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EFFECT OF COWPEA CROP RESIDUE MANAGEMENT ON SOIL MOISTURE CONTENT, CANOPY TEMPERATURE, GROWTH AND YIELD OF MAIZE - COWPEA INTERCROPS

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ABSTRACT

The major limitations to crop production in smallholder farms in Kenya are moisture stress and declining soil fertility. Incorporation of crop residues into the soil or their use as surface mulch has the potential of conserving moisture. A study was carried out at Pwani University and Kenya Agricultural and Livestock Research Organization (KALRO)-Mtwapa in 2012 to determine the effect of cowpea crop residue management on soil moisture content, canopy temperature, growth and yield of maize and cowpea intercrop. The experiment was laid out in a randomized complete block design (RCBD), with a factorial arrangement of treatments and replicated thrice. Data collected included: soil moisture content, canopy temperature, weed biomass, chlorophyll content, percent ground cover, leaf number, plant height, grain weight and grain yield of maize and cowpea. Cowpea root nodule number, numbers of pods per plant, number of grains per pod, maize ears per plant and stover yield were also determined. Data was analyzed using the general linear model (GLM) procedure for analysis of variance using SAS statistical package. Where the F values were significant, means were compared using the least significant difference (LSD) test, at $p = 0.05$. Application of crop residues (incorporated or mulched) increased soil moisture content and chlorophyll content, growth attributes, yield and yield components of cowpea and maize, but reduced canopy temperature and cowpea nodule number. The increase in cowpea and maize grain yield in Kilifi due to incorporation of crop residues into the soil was 111.1% and 440.5%, respectively. Crop residue incorporation outperformed surface mulching in most plant attributes.

Keywords: Cowpea, residue, management, moisture and temperature

1. INTRODUCTION

Water is a major limiting factor for crop production in the tropics, particularly in semi-arid regions (Rowland, 1993). Soil water availability is directly related to environmental factors (including precipitation, evapotranspiration, soil type and topography), but may be influenced by agronomic practices, including irrigation, fallowing and sowing time, or via specific water conservation practices, such as terracing and mulching (Martin, et al., 2008). Under semi-arid conditions, surface plant residues play an important role in conservation of soil water through reduced soil evaporation (Thomas, 1996). In addition, crop residues as a mulch moderate the temperature fluctuation in the top soil layer (Farahani, et al., 1998), enhance the activity of soil

Vol. 3, No. 05; 2018

ISSN: 2456-8643

microorganisms and fauna (Klocke, 1999) and nutrient release, improve water infiltration, and facilitate root development. According to van Donk, et al., (2012), retention of crop residues on the soil surface is a key strategy for reducing surface water runoff and erosion. A crop residue enhances water infiltration and protects the soil from sealing and crusting by rainfall (McGuire, 2009). A mulch of crop residues may also contribute to the control of weeds by smothering them or through allelopathic effects (Farahani, et al., 1998).

Africa is not able to feed its ever increasing population due to declining nutrient status of her soils (Omotayo and Chukwuka, 2009). For increased food production, nutrient replenishment is necessary (Tilman, et al., 2002). Nutrients are depleted due to nutrient mining through crop harvests, residue removal (Mugendi, et al., 2003), and soil erosion (Muchena, et al., 2005), coupled with inadequate external replenishment (Mugendi, et al., 2010). In Kenya declining soil fertility and high fertilizer costs are major limitations to crop production in smallholder farms in Kenya (Chemining'wa, et al., 2004). Water being one of the major physical constraints to crop production in semi-arid areas, there is a need to use it effectively (Rowland, 1993). The water conservation effect of surface residue may potentially increase crop yields in tropical environments (van Donk, et al., 2012).

In coastal lowland Kenya over 90% of small scale farmers intercrop or relay crop maize and cowpea during the long rains season (Obong'o, et al., 1993; Saha et al., 1993). Legumes have great potential for improving soil fertility at relatively low cost compared to inorganic fertilizers. The reliance on organic residues from the previous crop distinguishes crop residue mulch from other forms of mulching. This is because crop residue mulch is strategically located at the soil-atmosphere interface, whereby it affects soil conservation; soil ecology and crop yields (Erenstein, 1999). Hence the need to determine the effects of crop residues on soil moisture content, canopy temperature, chlorophyll content, growth and yield maize-cowpea intercrop.

