces average yields of 3.3 metric tonnes per hectare and thereby operates below potential compared to South Africa's average production of 8 metric tonnes per hectare (CARE, 2013; HCDA, 2017). Also, farmer's experience has shown that even drought-tolerant varieties, including KPF4 yellow passion fruit, succumb to drought stress (AGRA, 2014).

Passion fruit crop is known to thrive well in areas receiving evenly distributed annual rainfall ranging from 800 mm to 1750mm (Laredo, 2013) under conditions with similar or even higher reference evapotranspiration as in Kenya. Nevertheless, Drought in Embu and Kiambu regions in the orchards frequently occurs due to low (989mm annually at Kenya University) and poorly distributed rainfall (1200mm annually at Ugweri). Losses through deep percolation, surface runoff, and evaporation are high under these conditions, and drought remains a significant constraint to increasing productivity. During the vegetative developmental stage, water stress interferes with node formation, thereby limiting yields since flowers are initiated in new shoots' axils (Menzel *et al.*, 1986). Additionally, the inadequate water supply may cause adverse effects, including premature leaf defoliation, flower abortion, low fruit juice content, premature fruit drop, and fruit deformation, which reduces fruit quality and yield (Morton, 1987). Deformed fruits face market rejection or are sold at low prices, making farmers incur losses since the cost of production may exceed returns from sales.

Some of the key suggestions made by researchers for managing soil water constraints in crop lands include training famers on the use of water conserving technologiesand diversification of crops (Mwandalu and Mwangi, 2013; AGRA, 2014).Soil water conserving technologies such as hydrogels and mulches reduces loss of soil water through percolation, evaporation or runoff, thus making it available for plant use. Hydrogels are crystalline in nature, have the ability to absorb water and can swell more than 200 times their own weight(Montesano *et al.,* 2015**)**. They are commonly referred to as superabsorbent polymers (SAPs) because they can absorb and hold large amounts of water. In soil, hydrogels absorb water from irrigation and rainfall, hold it and under deficit conditions, avails it for plant uptake, thereby protecting plants from the effects of acute water shortages (Saini*et al.,* 2018). The water holding capacity of soil amended with hydrogels is often higher than untreated soils (Montesano *et al.,* 2015**)**.Khonglah *et al*. (2016) reported that the incorporation of hydrogel (stockosorb) and mulching regimes resulted in positive effect on growth indices and yield of Assam lemon [Citrus limon (L.) Burm.].According to this study, the highest increase in plant height (8.85%) was recorded in the treatment with 50g per plant hydrogel + black polythene mulch. Results showed that the treatment with 50g hydrogel per plant + black polythene mulching recorded significantly higher fruit yields (7.99kg per plant) and soil moisture content(27.93%) than the control.The treatments; 50g hydrogel per plant + black polythene mulching and 50g hydrogel per plant + rice husks mulch recorded significantly higher plant height and yields than the control. Similarly, higher water conservation, growth indices and yield due to the use of polythene mulch and hydrogel was reported by Jain *et al.* (2017) in peanut.Covering the soil with organic or inorganic materials reduces evaporation, weeds and runoff (Deng *et al.*, 2019), and ameliorate effects of water stress on plants because they enhance better capture of supplemental irrigation or rainfall (Kaur*et al.*, 2016).

Generally, in Embu and Kiambu counties, farmers have inadequate information on how to implement soil water-conserving technologies. Few studies on the use of hydrogel plus mulch have been conducted in the study areas. Systematic field studies are required to generate information on the effective use of hydrogels and mulches to conserve soil moisture and increase yellow passion fruit productivity. Such information will be attractive to farmers if it incorporates reports on profitability. Studies have shown that farmers are sensitive to technologies based on profits, and there is laxity in adoption when returns are very low or negative (Babalola, 2007; Chouinard et al., 2008; Mwangi and Kariuki, 2015). The costs and benefits of cropland water management interventions can be measured by taking into account returns from yields and operational costs (Drechsel et al., 2004). Therefore, this study was conducted to evaluate the comparative economic benefits of mulches and hydrogels to address the existing information gap.

2. Materials and Methods

2.1 Study areas

The study was carried out in two counties in Kenya; Kiambu and Embu. The study sites were; Kenyatta University (1.1767° S, 36.9365° E) in Kiambu County and Ugweri (0.4794° S, 37.6001° E) located in Runyenjes division of Embu County. Kenyatta University lies in the upper midland agro-ecological zone four (UM4) (Jaetzold and Schmidt, 1983), 1608m above sea level, receives an average annual rainfall of approximately 989mm, and experiences 19 to 20 ^{0}C as annual mean temperature. Rainfall is often bi-modal, with short rains received from October to December and long rains lasting from March to June. The soils of Kenyatta University are predominantly Acrisols (Jaetzold *et al.*, 2006). Ugweri lies within the Upper Midland agro-ecological zone three (UM3) (Jaetzold *et al.*, 2007). It has an altitude of 1347 m above sea level and an average annual temperature of 21 0C. The bi-modal rainfall falls in two seasons; short rains (October to December) and long rains occur from March to June. The soils are mainly Humic Nitisols.

2.2 Experimental design, treatments and maintenance

A field experiment was set up at Kenyatta University and Ugweri and lasted from April 2016 to April 2017 (52 weeks). There were six treatments; clear plastic mulch, hydrogel 20 g (rate recommended by the manufacturer), grass mulch, hydrogel 10 g plus grass mulch, hydrogel 10 g plus clear plastic mulch, and a control (non-mulched, without hydrogel). The experiment was a randomized complete block design comprising three replicates. There were 18 plots, each with dimensions of 2m x 9m. Seedlings of the KPF4 yellow passion fruit seedlings were obtained from Kenya Agriculture and Livestock Research Organization (KALRO). All the seedlings were at least 0.3 m tall, an appropriate height for planting in field conditions (Morton, 1987).

Before planting, sites were ploughed at a depth of 15 cm by a jembe, and all weeds were removed, which provided a level ground. Planting holes, each with dimensions of 0.45 m x 0.45 m x 0.45 m (0.10 m3 of soil), were dug using a jembe and a spade. During digging, the top soil was separated from the subsoil. The topsoil put inside each hole was mixed with 125 g (80 kg/ha) of di-ammonium phosphate fertilizer and 20 kg manure (13.34 t ha-1). Seedlings were planted, one in each hole, with a spacing of 3 m between the plants in a row and 2 m between the rows. The treatments were applied to the three plants in each of the 18 plots during the 6th week after planting. 1 m^2 of clear plastic mulch was applied, and it covered the soil surface around the plant up to 50 cm from the stem. The clear plastic mulch was replaced twice after it was torn. The soil around the plant (20 cm radius from the stem) was dug at a depth of 0.2 m (0.006 m^3 of soil) and thoroughly mixed with 10 g of hydrogel (in hydrogel 10g plus grass mulch or hydrogel 10 g plus clear plastic mulch treatments) and 20 g (in hydrogel 20 g treatment). In the treatments, grass mulch and grass mulch plus hydrogel 10 g grass mulch (0.10 m thickness) were applied, and it covered soil around the stem up to a radius of 0.50 cm.

