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Effects of Legume Cover Crops on Orange (*Citrus sinensis*) Fruit Weight and Brix

J. M. Mulinge[1*], H. M. Saha[1], L. G. Mounde[1] and L. A. Wasilwa[2]

[1]Department of Crop Sciences, Pwani University, P.O.Box 195-80108, Kilifi, Kenya.
[2]Kenya Agricultural & Livestock Research Organization (KALRO), P.O.Box 57811-00100, Nairobi, Kenya.

Authors' contributions

This work was carried out in collaboration between all authors. Author JMM designed the study, wrote the protocol managed the literature searches and wrote the first draft of the manuscript. Authors HMS, LGM and LAW supervised the field experiment and research work, managed the analyses of data from the study and suggested necessary corrections of the manuscript. All authors read and approved the final manuscript

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ABSTRACT

Recent reports show that orange yield and fruit quality is on the decline in Kenya's coastal lowlands hence need for an efficient and sustainable production system. A field study was conducted in Vitengeni, Ganda and Matuga locations within the coastal lowland of Kenya from May 2012 to April 2015 to evaluate the effect of three legume cover crops on orange fruit weight and brix. The treatments included mucuna (*Mucuna pruriens*), dolichos (*Lablab purpureus*), cowpea (*Vigna unguiculata*) cover crops and fallow of natural vegetation as the control. The experiment was laid out in a randomised complete block design (RCBD) and each treatment replicated four times within the four blocks. Data collected were orange fruit weight, orange fruit brix, weather, soil texture and composition. The data was subjected to the analysis of variance (ANOVA) using the procedures of R statistical analysis software version 3.3.2 (R Core team, 2015). Mean separation was done using the least significant difference (LSD) at 5% level of significance. The results from the study showed that mucuna, dolichos and cowpea significantly (*P*=.05) increased fruit weight and brix. There was interaction effect between treatments and sites. Mucuna increased orange fruit weight by 12.4%,

**Corresponding author: E-mail: mulingejack@gmail.com;*

10.5% and 7.6% for Ganda, Matuga and Vitengeni respectively. Orange fruit weight increased by 8.8%, 7.8% and 7.2% for Ganda, Matuga and Vitengeni respectively due to dolichos and 6.0% for Ganda due to cowpea. Orange fruit brix increased by 5.8%, 5.1% and 4.2% for Vitengeni, Matuga and Ganda respectively due to mucuna. Cowpea increased orange fruit brix by 4.6%, 3.8% and 3.2% for Vitengeni, Matuga and Ganda respectively. Orange fruit brix increased by 3.3% and 3.1% for Vitengeni and Matuga respectively due to dolichos. From the outcome of this study, mucuna is recommended for use in orange tree orchards as it is useful in improving yield and fruit quality.

Keywords: Legume cover crops; fruit weight; fruit brix; orange crop; Coastal Kenya.

1. INTRODUCTION

Citrus (*Citrus* spp.) fruits are the 7th most important fruit in both production and consumption in Kenya [1]. They are important sources of income to the resource-poor farmers, employment in rural areas and human nourishment. The main citrus species grown in Kenya are sweet oranges (*Citrus sinensis*), lemons (*Citrus limon*), limes (*Citrus latifolia*), tangerines (*Citrus tangerina*) and grapefruit (*Citrus paradisi*) [2]. There are four varieties of sweet orange grown in Kenya including Valencia, Washington naval, Hamlin and Pineapple. Valencia is the most popular variety of sweet orange in the coastal lowlands of Kenya because of its performance [3]. Orange crop occupies 13% of the total area under fruit production in coastal Kenya [4]. Orange fruit production has been declining over the decades with little effort being put in place to reverse the trend. Orange yields of 8-12 tons per hectare have been reported while the potential is 20 tons/ha under well-managed orchards [5]. [6] Researchers reported that one of the major cause of fruit production decline is low soil fertility which is associated with inadequate fertiliser use. Additionally, poor agronomic practices have contributed to low orange production [7]. The erratic rainfall which is poorly distributed affect orange production unusually dry spells during the fruiting periods.