2. MATERIALS AND METHODS

Study site

The study was carried out at Pwani University (PU), and Kenya Agricultural Research Institute (KARI). Pwani University is located 60 km north of Mombasa between latitudes 3° S and 4° S and longitudes 39° E and 40° E. Mean monthly minimum and maximum temperatures of about 22^0C and 30^0C, respectively, and mean relative humidity of 80% (Jaetzold, et al., 2012). The site is located in coastal lowland (CL) Kenya. The region receives an average annual rainfall of 600–1100 mm that occurs in two seasons (Sombroek, et al., 1982). The long rains are received in March/April through August while the short rains are received in October, November and December. The long rains season is the most important cropping season and 75% of the annual rainfall is usually received during this time (Saha, 2007). According to Sombroek, et al., (1982), the soils in coastal lowland Kenya are mostly ferralsols. They have low electron cation exchange, total N, organic carbon content are deficient in essential plant nutrients (such as calcium, magnesium, zinc and sodium), prone to leaching, and have a pH 5.6. The experiment was conducted during the long rains in July - October season in 2012.

Vol. 3, No. 05; 2018

ISSN: 2456-8643

Experimental design, treatments and crop husbandry

The experiment was laid out in a randomized complete block design, with a factorial arrangement of treatments and replicated three times. The treatments consisted of two intercrop systems and three cowpea crop residue management options. The intercrop systems were: (a) maize variety Lamu intercropped with cowpea variety Nyeupe and (b) Dryland Hybrid 04 (DH04) intercropped with cowpea variety Nyeupe. The crop residue management options were: (a) control (no residue), (b) crop residue surface mulch and (c) crop residue incorporated into soil. A drought/insect pest resistant cowpea variety Nyeupe was used for intercropping with maize in both cropping systems. Experimental plot size was 5 m x 5 m. Maize spacing was 100 cm x 50 cm giving a population of 20,000 plants per hectare. Cowpea was planted in between the maize with a spacing of 30 cm within the row, two plants per hill, giving a plant population of 66,660 plants/ha. All the cowpeas in the two sites were planted four weeks after the maize to reduce competition (Mureithi et al., 1996). The amount of crop residue applied was 110 g/hill. This was either applied on the soil surface or incorporated into the soil. Weeding was done by hand at two, four and six weeks after planting.

Data collection

Data collected included: soil moisture content, canopy temperature, chlorophyll content, ground cover, leaf number, plant height, grain weight, and grain yield for both maize and cowpea. Cowpea root nodule number, number of pods per plant and number of grains per pod, maize number of ears per plant and maize stover yield were also determined. Moisture content was determined by using a neutron probe. The methods of data collection were similar to those used in chapter six.

Data analysis

Collected data was analyzed by the general linear model (GLM) procedure for analysis of variance using SAS statistical package (SAS Institute, 1993). Where the F values were significant, means were compared using the least significant difference (LSD) test, at $p = 0.05$.

3. RESULTS

Soil moisture content

Cropping system and crop residue management significantly affected soil moisture content at 20 and 40 cm soil depth at all maize growth stages; however, cropping system and crop residue management had no significant effect on soil moisture content at 60 and 80 cm soil depth (Table 1). At 20 cm soil depth DH04-cowpea intercrop had higher soil moisture content than Lamu-cowpea intercrop, but the converse was true at 40 cm soil depth. Crop residue surface mulching and crop residue incorporation increased moisture content in both cropping systems, but the latter had higher moisture content than the former at most growth stages (Table 2).

Vol. 3, No. 05; 2018

ISSN: 2456-8643

Table 1: Effect of cropping system on moisture content (%) at 20, 40, 60 and 80 cm soil depths at different growth stages in Kilifi

Cropping system	Boot	Silk	Maturity	Boot	Silk	Maturity
	20 cm Soil depth			40 cm soil depth		
Lamu – cowpea	10.76	11.48	6.85	15.20	19.17	13.81
DH04-cowpea	11.60	12.95	8.56	14.16	17.08	12.10
P-value	0.0003	0.0117	0.0363	0.001	0.0003	0.0167
$LSD_{0.05}$	0.35	1.06	1.57	0.53	0.88	1.33
CV (%)	2.96	8.27	19.45	3.46	4.63	9.74
	60 cm Soil depth			80 cm soil depth		
Lamu – cowpea	18.40	21.59	16.76	22.99	26.33	20.01
DH04-cowpea	18.66	21.83	15.05	23.51	25.50	19.98
P-value	0.222	0.834	0.262	0.734	0.579	0.979
$LSD_{0.05}$	NS	NS	NS	NS	NS	NS
CV (%)	2.34	10.90	19.08	13.55	11.89	12.92