Three months after transplanting, soil moisture access tubes were installed in holes (80 cm deep) dug using an auger. The 1 m PVC tubes were installed 80 cm into the soil, leaving 20 cm above the ground to prevent water entry by surface flow. The bottom end of the tube inserted into the soil had a permanent water-tight lid fixed to prevent water entry into the tube. In each plot (3 plants), a PVC access tube spaced 15 cm from the stem of the middle plant was installed. A removable plastic cup was used to cover the top end of the access tube to prevent rainfall water entry. After the tubes were fitted, the soil was refilled tightly to minimize gaps that would accumulate air. The tubes were left undisturbed in the field until November 2016 to fit tightly and acclimatize into the soil profile.

Plants were irrigated (10 litres of water per plant) every two weeks to mitigate the effects of moisture deficits on productivity during prolonged dry periods. Weeds in the orchard were removed by hand-digging using a Jembe, and weeds beneath the clear plastic mulch were uprooted by hand as necessary. Two weeks after transplanting, topdressing with 17N: 17P: 17K was done at a rate of 170g per plant. The same fertilizer was applied at a rate of 100 g per plant at the onset of fruiting and 70g at the middle of the fruit setting stage to enhance productivity (Ulmer and MacDougal, 2004).

A trellis system of galvanized wire and posts was constructed in the orchard to support vines and fruits. Posts were treated with a termiticide to offer resistance against attack by termites and enhance longevity. Holes measuring 45cm deep and 3m apart were dug, after which posts with a diameter of 15cm and 2.70 m long were erected. Using nails, the galvanized wire was fixed in straight lines on the top of the poles and along the rows. The parent vine was staked on a string and trained to grow vertically to the trellis wire. Two vines growing on the parent vine were trained to grow along the trellis wire following opposite directions. The parent vine was cut at the top after it reached the trellis wire. The pruning shears were disinfected by dipping them in 70% concentrated ethanol before, during, and after use to prevent the spread of diseases. Spent laterals were pruned to give way to the development of new and more productive laterals (Nakasone and Paul, 1998). Pests in the orchard were controlled by applying thunder using a knapsack sprayer. Preventive disease management measures adopted included timely field inspection, pruning, weed control, and maintenance of field hygiene.

2.3Data collection

Soil moisture:Soil moisture was measured at intervals of two weeks during November 2016-February 2017. An automated neutron probe Sentek Diviner-2000 (Evett and Tolk, 2009) was used for soil moisture measurements at 0-60cm depth, ideal with more than 70% of the roots (Carr, 2013). The Sentek Diviner recorded moisture reading at intervals of 10cm. The readings were automatically taken and recorded in the display unit when the Diviner was lowered into the access tubes. The data stored in the display unit of Diviner-2000 were downloaded, read, and processed on a computer. The water content of the different soil layers, 0-10, 10-20, 20-30, 30-40, 40-50, and 50-60cm, was summed up to obtain the total soil water content of the 0-60cm profile.

Growth and yield: Measurements of growth (vine length) and yield (fruit weight) parameters were taken bi-weekly. During 10 weeks after transplanting (WAT), the length of each parent vine was measured using a tape measure until 16WAT. Harvesting of ripe fruits was done at intervals of two weeks, beginning at 44 WAT until 52 WAT. A hand-held weighing balance was used to take the reading of fruits harvested from each plant. Fruit weight was expressed in tonnes per hectare using the formula below;

Yield (t/ha) = $Y_m \times P_n$

Where; Y_m= mean weight of fruits per plant expressed in tonnes, P_n= Number of plants in one hectare orchard (ha^{-1}).

Total soluble solids: Fifteen ripe fruits were collected during each of the five harvests and used to measure total soluble solids (TSS). The concentration of total soluble solids can give an indication of sugars in fruits since sugars are the major constituent of soluble solids in fruit juice (Davies *et al.*, 1981). Fruits were cut longitudinally (Frett *et al.*, 2012), and juice was collected in a 50ml beaker by squeezing the pieces. A dropper was used to place a single drop of juice on the prism of the refractometer, held in place gently (to avoid the formation of bubbles) by the cover plate, and the reading (% brix) was recorded. The surface of the prism was rinsed using distilled water and wiped using a lint-free cloth before it was used for the next measurement.

2.4 Data analysis

Economic analysis: The economics of treatments used was worked out by considering the expenditure toward various inputs (land preparation, pesticides, seedlings, irrigation, manure, fertilizers, grass mulch, plastic mulch film, hydrogel, trellising system, rental value of land, operation costs, and other miscellaneous expenses) and outputs (money generated from the sale of yellow passion fruits) as per the prevailing costs. Time taken to do various activities was measured and used to calculate operation costs at local labor wages per day. Gross benefits were calculated based on the prevailing price of yellow passion fruits during harvesting. Net benefits were estimated by subtracting the total cost of cultivation from the gross benefits and benefit-cost ratio (a measure of returns per dollar invested) by dividing gross benefits by the total cost of cultivation.

***Statistical analysis*:** All data (fruit weight, vine length, total soluble solids, moisture content, economic data, and soil biophysical data) was subjected to analysis of variance (ANOVA) using SAS version 9.3 to test for significant differences between treatments. Significantly different means were separated using Fischer's least significant Difference test (LSD) at $P \leq 0.05$ for all variables except means for soil nutrient data (separated using a t-test).

3. Results

3.1 Effect of hydrogel and mulch on soil moisture

At Ugweri and Kenyatta University, there were significant differences (as shown by different letters, a-f) among treatments on soil moisture content in 0-60 cm profile (Figure 1 and 2). As the total rainfall decreased, the soil moisture content in all the treatments also decreased. At Ugweri, on 11/22/2016, soil moisture varied between 141 mm in the control and 192 mm recorded in hydrogel 10 g plus clear plastic mulch (Figure 1). During the same measurement point, the treatment with hydrogel 10 g plus grass mulch had the second-highest soil moisture content (181 mm). These trends were maintained across all the measuring points.