The use of legume cover crops is an economically feasible and ecologically sustainable practice that plays an essential role in the recovery of soil fertility [8]. [9] Researchers found that the potassium content in Valencia orange leaves increased as a result of using legume cover crops. According to [10], cover crops enhance the retention of organic soil carbon and nitrogen as well as soil aggregation and biological balance in orchard management practices. The legume cover crop plays a significant role in the provision or maintenance of soil phosphorus, potassium and calcium that are essential for fruit development, seed formation and fruit quality [11]. Legume cover crops produce vegetative material which decomposition in the soil, release nutrients which support plant growth and enhanced fruit yield [12]. [13] Researchers reported that rhizobacteria decompose soil biomass, releasing substantial nitrogen and other plant nutrients that can improve fruit yield. [14] showed that the increase in nutritional supply from the soil especially potassium improves the sugar composition of citrus fruits improving the fruit quality and flavonoid composition of citrus juices. The amount of moisture in the soil and its availability to a crop is an essential factor in fruit growth and development [15]. The ambient temperature influences fruit development and quality [16]. The use of mucuna as a cover crop in orange orchards increases soil moisture retention in the soil profile [17]. Cover crops are known to aid in soil and water management through reduction of soil erosion and runoff and reduced evaporation [18]. They also contribute to nutrient management through reduced losses and incorporation of plant nutrients into the soil [19]. Legume cover crops reported to be more beneficial than grass cover crops because they improve soil nitrogen through biological nitrogen fixation (BNF) [20]. The leguminous cover crop residues also provide residual soil N for the succeeding seasons [21].

[22] Researchers demonstrated that soil water retention in farming systems using cover crops is higher as compared to the bare soil surface. Unfortunately, there is limited information on the effects of cover crops on fruit crop growth and productivity in Kenya. This study conducted to evaluate the effect of cover crops on orange tree yield and fruit quality in the coastal lowlands of Kenya.

2. MATERIALS AND METHODS

2.1 Experimental Sites, Design and crop Husbandry

The experiment was established at Matuga and Ganda location in Kwale County and Vitengeni

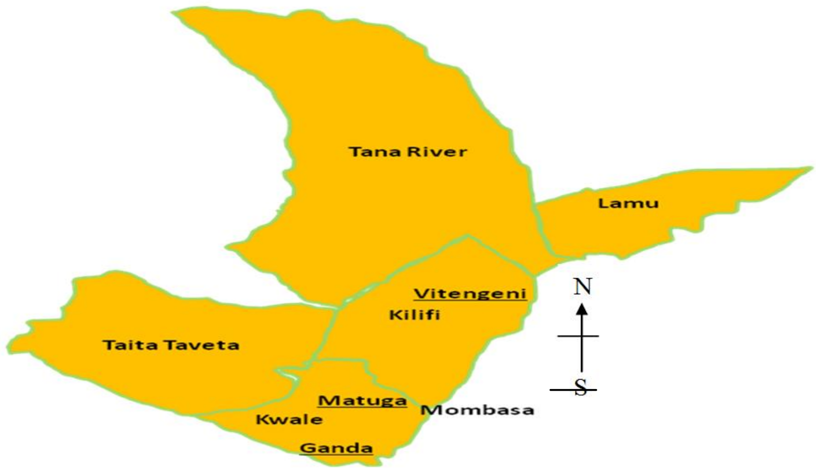

Fig. 1. Geographical location of coastal Kenya showing the experimental sites Matuga, Ganda and Vitengeni

location in Kilifi County, in the coastal region of Kenya from May 2012 to April 2015 (Fig. 1). The study sites are located between latitudes 1° and 4° South and longitudes 38°and 41° East, with an annual rainfall of 900 mm and temperature of 29°C during the day and 25°C during the night.