NS – Not significant

Table 2: Effect of crop residue management on moisture content (%) at 20 and 40 cm soil depth at different growth stages in Kilifi

Crop residue management	20 cm soil depth			40 cm soil depth		
	Boot	Silk	Maturity	Boot	Silk	Maturity
No crop residue	8.96	10.69	7.35	13.02	15.88	10.83
Surface mulch	12.53	11.93	7.67	15.39	18.10	11.26
Crop residue incorp.	12.04	14.03	8.09	15.62	20.41	16.78
P-value (CRM)	0.0001	0.0006	0.7014	0.0001	0.0001	0.0001
P-value (CPS x CRM)	0.024	0.263	0.109	0.009	0.011	0.006
$LSD_{0.05}$ (CRM)	0.43	1.30	NS	0.65	1.08	1.62
$LSD_{0.05}$ (CPS x CRM)	0.539	1.650	2.450	0.828	1.451	2.062
CV (%)	2.96	8.27	19.45	3.46	4.63	9.74

Ground cover and Canopy temperature

Cropping system, crop residue management and their interaction had significant effects on ground cover and canopy temperature (Table 3).

Vol. 3, No. 05; 2018

ISSN: 2456-8643

Table 3: Effects of cropping system and crop residue management on percent ground cover and canopy temperature at kilifi and at mtwapa sites during July – October 2011/2012 season

Cropping system (CPS)	Kilifi				Mtwapa			
	R_0	R_1	R_2	CPS-means	R_0	R_1	R_2	CPS-means
	Percent ground cover							
Lamu - cowpea	82.23	86.57	87.77	85.52	32.60	39.20	51.30	41.03
DH04 - cowpea	84.40	85.50	85.53	85.14	26.80	28.27	39.10	31.39
CRM-mean	83.32	86.04	86.65		29.70	33.74	45.20	
P-value (CPS)	0.003				0.0001			
P-value (CRM)	0.0001				0.0001			
P-value (CPS x CRM)	0.0001				0.0001			
$LSD_{0.05}$ CPS	0.22				1.00			
$LSD_{0.05}$ CRM	0.27				1.23			
$LSD_{0.05}$ CPS x CRM	0.39				1.84			
CV (%)	2.41				2.64			
	Canopy temperature (^oC)							
Lamu - cowpea	22.87	22.43	22.23	22.51	27.57	26.40	24.77	26.25
DH04 - cowpea	25.30	24.80	24.50	24.87	28.20	27.50	27.33	27.68
CRM-mean	24.09	23.62	23.37		27.89	26.95	26.05	
P-value (CPS)	0.0001				0.0001			
P-value (CRM)	0.0004				0.0001			
P-value (CPS x CRM)	0.002				0.0001			
$LSD_{0.05}$ CPS	0.17				0.20			
$LSD_{0.05}$ CRM	0.20				0.24			
$LSD_{0.05}$ CPS x CRM	0.30				0.36			
CV (%)	6.70				6.89			

Crop residue management (CRM) levels: R_0 = No crop residue; R_1 = crop residue on the soil surface; and R_2 = crop residues incorporated into the soil

Surface mulching and incorporation of crop residue into the soil increased percent ground cover of both cropping systems in both sites. Incorporation of crop residue into the soil had higher

Vol. 3, No. 05; 2018

ISSN: 2456-8643

ground cover than surface mulching in Mtwapa. Lamu maize intercropped with cowpea had higher ground cover than DHO4 maize intercropped with cowpea under all the residue management options except under the control (no residue treatment). Average percent ground cover was higher at Kilifi than at Mtwapa by 57.6%.

Surface mulching and incorporation of crop residue into the soil significantly reduced canopy temperatures in both sites and cropping systems (Table 7.3). Crop residue surface mulch had significantly higher canopy temperature than crop residue incorporation in Lamu-cowpea intercrop at Mtwapa. Lamu maize intercropped with cowpea had a significantly lower canopy temperature than DH04 maize intercropped with cowpea in all residue management options in both sites. Average canopy temperature was 13.8% higher in Mtwapa than in Kilifi.