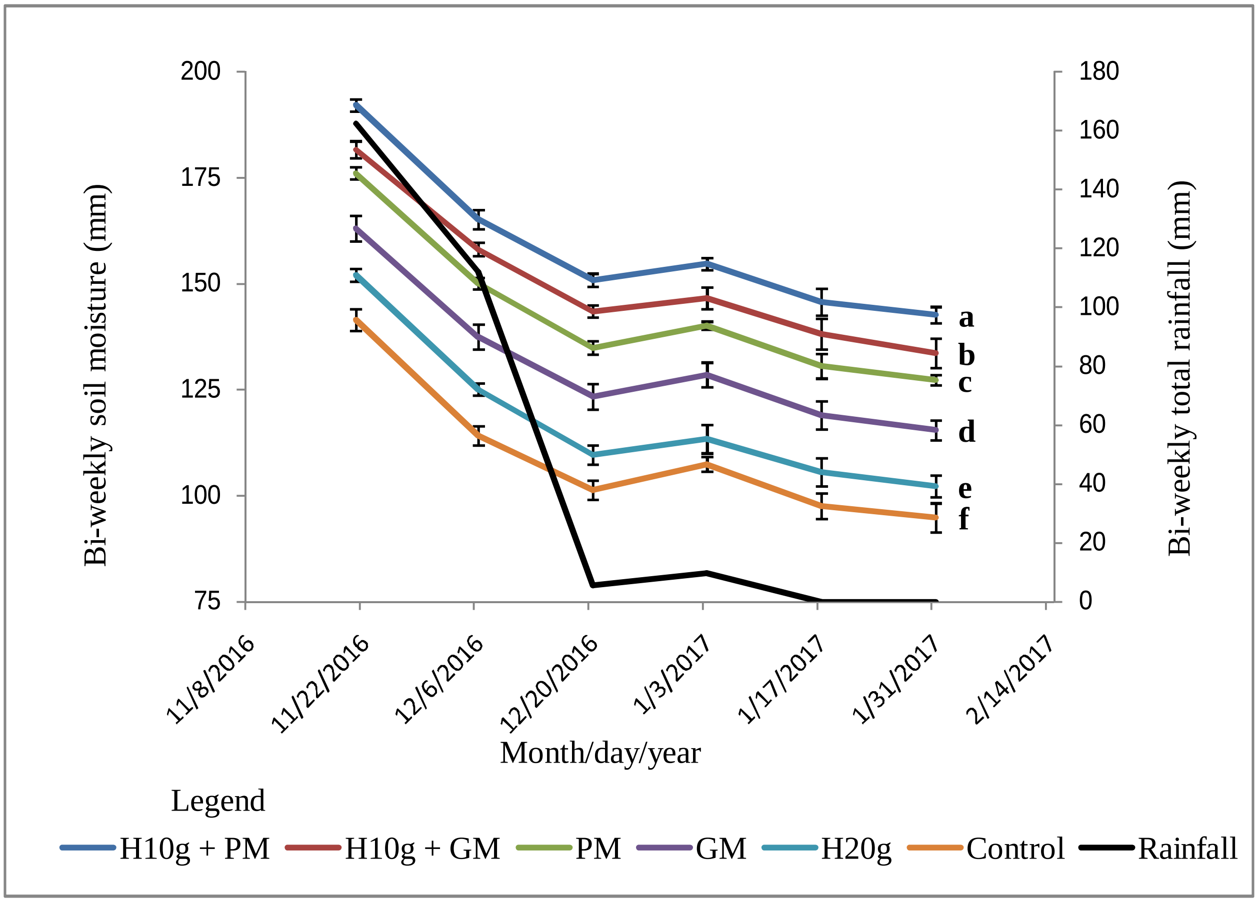

Figure 1: Biweekly moisture content (mm) at 0-60cm soil profile for various treatments at Ugweri. In black, sum of precipitation for the previous two-week period. The error bars denote standard error of the mean.

PM = Plastic mulch; **GM** = Grass mulch; **H20g** = Hydrogel 20 grams; **H10g + PM** = Hydrogel 10 grams plus plastic mulch; **H10g + GM** = Hydrogel 10 grams plus grass mulch.

At Kenyatta University, on 11/23/2016, the highest soil moisture was recorded in hydrogel 10 g + PM treatment (Figure 2). All treatments had significantly higher soil moisture content than the control throughout all the measuring points. These trends were replicated in the second, third, fourth, fifth, and sixth measuring points.