The fieldwork was superimposed on existing on-farm orange orchards in two locations (Ganda and Vitengeni) and on-station at Matuga. Research sites were selected depending on most common grown orange variety (Valencia) in the region, orchard size, recommended tree spacing (6m by 6m) and the tree history. Orange trees selected for the study were within tree age of 15-20 years. It is important to have trees of closer age because root growth increases with tree age [23,24].

The treatments included dolichos (*Lablab purpureus),* mucuna (*Mucuna pruriens*), cowpea (*Vigna unguiculata*), and a control plot (fallow of natural vegetation). The experiment was laid down in a randomized complete block design (RCBD) four blocks where a line of the orange tree formed a block (Fig. 2). The treatments were randomly applied in each block by planting at a spacing of 30 x 60 cm and replicated four times in the four blocks making a total of 16 experimental plots. Each site had four blocks and one orange tree represented an experimental unit/plot in the layout.

A tree was left (orange tree guard which were not part of the experiment) on each side of where treatments were applied such orange tree act as a guard tree i.e. within and between the blocks of the treated plots. This is because the legume cover crop especially mucuna and dolichos can grow beyond the 3 m radius of the orange tree/plot and this can create a treatment overlaps hence there was need for guard trees (Fig. 3).

Fig. 2. A view of orange tree line/block

Fig. 3. Mucuna at the full ground cover

Table 1. Soil textural properties for the three study sites

Property PSD*	Locations		
	Vitengeni	**Matuga**	**Ganda**
	soil texture	soil texture	soil texture
Sand %	65	84	91
Clay %	26	14	6
Silt %	9	2	3
Texture	SCL	LS	S

PSD Particle Size Distribution; SCL-sandy clay loam; LS- loamy sandy; S-sand*

2.2 Data Collection

Data was collected during the six orange fruiting seasons which included (i) weather data: rainfall, temperature and relative humidity from the nearest weather stations(ii) soil particle size distribution (soil texture) (iii) orange fruit yield: fruit weight (g) and (iv) fruit quality: orange fruit brix (%).

The weather data from meteorological stations nearest to the study site, Ramisi, Matuga and Vitengeni during orange fruiting cycles May 2012 to April 2015 period was collected The first orange fruiting cycle is from April to September, which coincides with May-August long rains. The second fruiting cycle is October to March coinciding with short rains October—December.

The average rainfall for Vitengeni during the six fruiting cycles was 328.5 mm, with mean monthly maximum and minimum temperature of 29.2ºC and 24.8ºC, respectively. Matuga had an average rainfall of 363.4mm during the six fruiting cycles was 363.4mm with a mean monthly maximum and minimum temperature of 28ºC and 24.3ºC. The average rainfall for Ganda during the six fruiting cycles was 470.6mm, with a mean monthly maximum and minimum temperature of 27.67ºC and 23.5ºC. The three-year period mean relative humidity for Ganda, Matuga and Vitengeni sites was 85.2%, 84.6% and 80.7%, respectively. The three site soils based on textural classes of soil (above Table 1).

Data on fruit weight (g) was determined by selecting 10 fully ripe oranges from different branches of each plot and weighed using electronic balance (Model PM 200, Mettler Instrument Limited, Switzerland). The average weight per fruit was determined by dividing total weight of fruits selected by ten. Fruits for fruit weight determination were sampled six times in every fruiting season making a total of 36 samples per experimental unit. Orange juice brix (%) was determined by selecting randomly five (5) fully mature fruits from different branches in each plot. The fruits were cut at the equatorial and two drops of fruit juice placed on a refractometer sensor. Fruits for brix determination were sampled six times in every fruiting season making a total of 36 samples per plot.The brix was measured and determined using a calibrated brix refractometer (Model; RHB 0-90 with three scales, Grand index solution Enterprise Ltd, Hong Kong, China) as described by [25].

