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Evaluation of the combined use of organic and inorganic fertilizers on bulb onion (*Allium cepa* L.) yields in West Ugenya Sub-County, Kenya

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Abstract

Low yields due to declining soil fertility continue to be a major constraint to onion production in Kenya, necessitating imports to meet market demand. A field experiment was carried out for two seasons in West Ugenya Sub-County during the 2015 and 2016 short and long rains seasons, respectively to evaluate the effect of combining organic and inorganic fertilizers on the soil nutrient status, growing period and yield of bulb onion (*Allium cepa* L.). The experiment was a Randomized Complete Block Design (RCBD). Treatments, each replicated three times were: T_1 (5Mega grams ha^{-1} cattle manure), T_2 (46kg P ha^{-1} x 26kg N ha^{-1} inorganic fertilizers), T_3 (unfertilized control), and T_4 (half T_1 x half T_2) were evaluated. Data from T_1 and T_4 at the end of the two growing seasons showed significantly ($P \leq 0.05$) higher mean yields compared to the control with highest bulb yield (25.2Mg ha^{-1}) recorded in T_4. Also, significantly ($P \leq 0.05$) higher soil available P and total organic carbon was recorded in T_4 at the end of season II compared to the other treatments in the same season. Seasonal variation in rainfall amount led to considerably lower yields in the short rains (season II), compared to long rains (season I). Observed data concluded that onion yields could be significantly increased by combining organic and inorganic fertilizers at the rates of 2.5Mgha^1 cattle manure containing 2% N, 0.6% P and 2.3% K, with 23kg P ha^{-1} x 13kg N ha^1 inorganic fertilizers.

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Introduction

The bulb onion (*Allium cepa* L.) is adapted to growing in different agro-ecological zones (Nguthi *et al*., 1994) and prefer medium textured soils with a pH range of 6-7 (Muendo and Tschirley, 2004), optimal germination soil temperature of 15 - 25°C (Jaetzold *et al*., 2009), and can be established either by direct seeding or seedling transplanting (Muvea *et al*., 2014). Although onion has been grown in Kenya over a long time, production per land area is still low at a national average of 15Mgha^{-1} compared to Korea (67Mgha^{-1}), Spain (54 Mgha^{-1}), Egypt (36Mgha^{-1}), Ghana (17Mgha^{-1}) and Ethiopia (10Mgha^{-1}) (FAOSTAT, 2012). In most parts of Kenya just like in the study area of West Ugenya sub-county, onion is mainly grown at small scale level, and soil fertility decline through nutrient mining and degradation is the main challenge to increased yields (Mango, 1999; Jaetzold *et al*., 2009; Okalebo *et al*., 2005), alongside post harvest losses (AFFA, 2016; USAID, 2012), and pests and disease (Muvea *et al*., 2014).

Combined use of organic and inorganic fertilizers has been proposed as a solution to reverse poor soil health and low crop yields (Vanlauwe *et al*., 2002; Sanginga and Woomer, 2009; Vanlauwe *et al*., 2015; Ruganzu *et al*., 2015). For instance onion yields resulting from combined use of organic and inorganic fertilizers in a field experiment in India were significantly ($P \leq 0.05$) increased by 77% compared to no fertilizer input, and up to 45% higher yields than sole inorganic fertilizers application (Rai *et al*., 2016). This study was thus premised on the need to increase onion production in Kenya to meet growing demand through integrated soil fertility management and raise income to the local farmers.

Materials and methods

Study Site

The study was conducted in Ukwala division (N 0° 12' 37"latitude and E 34° 7' 21" longitude and at an altitude of 1267m above sea level) in West Ugenya Sub County, Kenya. It falls under agro-climatic zone II, classified as sub humid (Jaetzold *et al*., 2009). Ferralsols are the dominant soil type in the study area (Jaetzold *et al*., 2009).

The mean monthly temperature is 21.7°C with March being the hottest (22.6°C) and July the coldest (20.7° C) months while rainfall is bimodal, with long rains in March- June and short rains from September to November (Jaetzold *et al*., 2009). The physiography of the area presents a lower middle to level uplands comprising of gently undulating slopes of between 2 and 8% (Mango, 1999; Jaetzold *et al*., 2009). The major land use is intensive mixed farming accounting for 71% of the Ugenya population (KNBS and SID, 2013). Main crops grown include maize *(Zea mays),* beans (*Phaseolus vulgaris*), sorghum *(Sorghum bicolor)*, cassava (*Manihot esculenta)* and sweet potatoes *(Ipomoea batatas)*. About 79% of the population own livestock consisting of indigenous (small East African Zebu) and hybrid cattle (Ayrshire and Friesian), goats, sheep, pigs, rabbits and poultry (KNBS, 2009).