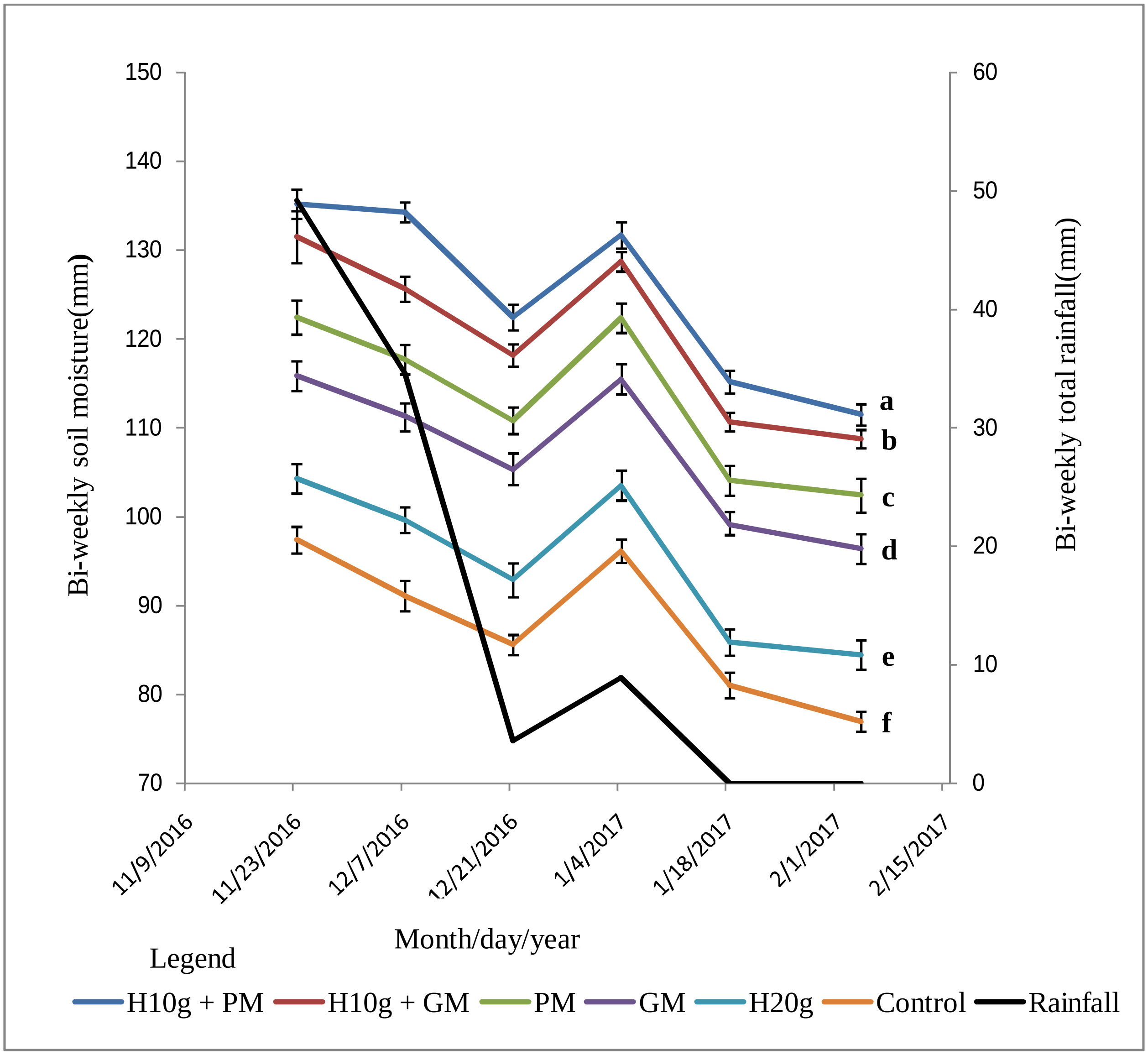

Figure 2: Biweekly moisture content (mm) at 0-60cm soil profile for various treatments at Kenyatta University. In black, sum of precipitation for the previous two-week period. The error bars denote standard error of the mean.

PM = Plastic mulch; **GM** = Grass mulch; **H20g** = Hydrogel 20 grams; **H10g + PM** = Hydrogel 10 grams plus plastic mulch; **H10g + GM** = Hydrogel 10 grams plus grass mulch

3.2 Effect of hydrogel and mulch on growth, yield and quality of yellow passion fruit

***Vine length*:** At Ugweri and Kenyatta University study sites, treatments significantly ($P \leq 0.05$) influenced vine length from 10 weeks after transplanting (WAT) until 16 WAT. Irrespective of the site and sampling period, all treatments had significantly higher vine lengths than the control. Three treatments; hydrogel plus plastic mulch, hydrogel plus grass mulch, and plastic mulch consistently had the highest vine length at both sites. The control had the least vine length on all sampling dates.

Table 1: Mean vine length (cm) of yellow passion fruit plants recorded in different treatments at Ugweri and Kenyatta University sites

Treatments	**Ugweri**				**Kenyatta University**			
	10WAT	12WAT	14WAT	16WAT	10WAT	12WAT	14WAT	16WAT
H10g + PM	248.22^{a}	265.67^{a}	301.44^{a}	349.78^{a}	89.21^{a}	115.22^{a}	160.00^{a}	224.00^{a}
H10g + GM	240.78^{a}	257.44^{a}	295.78^{a}	350.00^{a}	83.11^{a}	106.11^{a}	156.44^{a}	217.33^{a}
PM	213.06^{ab}	247.00^{ab}	293.56^{ab}	332.11^{ab}	71.52^{ab}	100.11^{ab}	148.77^{ab}	210.13^{ab}
GM	199.11^{b}	230.83^{b}	273.72^{b}	308.61^{b}	63.74^{b}	92.00^{b}	135.22^{b}	201.51^{b}
H20g	196.78^{b}	227.78^{b}	270.11^{b}	305.11^{b}	62.63^{b}	88.66^{b}	134.77^{b}	198.77^{b}
Control	158.50^{c}	198.72^{c}	238.33^{c}	269.40^{c}	41.60^{c}	65.11^{c}	113.80^{c}	175.00^{c}
P-value	0.0049	0.0023	0.0007	0.0004	0.0323	0.0298	0.0002	<.0001
LSD	35.610	25.605	24.338	28.207	18.786	17.954	16.494	14.898

* Means not sharing a common letter in a column are significantly different at 5 % probability level according to Fisher's Least Significant Difference test (LSD).

PM = Plastic mulch; **GM** = Grass mulch; **H20g** = Hydrogel 20 grams; **H10g + PM** = Hydrogel 10 grams plus plastic mulch; **H10g + GM** = Hydrogel 10 grams plus grass mulch; **WAT**=Weeks after transplanting

Yield: At both sites, the highest yield from 44 to 52 weeks after planting (Table 2 and 3) was consistently found in the H10 g + PM treatment. The yields ranged from 1.2 to 2.3 t ha-1 at Ugweri and 1.10 to 2.03 t ha-1 at Kenyatta University. At Ugweri, the treatment with hydrogel plus grass mulch was second best, with yields ranging from 1.02 to 2.12 t ha-1. At Kenyatta University, hydrogel 10 g + GM and PM ranked second. The control treatment consistently gave the lowest yields at both sites.

Table 2: Mean fresh fruit yield (t ha^{-1}) for various treatments at Ugweri experimental site

Treatments	44 WAT	46 WAT	48 WAT	50 WAT	52 WAT
H10g + PM	1.20^{a}	1.60^{a}	2.30^{a}	2.02^{a}	1.79^{a}
H10g + GM	1.02^{b}	1.43^{b}	2.12^{b}	1.85^{b}	1.54^{b}
PM	0.91^{bc}	1.13^{c}	1.83^{c}	1.47^{c}	1.44^{bc}
GM	0.89^{bc}	1.02^{c}	1.81^{c}	1.37^{c}	1.40^{bc}
H20g	0.80^{c}	1.01^{c}	1.73^{c}	1.35^{c}	1.31^{c}
Control	0.58^{d}	0.80^{d}	1.51^{d}	1.05^{d}	1.09^{d}
P-value	<.0001	<.0001	<.0001	<.0001	0.0003
LSD	0.1313	0.1253	0.1627	0.1461	0.1506

* Means not sharing a common letter in a column are significantly different at 5 % probability level according to Fisher's Least Significant Difference test (LSD).