2.3 Data Analysis

The data obtained on fruit weight and fruit brix were first tested for, normality and homogeneity of variance using Shapiro wilk test prior to statistical analysis. Data on fruits weight and fruit brix were found to meet the assumption for ANOVA and were not transformed before analysis with ANOVA at (P=.05) using procedures of R statistical analysis software version 3.3.2 [26]. Mean separation was done using least significant difference (LSD) at 5% level of significance.

3. RESULTS

3.1 Effects of Legume Cover Crop and Site on Orange Fruit Weight

The analysis of variance showed that there was a significant interaction between treatment and site (F= 3.32; P=.05) on orange fruit weight.

Effect of mucuna, dolichos and cowpea legume cover crops on the level of orange fruit weight varied with a site (Table 2). The Ganda site was found to have the highest orange fruit weight when compared with Vitengeni and Matuga. The Vitengeni site was found to have the lowest orange fruit weight when compared to Matuga and Ganda. With each site, orange fruit weight was highest in legume mucuna but lowest in cowpea. Mucuna treated plots recorded a significant increase in orange fruit weight by

12.4%, 10.5% and 7.6% for Ganda, Matuga and Vitengeni respectively. Dolichos treated plots recorded a significant increase in orange fruit weight by 8.8%, 7.8% and 7.2% for Ganda, Matuga and Vitengeni respectively. Cowpea treated plots recorded an increase in orange fruit weight by 6.0%, 2.9% and 2.5% for Ganda, Matuga and Vitengeni respectively. As opposed to mucuna and dolichos, cowpea treated plots increased a comparable orange fruit weight for Matuga and Vitengeni which was not significantly different.

3.2 Effects of Legume Cover Crop and Season on Orange Fruit Weight

The analysis of variance showed that there was a significant interaction between treatment and season (F= 2.77; *P*=.03) on orange fruit weight.

Effect of mucuna, dolichos and cowpea legume cover crops on the level of orange fruit weight varied with seasons (Table 3). Season six was found to have the highest orange fruit weight when compared with other season. The lowest orange fruit weight was during season one compared to the other seasons. Season four recorded low fruit weight compared to season three. Orange fruit weight was highest in legume mucuna but lowest in cowpea among the three cover crops. Mucuna increased orange fruit weight by 5.5%, 7.5%, 7.8%, 7.3%, 9.8% and 11.7% in seasons 1 to 6 respectively. Dolichos increased orange fruit weight by 3.8%, 5.3%, 7.1%, 6.5%, 8.1% and 9.0% in seasons 1 to 6 respectively. Cowpea increased orange fruit weight by 2.9%, 4.7%, 5.9%, 5.3%, 9.5% and 8.2% in seasons 1 to 6 respectively.

3.3 Effects of Legume Cover Crop and Site on Orange Fruit Brix

The results of analysis of variance showed a significant interaction between treatment and site (F= 3.37; *P*=.007) on fruit juice brix.

Effect of mucuna, dolichos and cowpea legume cover crops on the level of orange fruit brix varied with site (Table 4). The site Vitengeni was found to have the highest fruit brix when compared to Matuga and Ganda. Ganda site was found to have the lowest orange fruit brix when compared to Matuga and Vitengeni. Orange fruit brix was highest in legume mucuna but lowest in dolichos. Mucuna treated plots significantly increased orange fruit brix by 5.8%, 5.1% and 4.2% for Vitengeni, Matuga and Ganda respectively. Cowpea treated plots significantly increased orange fruit brix by 4.6%, 3.8% and 3.2% for Vitengeni, Matuga and Ganda respectively. Dolichos treated plots recorded a significant increase in orange fruit brix by 3.3% and 3.1% for Vitengeni and Matuga respectively.

Table 2. Effects of legume cover crop and site on orange fruit weight (g) at different locations

Treatments (cover crop)	Locations		
	Vitengeni	Matuga	Ganda
Control	234.7b	242.9b	253.5d
Dolichos	251.7a	261.8a	275.7b
Mucuna	252.6a	268.3a	284.4a
Cowpea	240.6b	249.6b	268.8c
LSD $_{(P \leq 0.05)}$	7.36	9.13	8.01
CV%	9.08	7.34	7.85
Pr >F	0.039	0.042	0.001

Means within the column followed by same letter are not significantly different at P ≤ 0.05.