Experimental Design and Treatments

Experimental design was RCBD replicated thrice on four treatments (T), namely: T_1 (5Mgha^1 cattle dung), T_2 (46kg P ha^{-1}x 26kg N ha^{-1} inorganic fertilizers), T_3 (unfertilized control), and T_4 (half of T_1 x half of T_2). The sources of Phosphorous (P) and Nitrogen (N) were Triple Super Phosphate (TSP) with 46% P_2O_5 and Calcium Ammonium Nitrate (CAN) containing 26% N, respectively, while composted cattle manure was obtained from a local cattle herder.

Table 1 shows the properties of the cattle manure used in the experiment during the two cropping seasons while table 2 shows the fertilizer application rates for onion. The test crop was bulb onion *(Allium cepa)*, variety Neptune, directly planted at a spacing of 20cm x 15cm, at 3.1Kgha^{-1} seed rate translating to about 300,000 plantsha^{-1}.

Table 1. Chemical properties of composted cattle dung used in season I and II.

Parameter	Season I	Season II
Total Nitrogen (TN), %	2.1	1.9
Phosphorous (P), %	0.5	0.7
Potassium (K), %	2.1	2.6
Organic Carbon (OC), %	28.5	31.7
Carbon-Nitrogen (C:N) ratio	13.6	16.7

Table 2. Organic and inorganic fertilizer application rates in season I and II.

Recommended application rates	Reference	Nutrient source
26 kg N ha^{-1}	Nguthi *et al.* (1994) and Muendo and Tschirley, (2004)	Calcium Ammonium Nitrate (26% N)
46 kg P ha^{-1}	Nguthi *et al.* (1994)	Triple Super Phosphate (46% P_2O_5)
5 Mg ha^{-1} manure	Muriuki and Qureshi, (2001) and Jaetzold *et al.* (2009)	Composted cattle dung

Soil and Manure Characterization

Initial soil characterization involved taking 6 soil samples from the experimental site with a soil auger in a transect, at 0 – 20cm depth, and mixing them to form a 1Kg soil composite sample that was collected in a polythene bag for chemical analysis. Also, a 1Kg cattle manure sample was collected in a separate polythene bag for chemical analysis.

At harvest in the two cropping seasons, plant litter on the soil surface was removed before post-soil sampling was done. Similarly, 1Kg soil samples were taken from each plot, replicated three times for better representation and accuracy, and analyzed for chemical properties separately. The samples were first air-dried, crushed and then passed through a 2mm mesh sieve for physical and chemical analyses. Soil pH was determined with a pH meter in a ratio of 1:2.5 soil/water suspension.

Soil texture was by hydrometer method as described by Glendon and Doni (2002). CEC (cation exchange capacity) and exchangeable bases (Ca, Mg, Na and K) in the soil and manure samples were determined from an ammonium acetate (NH_4OAc) extraction following procedures described by Okalebo *et al.* (2002). Organic carbon in soil and manure samples was determined following Walkley and Black (1934) method as described by Nelson and Sommers (1996). Total N was determined by micro-Kjeldhal distillation method as described by Bremner (1996). The Bray II (molybdate blue) method was used to determine available P.

Undisturbed core soil samples were also collected in a transect at a depth of 0-20cm using core-rings and used for bulk density and saturated hydraulic conductivity (Ksat) determination. Bulk density was determined by calculating the weight of oven dried soil at 105^{o}C divided by the soil volume, equivalent to the volume of the core rings. Porosity (P) was calculated according to Landon (2014) from the relationship;

$P = 1 - \frac{\rho_b}{\rho_s}.100$ Where; ρ_b = Bulk density, ρ_s = Particle density, and 100 and 1 are constants. Ksat determination was by the constant head permeameter method as described by Klute and Dirksen (1982).