PM = Plastic mulch; **GM** = Grass mulch; **H20g** = Hydrogel 20 grams; **H10g + PM** = Hydrogel 10 grams plus plastic mulch; **H10g + GM** = Hydrogel 10 grams plus grass mulch; **WAT**=Weeks after transplanting

Table 3: Mean fresh fruit yield (t ha^{-1}) for various treatments at Kenyatta University experimental site

Treatments	44 WAT	46 WAT	48 WAT	50 WAT	52 WAT
H10g + PM	1.10[a]	1.37[a]	2.03[a]	1.59[a]	1.29[a]
H10g + GM	0.86[b]	1.12[b]	1.83[b]	1.33[b]	1.17[b]
PM	0.77[bc]	1.03[bc]	1.80[b]	1.31[b]	1.17[b]
GM	0.68[cd]	0.98[c]	1.63[c]	1.14[c]	1.00[c]
H20g	0.59[d]	0.85[d]	1.49[d]	1.04[cd]	0.87[d]
Control	0.35[e]	0.67[e]	1.28[e]	0.95[d]	0.81[d]
P-value	<.0001	<.0001	<.0001	<.0001	0.0005
LSD	0.1187	0.1066	0.1252	0.8053	0.7792

* Means not sharing a common letter in a column are significantly different at 5 % probability level according to Fisher's Least Significant Difference test (LSD).

PM = Plastic mulch; **GM** = Grass mulch; **H20g** = Hydrogel 20 grams; **H10g + PM** = Hydrogel 10 grams plus plastic mulch; **H10g + GM** = Hydrogel 10 grams plus grass mulch; WAT=Weeks after transplanting

Total Soluble Solids: Total soluble solids were not significantly affected by the treatments at both sites (Table 4). Although not significant, during 44WAT, the control had higher (18 % brix) total soluble solids than other treatments, while the treatment with hydrogel 10 grams plus plastic mulch had the lowest (15 % brix). The trend was maintained during 46, 48, and 50 WAT at both sites.

Table 4: Average total soluble solids (% brix) for various treatments at Ugweri and Kenyatta University sites

Treatments	**Ugweri site**				**Kenyatta University site**			
	44WAT	46WAT	48WAT	50WAT	44WAT	46WAT	48WAT	50WAT
Control	17.8	17.70	17.70	17.90	17.76	17.82	17.64	17.34
H20g	17	17.41	16.95	17.19	16.87	16.84	16.93	17.08
OM	16.9	16.27	16.43	16.47	16.84	16.24	16.31	16.72
PM	15.9	16.08	16.38	16.32	15.80	16.22	16.27	16.48
H10g+OM	15.2	15.60	16.19	16.23	15.11	15.97	16.07	16.30
H10g+PM	15.2	15.22	15.90	16.11	15.09	15.93	15.99	15.52
P-value	0.09	0.35	0.37	0.31	0.08	0.26	0.29	0.22
LSD	2.7	2.7	2.0	2.14	2.8	2.8	1.9	2.1

*Means in a column are not significantly different at 5 % probability level according to Fisher's Least Significant Difference test (LSD)

.**PM** = Plastic mulch; **GM** = Grass mulch; **H20g** = Hydrogel 20 grams; **H10g + PM** = Hydrogel 10 grams plus plastic mulch; **H10g + GM** = Hydrogel 10 grams plus grass mulch; **WAT**=Weeks after transplanting

3.3 Economic benefits of hydrogel and mulch in the production of yellow passion fruit

Significant increases in economic returns were obtained by the application of hydrogel and mulching at Ugweri and Kenyatta University sites (Table 5). The treatment with hydrogel 10 grams plus plastic mulch provided higher net returns than other treatments (2599 USD ha-1 at Ugweri and 3390.40 USD ha-1 at Kenyatta University). At both sites, a higher benefit-cost ratio and return to labor were recorded in hydrogel 10 grams plus grass mulch and hydrogel 10 grams plus plastic mulch than in other treatments.

Table 5: Economic benefits analysis (net benefit, benefit-cost ratio, return to labour) in different treatments at Ugweri and Kenyatta University sites.

Treatments	**Ugweri site**			**Kenyatta University site**		
	Net benefit USD ha^{-1}	Benefit cost ratio	Return to labour	Net benefit USD ha^{-1}	Benefit-cost ratio	Return to labour
H10g+PM	2599.00^{a}	1.54^{a}	5.00^{ab}	3390.40^{a}	2.02^{a}	6.36^{a}
H10g+GM	2455.10^{a}	1.59^{a}	5.21^{a}	2770.10^{b}	1.78^{ab}	5.70^{a}
PM	1814.00^{b}	1.22^{b}	4.33^{cd}	2524.40^{bc}	1.75^{b}	5.75^{a}
GM	1804.30^{b}	1.33^{b}	4.69^{bc}	2403.20^{c}	1.70^{b}	5.82^{a}
H20g	1626.50^{b}	1.19^{bc}	4.32^{cd}	1781.00^{d}	1.25^{c}	4.45^{b}
Control	1249.10^{c}	1.04^{c}	3.95^{d}	1549.20^{d}	1.19^{c}	4.43^{b}
P value	<.0001	<.0001	0.0014	<.0001	<.0001	0.0002
LSD	241.34	0.1787	0.5044	350.74	0.2526	0.6709

* Means not sharing a common letter in a column are significantly different at 5 % probability level according to Fisher's Least Significant Difference test (LSD).

4.Discussion

At both sites, soil moisture was significantly higher in other treatments than the control, likely because more water is lost in bare soil through evaporation, percolation, and runoff. At field capacity, the amount of moisture retained by all treatments decreased as the rainfall decreased. This occurred probably because less rainfall resulted in less water input into the soil. The treatment with hydrogel 10 grams plus clear plastic mulch had the highest soil moisture. This most likely occurred because of the positive cumulative effect of hydrogel and clear plastic mulch in suppressing soil water losses through evaporation, percolation, and surface runoff. This agrees with Lalitha *et al.* (2010), who reported that plastic mulched treatments conserve more soil water compared to the control partly because the water that condenses on the lower part of the film keeps a high water potential on the soil surface that prevents capillary rise, thus reducing evaporation. The positive effect of hydrogel was probably because of its inherent ability to absorb and retain water, thereby minimizing percolation, runoff, and evaporation losses. This explanation is supported by Lin *et al.* (2004) and Shahid *et al.* (2012), who found that plots treated with hydrogel had higher soil moisture than the control. Similarly, hydrogel and grass mulch had significantly higher soil moisture than the control, implying enhanced cumulative effectiveness in retarding water losses. The contribution of grass mulch in moisture conservation was profound, most likely because it absorbs much of the sun's incident radiation, thereby reducing water losses through evaporation (Gupta and Gupta, 1983). On the other hand, grass mulch might have provided a more effective barrier against the surface flow, which allowed more infiltration. The better water retention observed in hydrogel 10 grams plus clear plastic or grass mulch than in the sole application of hydrogel implies that mulching could have improved the water retention properties of the hydrogel. This is in consonance with the explanation that mulching modifies soil temperature (Narjary *et al.*, 2013) and maintains a relatively uniform water status (Huang, 2005), two main pre-conditions for better retention of water by hydrogels. Therefore, it is likely that there could be a water status threshold in the soil critical for effective water retention by hydrogels. Furthermore, this water threshold could most likely vary depending on the place, farming system (rain-fed/irrigated), or climatic conditions.