Table 3. Effects of cover crop and season on orange fruit weight (g) in six fruiting seasons (FS)

Treatments (cover crop)	2012		2013		2014	
	FS 1	FS 2	FS 3	FS 4	FS 5	FS 6
Control	242.3a	241.2b	242.7b	241.0b	244.8b	243.6b
Dolichos	251.6a	254.0b	259.9a	256.7a	264.6a	265.5a
Mucuna	255.7a	259.4a	261.6a	258.6a	268.8a	272.1a
Cowpea	249.3a	252.5b	257.0b	253.8b	263.2a	263.6a
LSD $_{(P \leq 0.05)}$	14.83	17.51	16.46	14.26	16.78	18.67
CV %	10.35	11.40	9.81	9.84	11.48	12.32
Pr >F	0.279	0.046	0.041	0.012	0.008	0.018

Means within the column followed by same letter are not significantly different at P=.05. FS= Fruiting Season

Table 4. Effects of legume cover crop and site on orange fruit brix (%) at different locations

Treatments (cover crop)	Locations		
	Vitengeni	Matuga	Ganda
Control	45.21d	45.15d	44.68c
Dolichos	46.69c	46.55c	45.64c
Mucuna	47.84a	47.43a	46.57a
Cowpea	47.18b	46.87b	46.12b
LSD $_{(P \leq 0.05)}$	0.29	0.30	0.21
CV%	4.97	4.42	5.42
Pr >F	0.0072	0.002	0.016

Means within the column followed by same letter are not significantly different at P=.05.

Table 5. Effects of legume cover crop and season on orange fruit brix (%) in six fruiting seasons (FS)

Treatments (cover crop)	Year					
	2012		2013		2014	
	FS 1	FS 2	FS 3	FS 4	FS 5	FS 6
Control	45.99b	46.01b	46.00d	45.98d	45.97d	45.95d
Dolichos	46.00b	46.05b	46.43c	46.55c	46.86c	46.96c
Mucuna	46.39a	46.70a	46.92a	47.34a	47.68a	47.82a
Cowpea	46.01b	46.67a	46.78b	46.95b	47.08b	47.26b
LSD $_{(P \leq 0.05)}$	0.029	0.044	0.062	0.034	0.052	0.064
CV%	0.961	0.856	1.462	1.063	1.479	1.569
Pr >F	0.032	0.001	0.034	0.001	0.001	0.001

Means within the column followed by same letter are not significantly different at P=.05. ,FS =Fruiting Season

3.4 Effects of Legume Cover Crop and Season on Orange Fruit Brix

The results of analysis of variance showed a significant interaction between treatment and season (F= 2.27; *P*=.003) on fruit juice brix.

Effect of mucuna, dolichos and cowpea legume cover crops on the level of orange fruit brix varied with season (Table 5). The sixth season was found to have the highest orange fruit brix when compared to other seasons. First season was found to have the lowest orange fruit brix when compared to the other seasons. Orange fruit brix was highest in legume mucuna but lowest in dolichos. The orange brix (fruit sweetness) level increase as a result of using legume cover crops. Mucuna significantly increased orange fruit brix by 0.9%, 1.5%, 2.0%, 3.0%, 3.7% and 4.1% from 1st season to 6th season respectively. Cowpea significantly increased orange fruit brix by 1.4%, 1.7%, 2.1%, 2.4% and 2.9% from 2nd season to 6th season respectively. Dolichos significantly increased orange fruit brix by 0.9%, 1.2%, 1.9% and 2.2% from 3rd season to 6th season respectively.