Agronomic Practices

Land was tilled using oxen plough, and hand hoes used to prepare 40m x 1m raised beds at 10cm above the ground with 1m boundary between the raised beds. Onion seeds were sown directly along 5cm deep furrows on the raised beds, and covered lightly with soil at the beginning of September 2015 in season I, and March 2016 in season II. The germinated seeds were thinned to attain a spacing of 15cm within rows and 20cm between rows 6 weeks after emergence. Hand weeding was done after every 4 weeks or any time the weeds emerged to avoid competition for moisture, sunlight and nutrients. Diseases: Downey mildew, purple blotch, and blight were controlled by spraying with 20ml of Mistress 72 WP™ fungicide in a 20liters knapsack at the onion vegetative stage, while continuous visual inspection of plants in the field was done for any signs of pest or disease attack. Harvesting was 130 days after crop emergence when 80% of the crops in a 1m^2 quadrant had their leaves fallen over, by uprooting the onions from the ground by hand and sun drying in the field for 7 days.

Crop Data

At physiological maturity, crop yield data was collected in four evenly spaced sections in each of the 40m x 3m plots using a 1m^2 quadrant. Bulb weight was computed by weighing together the bulbs inside the quadrant. The yield weight was extrapolated to Mega grams (Mg) ha^{-1}.

Climate Data

Rainfall (mm), relative humidity (%), wind speed (ms^{-1}) at 2m above ground, maximum and minimum air temperature (^oC), and sunshine hours for the study period were obtained from the Kenya Meteorological Department from the closest station ~ 40km away from the study site. The data allowed for calculation of Reference Crop Evapo-transpiration (ETo) using FAO-ETo calculator version 3.2 that utilizes the Penman Monteith method (Allen *et al.*, 1998). The United States Department of Agriculture (USDA) Soil Conservation Service method for estimating effective rainfall in Allen *et al.* (1998) was used to calculate the effective rainfall in the study area. Effective rainfall is rain water remaining in the soil after losses from run off and deep percolation (FAO, 1978).

Statistical Analysis

Soil and crop yield data were arranged in Microsoft excel spread sheets and imported into Genstat statistical software, 15^{th} edition (Payne *et al.*, 2009) where they were subjected to analysis of variance (ANOVA). Least Significant Differences (LSD) at 5% level were used to detect differences among means.

Results and discussions

Initial Soil Fertility Status

The soil (Table 3) was coarse textured, exhibiting high sand content (52%) and moderate clay, (38%) implying low water retention capacity. Hence onion crop failure was imminent in the event of a drought due to high soil water percolation. Bationo *et al.* (2012) indicated that soils of sub Saharan Africa exhibiting ≥ 35% sand have low water holding capacity and therefore prone to nutrient leaching by percolating water. In addition, the high Ksat of 64.7 $mmday^{-1}$ in the 0-20cm soil depth, categorized as moderately rapid (Gaines and Gaines, 1994) and a moderate rating of CEC of 17.4 meq $100g^{-1}$ (FAO, 2006) all implied significant nutrient leaching was expected, such that limited nutrient availability would hinder onion growth.

Table 3. Initial soil characterization of the study site.

Parameters	Soil characterization	Very high	High	Medium	Low	Very low
Sand (%)	52	-	-	-	-	-
Silt (%)	10	-	-	-	-	-
Clay (%)	38	-	-	-	-	-
Texture class	Sandy clay - - - -					-
pH-H_2O (1:2.5)	6.05	-	> 7	5.5 – 7.0	<5.5	-
CEC (meq $100g^{-1}$)	15.40	> 40	25 – 40	12 - 25	6 - 12	< 6
OC (%)	2.59		> 2.5	1.5 – 2.5	< 1.5	
TN (%)	0.17		> 0.7	0.5 – 0.7	< 0.5	
P (ppm)	15.00	> 46	26 - 45	16 – 25	10 - 15	< 9
K (meq $100g^{-1}$)	1.50	> 1.2	0.6 – 1.2	0.3 – 0.6	0.2 – 0.3	< 0.2
Ca (meq $100g^{-1}$)	12.60	> 20	10 - 20	5 - 10	2 - 5	< 2
Mg (meq $100g^{-1}$)	4.90	> 8	3 - 8	1 - 3	0.3 - 1	< 0.3
Na (meq $100g^{-1}$)	1.30	> 2	0.7 - 2	0.3 – 0.7	0.1 – 0.3	< 0.1
ESP (%)	7.50		> 25	20 - 25	< 20	
Bulk density (g cm^{-3})	1.21	> 1.9	1.6 – 1.9	1.3 – 1.6	1.0 – 1.3	< 1.0
Porosity (%)	54.50		>50	50	< 50	
Ksat ($mmday^{-1}$)	64.70					

Legend: CEC – Cation Exchange Capacity, OC – Organic Carbon, TN – Total Nitrogen, P – Phosphorous, K – Potassium, Ca – Calcium, Mg – Magnesium, Na – Sodium, ESP – Exchangeable Sodium Percentage, Ksat – Saturated hydraulic conductivity.