The highest vine length was observed in hydrogel 10 grams plus clear plastic mulch and hydrogel 10 grams plus grass mulch. This may be linked to more soil water retention due to decreased evaporation, percolation, and higher infiltration. The roots absorbed the water retained and used in the plant to support cell division and elongation, leading to the longer vine. This agrees with previous studies that reported higher growth indices in citrus grown with the use of hydrogel (Arbona *et al.*, 2005) and groundnuts with plastic mulch (Ramakrishna *et al.*, 2006) than the control. The profound effect on vine length observed in the mulched treatments was likely because of a better soil microclimate that favored plant growth. The improved soil environment for plant growth, according to Anikwe *et al.* (2007), comprises of weed suppression, reduced compaction of soil, and better nutrient utilization. A combination of hydrogel 10 grams plus grass mulch increased vine length significantly more than grass mulch alone. This was probably because hydrogel 10 grams plus grass mulch conserved more soil moisture. This confirms the finding by Yang *et al.* (2018), who established that amendment of soil with hydrogel plus straw mulch enhanced soil aggregate stability and the structure of pores that improve the movement of water and its retention, which may promote faster plant growth. The lower vine length observed in the control than other treatments may be explained by the high water losses due to surface flow, evaporation, and percolation in bare soil. High soil water losses may result in the stunted growth of plants.

The variation observed in the yield during the harvesting periods could be due to differences in ripening. Many factors, including variations in air temperature and humidity, can lead to variations in the time of maturation or ripening of fruits (Giovannoni, 2001). This is in agreement with the findings of Das *et al.* (2013), who established that passion fruit yield varied between harvests and seasons. The hydrogel plus clear plastic mulch treatment provided superior yields than other treatments at both sites. This is associated with more retained soil moisture, as soil moisture data shows. The high retention of soil moisture probably provided a favorable soil microclimate characterized by more even distribution and availability of moisture to plants within the growing season. This finding is similar to that of Jain *et al.* (2017) and Yang *et al.* (2018), who reported that plastic-mulched plants grown with the use of hydrogel had better availability and utilization of soil moisture than the control. Hydrogels also increase soil water holding capacity and boost the retention of plant available water (Abedi-Koupai *et al.*, 2008), which significantly affects plant development (Wróblewska *et al.,* 2012). The positive response to plastic mulching expressed by, among others, higher yields is attributed to its role in increasing water use and nutrient efficiency in plants through suppression of weeds, reduction in evaporation, and minimized seepage of water into the aquifer (Chen *et al.,* 2015; Yu *et al.,* 2018). Higher yields might have also resulted from the positive influence of plastic mulch and hydrogel on plants' metabolic processes, including enhanced leaf and xylem water potential, diminished transpiration, reduction in oxidation stress, as well as nitrogen uptake efficiency (Islam *et al.,* 2011).

The sole grass mulch and clear plastic mulch treatments had significantly higher yields than the control at both sites. This might be attributed to higher moisture retention, whereby grass or plastic mulching provided a more effective barrier against evaporation than the control. The more even moisture availability can enhance better plant growth and contribute to high yields in passion fruit (Paul and Duarte, 2012). This may occur because mulching minimizes the consumptive use of soil water by suppressing weeds and also reduces evaporation. Alternatively, mulching modifies soil temperatures, which may lead to better yields of crops (Lamont, 2005). This is likely because higher soil temperatures enhance the accumulation of photosynthates and the mobilization of nutrients, which is important for improved yields. Similarly, hydrogel 20 grams performed better than the control, most likely because it retained more soil moisture that was also available to the plants. This explanation is supported by the finding of Akhter *et al.* (2004), who confirmed that soils treated with hydrogel had higher available soil water than bare soil.

There was no significant effect of treatments on the total soluble solids of yellow passion fruits. This observation is similar to that of Gaturuku and Isutsa (2011) in purple passion fruit. A trend emerged where the control had higher (although insignificant) total soluble solids than other treatments. This may be explained by the expected low water content in fruits in the control treatment, which implies a high concentration of total soluble solids (McAvoy, 1995). This agrees with Baselga *et al.* (1992), who reported the least soil moisture and highest total soluble solids in the control treatment than other treatments in tomato fruit. The low yields and higher total soluble solids, especially in the control, could therefore imply the failure of the crop to reach its water demand.

The treatments, hydrogel 10 grams plus grass mulch and hydrogel 10 grams plus plastic mulch, significantly increased net benefits than other treatments at both sites. This may be explained by the higher yields obtained under these treatments that were adequate to offset the cost of cultivation. The higher yields also paid off the labor and non-labor costs leading to significant increases in the benefit-cost ratio and return to labor as recorded in hydrogel 10 grams plus plastic mulch and hydrogel 10 grams plus grass mulch. Although soil moisture conserving technologies have been associated with several benefits (Hobbs *et al.*, 2007; Olarinde *et al.*, 2012), high net benefits and benefit-cost ratio are crucial for farmers' adoption (Srivastava *et al.*, 2004).

5. Conclusions

Hydrogel 10 grams plus clear plastic mulch and hydrogel 10 grams plus grass mulch conserved more soil moisture than other treatments during the growing season of yellow passion at Ugweri and Kenyatta University sites. The soil moisture stored under these treatments supported better growth of yellow passion fruit plants and eventually resulted in higher yields and net benefits.

Therefore, the challenge of soil water deficits and crop failure in Embu and Kiambu Counties may, at least partly, be overcome by growing plants using hydrogel 10 grams plus clear plastic mulch or hydrogel 10 grams plus grass mulch. These soil water conserving technologies are also suitable for improving yellow passion yields in the study areas, leading to better food security and higher incomes.

References

Abedi-Koupai, J., Sohrab, F., and Swarbrick, G. (2008). Evaluation of hydrogel application on soil water retention characteristics. *Journal of Plant Nutrition*, *31*(2), 317-331.

AGRA. (2014). *Africa agriculture status report 2014: Climate change and smallholder agriculture in sub-saharan Africa*. Retrieved from AGRA website:https://ccafs.cgiar.org/publications/africa-agriculture-status-report-2014-climate-change-and-smallholder-agriculture-sub#.XNVWGRQzbIU.

Akhter, J., Mahmood, K., Malik, K. A., Mardan, A., Ahmad, M., and Iqbal, M. M. (2004). Effects of hydrogel amendment on water storage of sandy loam and loam soils and seedling growth of barley, wheat and chickpea. *Plant Soil and Environment*, *50*(10), 463-469.