Chlorophyll contents of cowpea and maize

Cropping system, crop residue management and their interactions had significant effects on cowpea chlorophyll content at Mtwapa (Table 4). At Kilifi only the cropping system had a significant effect on chlorophyll content. Surface mulching and incorporation of crop residue into the soil significantly increased cowpea chlorophyll content in both cropping systems at Mtwapa. Crop residue incorporation had significantly higher chlorophyll content than surface mulch in both cropping systems. Cowpea intercropped with Lamu maize had significantly higher chlorophyll content than cowpea intercropped with DHO4 maize in both cropping systems at both sites. At Kilifi, cowpea intercropped with Lamu maize had significantly lower cowpea chlorophyll content than cowpea intercropped with DHO4 maize.

Cropping system, crop residue management and their interactions had significant effect on maize chlorophyll content (Table 4). Surface mulching and incorporation of crop residue into the soil significantly increased maize chlorophyll content in Kilifi for both cropping systems. Incorporation of crop residue into the soil had significantly higher maize chlorophyll content than crop surface mulching. DHO4 maize intercropped with cowpea had higher chlorophyll content than Lamu maize intercropped with cowpea under control and surface mulched plots. Average maize chlorophyll content in Mtwapa was 11.1% higher than in Kilifi for both intercrops.

Table 4: Effects of cropping system and crop residue management on chlorophyll content of cowpea and maize at Kilifi and at Mtwapa sites during July – October 2011/2012 season

Cropping system (CPS)	Kilifi				Mtwapa			
	R_0	R_1	R_2	CPS-means	R_0	R_1	R_2	CPS-means
	Cowpea chlorophyll content (index)							
Lamu - cowpea	48.73	47.67	44.10	46.83	54.73	55.67	56.83	55.74
DH04 - cowpea	49.63	49.47	50.23	49.78	46.43	53.33	54.97	51.58

CRM-mean	49.18	48.57	47.17		50.58	54.50	55.90	
P-value (CPS)	0.026				0.0001			
P-value (CRM)	0.366				0.0001			
P-value (CPS x CRM)	0.181				0.0001			
$LSD_{0.05}$ CPS	2.52				0.26			
$LSD_{0.05}$ CRM	Ns				0.32			
$LSD_{0.05}$ CPS x CRM	Ns				0.47			
CV (%)	4.97				0.46			
	Maize chlorophyll content (index)							
Lamu - cowpea	35.40	38.57	41.53	39.49	44.47	45.50	44.00	44.66
DH04 - cowpea	38.33	40.83	44.50	40.23	40.80	41.57	46.67	43.01
CRM-mean	36.87	39.70	43.02		42.64	43.534	45.34	
P-value (CPS)	0.0001				0.461			
P-value (CRM)	0.0001				0.595			
P-value (CPS x CRM)	0.0001				0.398			
$LSD_{0.05}$ CPS	0.11				Ns			
$LSD_{0.05}$ CRM	0.13				Ns			
$LSD_{0.05}$ CPS x CRM	0.20				Ns			
CV (%)	2.60				10.38			

Crop residue management (CRM) levels: R_0 = No crop residue; R_1 = crop residue on the soil surface; and R_2 = crop residues incorporated into the soil

Leaf numbers of cowpea and maize

Cropping system, crop residue management and their interactions had significant effects on cowpea and maize leaf numbers (Table 5). Surface mulching and incorporation of crop residue into the soil significantly increased cowpea and maize leaf numbers in both cropping systems and sites. Generally crop residue incorporation had significantly higher cowpea and maize leaf numbers than crop residue surface mulch in both cropping systems. Cowpea intercropped with DHO4 maize variety had significantly higher cowpea leaf number than cowpea intercropped with Lamu maize under the different residue management options.

Table 5: Effect of cropping system and crop residue management on leaf number of cowpea and maize at kilifi and at mtwapa sites during July – October 2011/2012 season

Cropping system (CPS)								
	Kilifi				Mtwapa			
	R_0	R_1	R_2	CPS-means	R_0	R_1	R_2	CPS-means