The soil was slightly acid with initial pH of 6.05 that was within the 6 – 7 optimal pH range for onion growth and development (Muendo and Tschirley, 2004). Initial organic carbon (OC) was 2.6%, and adequate (≥1.5%) based on Bationo *et al.* (2012). The mean bulk density of 1.28 gcm^{-3} and 1.21 gcm^{-3} in season I and II, respectively was low according to Hazelton (2007), probably due to the high OC content (Alemayehu *et al.*, 2016; Karuku and Mochoge, 2016) in the 0 – 20cm depth. Low bulk density would imply no hindrance to root penetration (Landon, 2014) by the onion crop root system. Also, initial soil porosity was 55% which was within recommended range of ≥ 50% (Landon (2014) that would not limit root growth and extension.

Organic matter is an important source of soil N for crop growth through gradual decay and mineralization in the soil. Initial total Nitrogen (TN) was low at 0.17% according to FAO (2006) that classifies low N as < 0.5%. Deficiency of N would result in reduced onion yields with respect to size and weight of the bulb (Mohammad and Moazzam, 2012).

Initial available P was fairly low at ≤ 15 ppm as confirmed in earlier experiments in the study area by Mango (1999), Okalebo *et al.* (2005), Jaetzold *et al.* (2009) and Owino *et al.* (2015). This implies that the onion crops could experience poor root development, stunted growth and delay in crop maturity unless P is supplemented as either foliar spray or soil fertilizer. Chacon *et al.* (2011) reported that inadequate P inhibit cell division in the meristematic tissues and encourage premature cell differentiation within the root tip, resulting in inhibition of primary root growth of young flowering plants.

Initial exchangeable K indicated high levels at 1.5 meq $100g^{-1}$ (FAO, 2006), implying high 'luxury consumption' whereby plants take up excess K than is required for their physiological needs. In water stressed conditions, K is important particularly for maintenance of turgor pressure, accumulation and transport of metabolic products in plants (Bationo *et al.*, 2012) hence an essential nutrient for optimal crop production and yields. This is in agreement with Mageed *et al.* (2017) who noted that application of higher levels of K fertilizer in calcareous soils of Egypt where environment is arid, improved plant water status as well as growth and yield of soya beans. This implies that onion crop will be highly resilient to water stress and subsequent withering during dry spells within the short and long rainy seasons in the study area.

Initial exchangeable Ca and Mg were also high at 12.6 and 4.9 meq $100g^{-1}$ soil according to rating by FAO (2006) of > 10 and > 3 meq $100g^{-1}$, respectively. Ca and Mg are important in plants for enzyme activation and carbohydrate transport (Bationo *et al.*, 2012). Mg deficiency mostly results in leaf chlorosis (Hao and Papadopoulos, 2004; Keino *et al.*, 2015), while stunting of new growth in stems, flowers and roots occurs when Ca is limiting (Bationo *et al.*, 2012). This implies that photosynthesis in the onion crop would not be hindered due to these macro nutrients.

Initial exchangeable Na was high at 1.3 meq $100g^{-1}$ in the study site according to FAO, (2006) ranking of 0.7 – 2 meq $100g^{-1}$. Although small quantities of Na are used in plant metabolism, it is not an essential plant element hence deficiency does not appear to exhibit any symptoms on onion crop (FAO, 2006). The exchangeable sodium percentage (ESP) was below the 20 - 25% tolerance range for onions (FAO, 2006) implying it was too low to inhibit the crop's nutrient mining ability in the soil of the study site. ESP greater than 15 results in clay dispersion thereby affecting soil permeability and consequently water transmission properties (FAO, 1996).