Anikwe, M. A. N., Mbah, C. N., Ezeaku, P. I., and Onyia, V. N. (2007). Tillage and plastic mulch effects on soil properties and growth and yield of cocoyam (*Colocasia esculenta*) on an ultisol in southeastern Nigeria. *Soil and Tillage Research*, *93*(2), 264-272.

Arbona, V., Iglesias, D. J., Jacas, J., Primo-Millo, E., Talon, M., and Gómez-Cadenas, A. (2005). Hydrogel substrate amendment alleviates drought effects on young citrus plants. *Plant and Soil*, *270*(1), 73-82.

Babalola, O., Oshunsanya, S. O., & Are, K. (2007). Effects of vetiver grass (Vetiveria nigritana) 426 strips, vetiver grass mulch and an organomineral fertilizer on soil, water and nutrient 427 losses and maize (Zea mays, L) yields. *Soil and Tillage Research*, *96*(1-2), 6-18.

Barrow, C. J. (2016). *Water Resources and Agricultural Development in the Tropics*. London, England: Routledge.

Baselga J., Prieto Losada, M. H., Rodríguez del Rinc, and Oacu, A. (1992). Response of processing tomato to three different levels of water and nitrogen applications. In *International Symposium on Irrigation of Horticultural Crops 335* (pp. 149-156).

CARE (2016). Political Economy Analysis of Kenya' s Horticultural sector: interests and motivations in Kenya's horticultural sector effecting outcomes and impacts CARE Kenya's target groups with specific focus on product value chain: UKaid https://doi.org/10.1093/oxfordhb/9780199560103.003.0005.

Carr, M. K. V. (2013). The water relations and irrigation requirements of passion fruit (*Passiflora edulis*): A review. *Experimental Agriculture*, *49*(4), 585-596.

Chen, Y., Liu, T., Tian, X., Wang, X., Li, M., Wang, S., and Wang, Z. (2015). Effects of plastic film combined with straw mulch on grain yield and water use efficiency of winter wheat in Loess Plateau. *Field Crops Research*, *172*, 53-58.

Chouinard, H. H., Paterson, T., Wandschneider, P. R., & Ohler, A. M. (2008). Will farmers trade 443 profits for stewardship? Heterogeneous motivations for farm practice selection. *Land* 444 *Economics*, *84*(1), 66-82.

Das, M. R., Hossain, T., Mia, M. B., Ahmed, J. U., Kariman, A. S., and Hossain, M. M. (2013). Fruit setting behaviour of passion fruit. *American Journal of Plant Sciences*, *4*(05), 1066.

Davies, J. N., Hobson, G. E., and McGlasson, W. B. (1981). The constituents of tomato fruit—the influence of environment, nutrition, and genotype. *Critical Reviews in Food Science & Nutrition*, *15*(3), 205-280.

Deng, H. L., Xiong, Y. C., Zhang, H. J., Li, F. Q., Zhou, H., Wang, Y. C., and Deng, Z. R. (2019). Maize productivity and soil properties in the Loess Plateau in response to ridge-furrow cultivation with polyethylene and straw mulch. *Scientific reports, 9*(1), 3090.

Drechsel, P., Giordano, M., & Gyiele, L. (2004). *Valuing nutrients in soil and water: concepts and techniques with examples from IWMI studies in the developing world* (Vol. 82). Iwmi.

Evett S. R., and Tolk J. A. (2009). Introduction: Can Water Use Efficiency be modeled. *Agronomy Journal*. 101, 423–425.

Frett, T. J., Gasic, K., Clark, J. R., Byrne, D., Gradziel, T., and Crisosto, C. (2012). Standardized phenotyping for fruit quality in peach (*Prunus persica* (L.) Batsch). *Journal of the American Pomological Society*, *66*(4), 214.

Gaturuku, J. K., and Isutsa, D. K. (2011). Irrigation and mulch significantly enhance yield but not quality of purple passion fruits. *Journal of Agricultural and Biological Science*, *6*(11), 47-53.

Giovannoni, J. (2001). Molecular biology of fruit maturation and ripening. *Annual review of plant biology*, *52*(1), 725-749.

Gupta, J. P., and Gupta, G. N. (1983). Effect of grass mulching on growth and yield of legumes. *Agricultural Water Management*, *6*(4), 375-383.

Hansen, J. W., Mason, S. J., Sun, L., and Tall, A. (2011). Review of seasonal climate forecasting for agriculture in sub-Saharan Africa. *Experimental Agriculture*, *47*(2), 205-240.

Hobbs, P. R., Sayre, K., and Gupta, R. (2007). The role of conservation agriculture in sustainable agriculture. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *363*(1491), 543-555.

Horticultural Crop Development Authority. (2017). Horticultural crops production validated annual report. Nairobi, Kenya.

Huang, Z. B. (2005). The application principle and technology of super absorbent polymer in agriculture. *Beijing (China): China Agricultural Science and Technology Press (in Chinese)*.

Islam, M. R., Hu, Y., Mao, S., Mao, J., Eneji, A. E., and Xue, X. (2011). Effectiveness of a water-saving super-absorbent polymer in soil water conservation for corn (Zea mays L.) based on eco-physiological parameters. *Journal of the Science of Food and Agriculture*, *91*(11), 1998-2005.

Jaetzold, R., Schmidt, H., Hornet, Z. B., and Shisanya, C. A. (2007). Farm Management Handbook of Kenya. Natural Conditions and Farm Information. 2nd Edition. Vol.11/ C. Eastern Province. Ministry of Agriculture/GTZ, Nairobi, Kenya.

Jaetzold, R., Schmidt, H., Hornetz, B., and Shisanya, C. (2006). Farm management handbook of Kenya, revised edition vol. II. *Ministry of Agriculture, Nairobi*.

Jaetzold, R., and Schmidt, H. (1983). Farm Management Handbook of Kenya (Vol. II, Part C): Natural Conditions and Farm Management Information, East Kenya.

Jain, N. K., Meena, H. N., and Bhaduri, D. (2017). Improvement in productivity, water-use efficiency, and soil nutrient dynamics of summer peanut (*Arachis hypogaea* L.) through use of polythene mulch, hydrogel, and nutrient management. *Communications in soil science and plant analysis*, *48*(5), 549-564.

Kaur, A., and Brar, A. S. (2016). Influence of mulching and irrigation scheduling on productivity and water use of turmeric (Curcuma longa L.) in north-western India. *Irrigation science*, *34*(4), 261-269.

Khonglah, L., Hazarika, B. N., Wangchu, L., Singh, B., Pattanaik, S. K., and Singh, S. (2016). Effect of stockosorb and mulching on growth and yield of Assam lemon [Citrus limon (L.) Burm.]. *Research on Crops*, *17*(4).