4. DISCUSSION

The sites varied in terms of soil type and rainfall received and this could have contributed to the site effects. Each site has different soil type and received different amount of rainfall which could have influenced the site variation, orange tree water uptake and orange fruit water accumulation. The biomass when on the soil surface acts as mulching material, lowering soil temperature fluctuations and moisture loss through evaporation [27]. The increase in fruit weight because of legume cover crop could have been attributed to improved soil nutritional status, soil water holding capacities fruit nutritional tree support.

The sixth season recorded the highest increase in orange fruit weight while the first season recorded the least orange fruit weight gain. Season 4 recorded the low fruit weight as compared to season 3, the said season 4 received lowest rainfalls across the sites as compared to other seasons. According to [28], weather conditions influence citrus tree vegetative growth, flowering, fruit formation and fruit quality. Additionally, [29] reported that water influences nutrient uptake by fruits trees thus influencing fruit quality and quantity. It can be argued that the weight gain over the season is a clear indication of nutritional and moisture increase in the soil due to cover cropping. Fruit trees require plant nutrients and water to support the fruit development and expansion. [30] argued that the amount of water in soil dictated orange tree growth and fruit development. The legume cover crop increased soil moisture retention based on type of legume and this may have also influenced fruit weight gain. [31] observed that storage of soil moisture improved with the use of cover crops. The increased fruit weight recorded during the 2014 (5^{th} and 6^{th} season) may have been attributed to accumulation of plant nutrients in the soil over time because of legume cover crop. According to [22-35] legume cover crop contributed to the increase of plant nutrients in the soil through biological and chemical processes.

The amount of rainfall received by each site was different and this could have influenced the level of brix accumulation by the orange fruit. Ganda site received the highest amount of rainfall during the fruiting period and has the lowest orange fruit brix. Vitengeni site received lowest amount of rainfall during the fruiting periods but recorded the highest orange fruit brix. It can be argued that the more the soil moisture, the more the juice but the less the fruit brix. [36] showed that there is fruit sucrose hydrolysis on well watered trees.

The fifth and sixth seasons of year three (2014) recorded the highest increase in orange fruit brix while the first and second seasons of year one (2012) recorded the least amount of orange fruit brix. The increase in fruit brix over the three years may have been attributed to the use of cover crops. [37] argued that the sugar accumulation in citrus fruit was influenced by plant water relations. It can be argued that the fruit brix gain over the seasons is a clear indication of increase in plant nutrients in the soil. Fruit trees require plant nutrients and water to support the fruit development and brix. The observed results agree with [38] who reported that low irrigated citrus influence the fruit soluble solids composition in the juice. Although season 4 recorded low rainfall in all the sites, the fruit brix increased despite low moisture level. The results agree with [39] who reported that water stressed tree reduces citrus fruit yield components and fruit composition it in the juice. [40] indicated that the soluble solid in fruit juice is a factor of the available water in the fruits.

5. CONCLUSION AND RECOMMENDATION

The results of this study showed that the use of legume cover crops significantly increased orange tree yield and improved fruit quality compared to the control. The use of mucuna contributed to high increase in orange fruit weight across the sites and seasons. The fruit brix increased as a result of using mucuna, cowpea and dolichos across the sites and seasons. Mucuna cover crop recorded the highest increase in orange fruit weight and fruit brix while cowpea cover crop had the least increase. The control plots recorded the lowest in all the parameters under evaluation. Increase in orange yield is ordered as follows; mucuna > dolichos > cowpea while orange fruit quality improvement is ordered as follows; mucuna > cowpea > dolichos.

It can, therefore, be concluded that mucuna cover crop contribute to increased production and improved fruit quality. From the outcome of this study, mucuna legume cover crop is recommended for use in orange tree orchards. The adoption of these findings by farmers can aid in improving soil fertility management and orange productivity in the coastal lowlands of Kenya. Further studies are however, suggested to evaluate the long term (> 3years) effect of the different cover crops on orange tree yield and fruit quality under different agro-ecological zones.

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COMPETING INTERESTS

All the authors have declared that no competing interests exist.

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