Weather Conditions during Onion Development Stages

In season I, the onion seed was planted 14 days after ½ETo equaled rainfall at 2.6 $mmday^{-1}$ (Fig. 1) depicting the start of the growing period as rainfall was increasing (Karuku *et al.*, 2014). The late planting implied that potential yields would be reduced as the rain-fed crop would not receive adequate water unless supplemental irrigation was carried out. As the onion development progressed it was accompanied by 85 days humid period where rainfall maintained above the ½ETo. The humid period helped to store water in the soil for crop use as water loss from crop transpiration and evaporation from soil surface was low (FAO, 1986). End of the growing period was marked when rainfall reduced to ½ETo at 3.2 mm day^{1}. End of the growing period come 16 days early to the 130 days requirement for onion (variety Neptune) growing period; and the inherent coarse texture of the soil could not store the water during the humid period due to its high percolation rate, which would necessitate supplemental irrigation for the crop to meet its full water requirements.

In season II, onion seed was also planted late 9 days after ½ETo equaled rainfall at 2.9 mm day^{-1} (Fig. 1). The humid period in this season lasted 67 days and the growing period was shortened by 32 days compared to season I causing premature senescence of the crop as excess water stored in the soil during the humid period was lost before crop use due to the low water holding capacity of the sandy soil. The shorter growing period compared to season I was due to reduced rainfall which had the effect of increasing the yield reduction factor and lowered onion yield, as crop water needs were higher than available soil moisture.

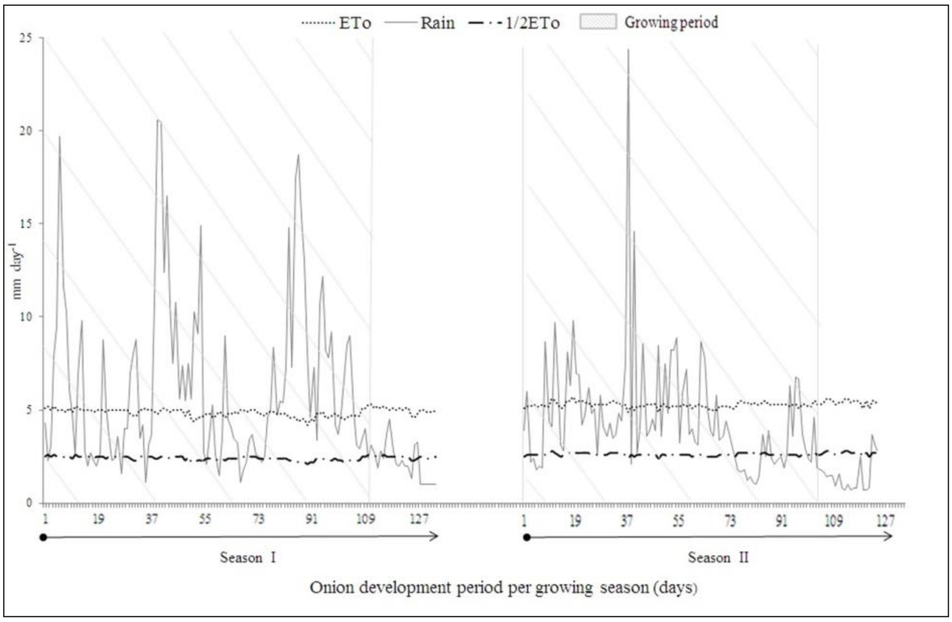

Fig. 1. Rainfall, evapotranspiration (ETo) and half evapotranspiration (½ETo) during onion growing period.

In season I, effective rainfall was 85.2mm at initiation stage and continuously increased up to the end of the reproductive stage, then reduced as expected at maturation (Table 4). In season II, the initiation stage received 65.6mm effective rainfall and increased in the vegetative and reproductive stages to 118 and 148mm, respectively. The maturation stage saw a rainfall reduction to 53mm, which was necessary as this stage requires relatively dry and warm weather to attain high quality onion yields, otherwise rotting and bulb splitting would occur. For instance, Karuku *et al.* (2014) observed that an increase in precipitation in the maturation stage of tomatoes affected yield quality and quantity through fruit drops. Effective rainfall was within the 300 to 500 mm water requirement for onion optimal growth and yields (FAO, 1986), where it was higher at 413mm throughout season I compared to 384 mm in season II. Reduced rainfall in season II compared to season I (Table 4) would imply that crop yield in season II could be lower as uptake of water and nutrients by plant roots would difficult as water is held at higher tension meaning more energy expended in water uptake that could go to yield production.

Table 4. Weather and related crop data during onion growth stages.