Lalitha, M., Kasthuri Thilagam, V., Balakrishnan, N., and Mansour, M. (2010). Effect of plastic mulch on soil properties and crop growth-a review. *Agricultural Reviews*, *31*(2).

Lamont, W. J. (2005). Plastics: Modifying the microclimate for the production of vegetable crops. *HortTechnology*, *15*(3), 477-481.

Laredo, R. R. (2013). Size of the seedlings in the production and quality of passion fruit cv. Red Round (Master Dissertation). Federal University of Lavras, Lavras, Brazil.

Lin, W., Ma, H., Zhou, J., Zhang, Z., and Gan, Y. (2004). Effects of hydrogel on the growth of seedlings and their physiological properties under drought stress. *Arid Zone Research*, *21*(4), 353-357.

McAvoy, R. (1995). Don't let your tomatoes crack up-Here's how to prevent those unsightly and profit-robbing-cracks on fruit. *Am. Veget. Grower, August*, 46-47.

Menzel, C. M., Simpson, D. R., and Price, G. H. (1986). Effects of foliar-applied nitrogen during winter on growth, nitrogen content and production of passionfruit. *Scientia horticulturae*, *28*(4), 339-346.

Morton, J. (1987). Passion fruits: Fruits of warmer climates. *Miami-Florida: Julia F Morton*.

Montesano, F. F., Parente, A., Santamaria, P., Sannino, A., and Serio, F. (2015). Biodegradable superabsorbent hydrogel increaseswater retention properties of growing media and plant growth. *Agriculture and Agricultural Science Procedia*, *4*, 451-458.

Mwadalu, R., and Mwangi, M. (2013). The potential of sorghum in enhancing food security in semi-arid eastern Kenya. A review. *Journal of Applied Biosciences*, *71*, 5786-5799.

Mwangi, M., & Kariuki, S. (2015). Factors determining adoption of new agricultural technology 524 by smallholder farmers in developing countries. *Journal of Economics and sustainable* 525 *development*, *6*(5).

Mwenda, B., Kiambi, D., Kungu, J., Van De Gevel, J., Farda, C., and Morimoto, Y. (2019). Vulnerability and adaptation strategies to drought and erratic rains as key extreme events: Insights from small scale farming households in mixed crop agro ecosystems of semi-arid eastern Kenya.*African Journal of Agricultural Research*, *14*(15), 712-728.

Nakasone, H. Y., and Paull, R. E. (1998). *Tropical fruits*. Cab International.

Narjary, B., Aggarwalº, P., Kumarº, S., and Meena, M. D. (2013). Significance of hydrogel. *Indian Farming*, *62*(10), 15-17.

Olarinde, L. O., Oduol, J. B., Binam, J. N., Diagne, A., Njuki, J., and Adekunle, A. A. (2012). Impact of the Adoption of Soil and Water Conservation Practices on Crop Production: Baseline Evidence of the Sub Saharan Africa Challenge Programme. *Kano, Nigeria*.

Patt, A. G., Tadross, M., Nussbaumer, P., Asante, K., Metzger, M., Rafael, J., and Brundrit, G. (2010). Estimating least-developed countries' vulnerability to climate-related extreme events over the next 50 years. *Proceedings of the National Academy of Sciences*, *107*(4), 1333-1337.

Paul, R.E., and Duarte, O. (2012). Passion fruit and grant passion fruit In: *Tropical Fruits*, [e-book] Vol. 2. Atherton, J. ed. [accessed 15 May 2018].

Ramakrishna, A., Tam, H. M., Wani, S. P., and Long, T. D. (2006). Effect of mulch on soil temperature, moisture, weed infestation and yield of groundnut in northern Vietnam. *Field Crops Research*, *95*(2-3), 115-125.

Saini, A., Patel, A., Chaudhary, P., and Saini, L. (2018). Impact assessment of irrigation, fertility and hydrogel levels on growth attributes, yield and economics of summer pearl millet (Pennisetum glaucum L.) under North Gujarat conditions. *Journal of Pharmacognosy and Phytochemistry*, *7*(2), 2914-2918.

Shahid, S. A., Qidwai, A. A., Anwar, F., Ullah, I., and Rashid, U. (2012). Improvement in the water retention characteristics of sandy loam soil using a newly synthesized poly (acrylamide-co-acrylic acid)/AlZnFe2O4 superabsorbent hydrogel nanocomposite material. *Molecules*, *17*(8), 9397-9412.

Srivastava, R. C., Singhandhupe, R. B., and Mohanty, R. K. (2004). Integrated farming approach for runoff recycling systems in humid plateau areas of eastern India. *Agricultural Water Management*, *64*(3), 197-212.

Tesfaye, K., Kassie, M., Cairns, J. E., Michael, M., Stirling, C., Abate, T., and Gerard, B. (2017). Potential for scaling up climate smart agricultural practices: Examples from sub-Saharan Africa. In *Climate Change Adaptation in Africa*, 185-203. Springer, Cham.

Ulmer, T., and MacDougal, J. M. (2004). *Passiflora: passionflowers of the world*. Timber Press (OR).

Wangungu, C., Maina, M., Mbaka, J., Kori, N., and Gathu, R. (2010). Biotic constraints to passion fruit production in central and eastern provinces of Kenya. In *Proceedings of the 2nd RUFORUM Biennial Meeting. Entebbe, Uganda*.

World Resources Institute (WRI), Kenya Ministry of Environment and Natural Resources, Kenya Ministry of Planning and National Development, & International Livestock Research Institute. (2007). Nature's benefits in Kenya: An atlas of ecosystems and human well-being. Washington, DC and Nairobi: World Resources Institute. Retrieved from http://pdf. wri.org/kenya_atlas_fulltext_150.pdf

Wróblewska, K., Dębicz, R., and Bąbelewski, P. (2012). The influence of water sorbing geocomposite and pine bark mulching on growth and flowering of some perennial species. *Acta Sci. Pol. Hortorum Cultus*, *11*(2), 203-216.

Yang, Y., Wu, J., Zhao, S., Han, Q., Pan, X., He, F., and Chen, C. (2018). Assessment of the responses of soil pore properties to combined soil structure amendments using X-ray computed tomography. *Scientific reports*, *8*(1), 695.

Yu, Y. Y., Turner, N. C., Gong, Y. H., Li, F. M., Fang, C., Ge, L. J., and Ye, J. S. (2018). Benefits and limitations to straw-and plastic-film mulch on maize yield and water use efficiency: A meta-analysis across hydrothermal gradients. *European journal of agronomy*, *99*, 138-147.