Growth stages	Season I					Season II			
	Growth length (days)	R (mm)	ETo (mm day^{-1})	ET_{onion} (mm day^{-1})	T_{mean} (°C)	R (mm)	ETo (mm day^{-1})	ET_{onion} (mm day^{-1})	T_{mean} (°C)
Initial	15	85.2	5.1	2.6	24.6	65.5	5.4	2.7	24.1
Vegetative	25	107.9	4.9	3.7	23.2	117.5	5.5	4.1	23.4
Reproductive	70	170.4	5.0	5.3	23.6	147.7	4.8	5.0	23.5
Maturity	20	49.1	4.8	4.1	25.3	53.5	4.6	3.9	23.8

Legend: R – effective rainfall; ETo – evapotranspiration; ET_{onion} – actual onion evapotranspiration; T_{mean} – mean air temperature.

In season I, ET_{onion} was between 2.6 and 5.3 mmday^{-1} during the growing period and was largely outside the 5 to 6 mmday^{-1} range that would allow the onion meet its full transpiration water requirements (FAO, 1986). In season II, ET_{onion} ranged between 2.7 and 5.0 mmday^{1}, and due to lower rainfall, resulted in onion water stress at reproductive stage of bulb formation that could have led to high yield reduction factor (Ky) in this stage. In both season I and II, supplemental irrigation or other soil water conservation management practice such as mulching was necessary for the onion crop to meet its full water requirements.

Actual onion evapotranspiration, ET_{onion} (i.e. ETo x Kc) at the initial stage was low, 2.6 mmday^{-1} in season I and 2.7 mmday^{-1} in season II because of a low onion crop coefficient (Kc initial = 0.5, FAO, 1986). This implied that moisture loss from the soil through the plant atmosphere continuum was dominantly due to direct evaporation from the soil surface as the crop's canopy cover was small to transpire a significant amount of water. At the onion vegetative stage ET_{onion} increased due to increase in Kc to 0.75. ET_{onion} was at its maximum at the reproductive stage since Kc had increased to its highest 1.05 value (FAO, 1986), implying that onion canopy cover had spread substantially to shade the underlying soil from the sun, hence less moisture loss through leaf surface. At maturity stage, ET_{onion} was 4.1mm day^{-1} in season I and 3.9mm day^{-1} in season II. This decrease in ET_{onion} was due to a steady decline in Kc maturity to 0.85 (FAO, 1986) due to senescence. Mean air temperature was between 23 and 25^{o}C in both growing seasons which was within the optimal thermal range of 15 – 25 ^{o}C for onion germination and growth (Jaetzold *et al.*, 2009).

Soil Nutrients Status at the End of Season I and II of Cropping

There was a significant ($P \leq 0.05$) increase in soil pH in T_1 and T_4 compared to T_2 and the control in season I (Table 5). This pH increase could have been due to high levels of lime-like materials such Ca and Mg compounds in the applied organic cattle manure (Table 2) in T_1 and T_4 that neutralized the concentration of acidifying H+ ions from the soil (FAO, 2006).

Table 5. Soil properties after harvesting the first and second season crop.

T	Season I					Season II				
	pH (H_2O)	OC (%)	TN (%)	P (ppm)	K (meq 100g^{-1})	pH (H_2O)	OC (%)	TN (%)	P (ppm)	K (meq 100g^{-1})
T_1	6.08^{c}	2.98^{c}	0.20^{b}	16.1^{b}	1.5^{a}	6.08^{b}	3.06^{b}	0.21^{c}	16.5^{b}	1.5^{a}
T_2	6.04^{a}	2.51^{a}	0.18^{ab}	17.6^{c}	1.4^{a}	5.98^{a}	2.56^{ab}	0.19^{b}	18.1^{c}	1.5^{a}
T_3	6.03^{a}	2.47^{a}	0.17^{a}	15.1^{a}	1.4^{a}	6.04^{b}	2.50^{a}	0.17^{a}	15.9^{a}	1.4^{a}
T_4	6.06^{b}	2.94^{c}	0.19^{ab}	17.2^{c}	1.5^{a}	6.06^{b}	3.36^{c}	0.21^{c}	17.8^{c}	1.5^{a}
SE	0.01	0.09	0.02	0.34	0.06	0.03	0.14	0.01	0.25	0.10

Legend: T – Treatment, T_1 - 5Mgha^{-1} cattle manure, T_2 - 46kg P ha^{-1} x 26kg N ha^{-1} inorganic fertilizers, T_3 – control, T_4 - half T_1 x half T_2, SE – standard error, Mean Fig.s followed by same letter down the columns are not significantly different at $P \leq 0.05$.

At the end of season II, soil pH ranged between 5.98 and 6.08 and was lowest in T_2 compared to the other treatments probably due to a net increase in protons through nitrification process of NH_4^+ ions in CAN fertilizer ($CaCO_3$ + NH_4NO_3) applied, thereby releasing H^+ ions (Yan *et al.*, 1996; Braos *et al.*, 2015).

Comparison of soil pH in season I and season II showed no significant difference between T_1, T_3 and control. This was could have been due to vegetative onion parts in season I being returned to the soil as decomposing crop litter and acting as a buffer to pH change in season II. Organic matter contains weak acids having carboxyl group (-COOH); which dissociates to attain a negative charge (-COO-) thus buffering soil pH (FAO, 2005). However, T_2 was characterized by a significant pH reduction in season II compared to season I probably due to a net increase in H+ ions beyond the buffering capacity of the soil by organic matter from leaf litter.

The pH increase could also have been due to plant nutrient uptake whereby attraction of soil nutrient cations to the charged surface of root hair cells caused the plant root hairs to release H+ ion which acidified the rhizosphere (Henkel, 2015).

At the end of season I and season II, there was a significantly higher ($P \leq 0.05$) OC and TN in T_1 and T_4 compared to the control. This might be attributed to decomposition of cattle manure in both T_1 and T_4, in addition to organic residues arising from decomposition of crop litter fall during the onion growing period. Application of organic manure as well as decomposition of crop litter can significantly increase soil OC (Bedada *et al.*, 2014; Cotrufo *et al.*, 2015; Novara *et al.*, 2015; Mariaselvam *et al.*, 2014) and TN (Abbasi *et al.*, 2015 and Mahmoud *et al.*, 2009). Despite inorganic fertilizer application that indirectly increased OC by up to 2% above the control, from organic matter arising from high vegetative growth that was returned to the soil as decomposing plant litter, T_2 showed no statistical difference to T_1, T_4 and the control. This may be due to the sandy nature of the soil (Table 3) that promoted leaching of salts in applied inorganic fertilizer beyond the rooting zone of the onion crop. Tropical soils with high sand content (≥ 35%) are highly susceptible to leaching of nutrients (Bationo *et al.*, 2012). Leaching reduced vegetative growth vigor in T_2 compared to T_1 and T_4 that resulted in lower litter fall that would have otherwise mineralized to add to the soil OC and TN stock.

Due to inorganic P fertilizer application, significantly ($P \leq 0.05$) higher soil available P was observed in T_2 and T_4 in comparison to T_1 and the control, at the end of the two onion growing seasons. T_1 with sole cattle manure application had significantly ($P \leq 0.05$) lower soil available P compared to T_2 and T_4 in both seasons because in contrast to inorganic fertilizers, the P concentration in livestock manures is much lower (Bationo *et al.*, 2012).

There was no significant change in exchangeable K across all treatments in season I compared to the initial soil K status. This is because Ferralsols, the soils of the study area, are dominated by low activity clay minerals, mainly kaolinite (WRB, 2006), which have inaccessible inter-layers due to hydrogen bonding that prevents K fixation (Tran, 2010; WRB, 2006). Similarly, no significant difference in K across all treatments was observed in season II due to the reason adduced above on K fixation. There was no statistically significant difference in K between season I and season II probably due to luxury crop uptake (FAO, 2006). Also, K is prone to leaching especially in areas with heavy rainfall (Keino *et al.*, 2015), as is the case in the study area, hence additions from cattle manure application in T_1 and T_4 could have been lost through moderate leaching in the study area.

Bulb Onion Yield at the End of season I and II

In season I, the yields ranged between 20.3 and 25.2 $Mgha^{-1}$ (Table 6). T_1 and T_4 had significantly ($P \leq 0.05$) higher mean onion yields, 15% and 19% above the control, respectively. This is attributed to the nutrients retained on the soil surface being available for plant uptake in the cattle manure that could have reduced leaching (Bationo *et al.*, 2012), unlike T_2 where much of the applied inorganic fertilizer could have leached with increasing rainfall. According to Vanlauwe *et al.* (2002), Okalebo *et al.* (2005), and Ruganzu *et al.* (2015), addition of organic materials improves the soil chemical, physical and biological properties that enhance nutrient availability, retention and uptake by crops.

This is also in agreement with Otinga *et al.* (2013) who found application of composted cattle manure increased maize yields compared to sole use of inorganic P fertilizer.

Table 6. Onion yields ($Mgha^{-1}$) as affected by the different treatments.

Treatment (T)	Season I	Season II
T_1	24.1^b	16.2^d
T_2	20.7^a	12.9^c
T_3	20.3^a	12.3^c
T_4	25.2^b	16.3^{cd}
SE	1.2	1.9

Legend: T_1 – 5Mg ha^{-1} cattle manure, T_2 – 46kg P ha^{-1} + 26 kg N ha^{-1} inorganic fertilizers, T_3 – unfertilized control, T_4 - half T_1 + half T_2, SE – standard error, mean Fig.s followed by same letter in the rows or columns are not significantly different at $P \leq 0.05$.

While there were no significant differences between onion yields of T_1 and T_4, mean separation data indicated that T_4 had 4% more yield than T_1. Higher yields in T_4 could have been due to organic fertilizer that gradually released its nutrients, further supplemented with inorganic fertilizer that released nutrients more readily, thus increasing T_4 nutrient status compared to T_1. Studies have shown that combined use of organic manures with inorganic fertilizers significantly increase soil nutrients uptake by plants and maximizes yields compared to sole application of either organic or inorganic fertilizers (Rai *et al.*, 2016; Sanginga and Woomer, 2009; Vanlauwe *et al.*, 2015).

There was no significant difference between onion yields of T_2 and the control in season I mainly because heavy rains in the initial growth stage dislodged and damaged the young onions plants thus reduced plant population and expected yield in a large section of T_2 plots. Gaping to replace the destroyed onion seedlings was not done as it would have required three more weeks to sow afresh onion seeds, that would have resulted in non-uniform growth as the gap replacement onion crop would not have attained maturity by the time yield of the remaining majority onion crop that withstood dislodging and damage was being determined.

In season II, trend in the results were similar to season I and yields significantly ($P \leq 0.05$) varied between 12.3 and 16.3 Mgha^{-1}. The highest onion mean yields were recorded in T_4 at 16.3 Mgha^{-1} with the lowest in the control. Thus, the addition of organic materials to soil improved the chemical, physical and biological properties that enhance availability of nutrients and their uptake by crops (Otinga *et al.*, 2013 and Ruganzu *et al.*, 2015).

No significant differences were observed between T_2 and the control. This is probably due to lower rainfall in season II that could have caused low availability of inorganic fertilizer in T_2 which did not to fully dissolve, and probably burnt the onion seedlings. Hergert *et al.* (2012) found out that reduced crop emergence and stand in maize, sorghum and soya bean can occur when soil moisture is limited and fertilizer is placed too close to the seed, as this increases salt concentration which interferes with root development.

Also, no significant difference was observed in mean onion yields between T_1 and T_4, both at 24% higher than the control. It would have been expected that T_4 with higher nutrient content from the combination of organic and inorganic sources, would give higher onion yields compared to T_1. However, this was not the case because most of the inorganic nutrients in T_4 could have been bound with organic cattle manure thus temporarily immobilizing nutrients (Vanlauwe *et al.*, 2002).

Mean yields comparison between seasons and treatments showed that season I was higher at 22.5 Mgha^{-1}compared to season II at 14.4 Mgha^{-1}. The difference in yield was due to the low rainfall of 286 mm in season II which was a limiting factor in contrast to season I at 390mm (Table 4) as it provided less water to the sandy soil with inherent low water holding capacity. The soil moisture was insufficient for optimal onion transpiration needs leading to low yields as Zhang *et al.* (2004) found in wheat yields under varying levels of soil water deficit, as onions require 350 – 600mm rain for mean yields of 17 Mgha^{-1} in the study area (Jaetzold *et al.*, 2009).

Conclusion

The objective of this study was to evaluate the influence of the four soil fertilizer treatments on soil properties, bulb onion yields, and recommend the best fertilizer option for small scale onion farmers in Ugenya, Siaya County. From data of two growing seasons, treatment 4 (T_4) consisting of 2.5Mgha^{-1} cattle manure in combination with inorganic fertilizers (23kg P ha^{-1}x 13kg N ha^{-1}) gave the highest increase in onion yields by 19 to 24% on bulb weight in comparison to the unfertilized control. Thus, integrated soil fertility management option of use of organic manure and inorganic fertilizer resulted in highest yields due to increased soil nutrient availability and crop uptake, and should be recommended in the study area for sustainable bulb onion farming.

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