Vol. 3, No. 05; 2018

ISSN: 2456-8643

	Cowpea leaf number per plant							
Lamu - cowpea	18.60	19.70	21.67	19.99	18.50	23.43	33.20	25.04
DH04 - cowpea	23.40	25.40	30.40	26.40	23.43	24.37	28.50	25.43
CRM-mean	21.00	22.55	26.04		20.97	23.90	30.85	
P-value (CPS)	0.0001				0.0008			
P-value (CRM)	0.0001				0.0001			
P-value (CPS x CRM)	0.0001				0.0001			
$LSD_{0.05}$ CPS	0.17				0.18			
$LSD_{0.05}$ CRM	0.20				0.22			
$LSD_{0.05}$ CPS x CRM	0.30				0.33			
CV (%)	0.68				0.69			
	Maize leaf number per plant							
Lamu - cowpea	10.70	11.57	15.33	12.53	9.20	9.73	10.03	9.65
DH04 - cowpea	11.30	11.50	12.80	11.87	8.60	8.87	8.97	8.81
CRM-mean	11.00	11.54	14.07		8.90	9.30	9.50	
P-value (CPS)	0.0001				0.0001			
P-value (CRM)	0.0001				0.0001			
P-value (CPS x CRM)	0.0001				0.0001			
$LSD_{0.05}$ CPS	0.13				0.08			
$LSD_{0.05}$ CRM	0.16				0.09			
$LSD_{0.05}$ CPS x CRM	0.24				0.14			
CV (%)	1.04				0.79			

Crop residue management (CRM) levels: R_0 = No crop residue; R_1 = crop residue on the soil surface; and R_2 = crop residues incorporated into the soil

Lamu maize intercropped with cowpea had significantly higher maize leaf number than DHO4 maize intercropped with cowpea. Mtwapa had 8.8 % higher average cowpea leaf number than Kilifi. In contrast Kilifi had 24.3% higher average maize leaf number than Mtwapa.

Plant height of cowpea and maize

Cropping system, crop residue management and their interactions had significant effects on cowpea and maize plant heights (Table 6).

Table 6: Effect of cropping system and crop residue management on plant height (cm) of cowpea and maize at kilifi and at mtwapa sites during July – October 2011/2012 season

Cropping system (CPS)	Kilifi				Mtwapa			
	R_0	R_1	R_2	CPS-means	R_0	R_1	R_2	CPS-means
	Cowpea plant height (cm)							
Lamu - cowpea	21.73	23.67	28.8	24.73	31.40	33.67	37.37	34.15
DH04 - cowpea	22.33	25.77	27.13	25.08	28.47	31.20	33.67	31.11
CRM-mean	22.03	24.72	27.97		29.94	32.44	35.52	
P-value (CPS)	0.442				0.0001			
P-value (CRM)	0.011				0.0001			
P-value (CPS x CRM)	0.0001				0.0001			
$LSD_{0.05}$ CPS	Ns				0.14			
$LSD_{0.05}$ CRM	1.17				0.17			
$LSD_{0.05}$ CPS x CRM	1.76				0.25			
CV (%)	3.67				0.40			
	Maize plant height (cm)							
Lamu - cowpea	168.60	177.50	187.57	177.89	116.20	156.43	187.70	153.44
DH04 - cowpea	140.30	140.50	142.40	141.07	146.10	146.40	149.33	147.28
CRM-mean	154.45	159.00	164.99		131.15	151.42	168.52	
P-value (CPS)	0.0001				0.0001			
P-value (CRM)	0.0001				0.0001			
P-value (CPS x CRM)	0.0001				0.0001			
$LSD_{0.05}$ CPS	0.24				0.13			
$LSD_{0.05}$ CRM	0.28				0.16			
$LSD_{0.05}$ CPS x CRM	0.43				0.24			
CV (%)	0.14				0.08			

Crop residue management (CRM) levels: R_0 = No crop residue; R_1 = crop residue on the soil surface; and R_2 = crop residues incorporated into the soil

Surface mulching and incorporation of crop residue into the soil significantly increased cowpea plant height in both cropping systems in both sites. Incorporation of crop residues into the soil had higher cowpea plant height than surface mulching in both cropping systems in Mtwapa and in Lamu-cowpea intercrop in Kilifi. Cowpea intercropped with Lamu maize had significantly higher cowpea plant height than cowpea intercropped with DH04 maize under the different, crop residue management options at Mtwapa. Mean cowpea plant height in Mtwapa was 31.0% higher than in Kilifi. Surface mulching and incorporation of crop residues into the soil increased

Vol. 3, No. 05; 2018

ISSN: 2456-8643

maize plant height in Lamu-cowpea intercrop in both sites and DH04-cowpea intercrop in Mtwapa. Incorporation of crop residue into the soil had higher maize plant height than surface mulching in both cropping systems and sites. Lamu maize intercropped with cowpea had significantly higher plant height than DH04 maize intercropped with cowpea cropping system under all the crop residue management options. The mean maize plant height in Kilifi was 6.1% higher than in Mtwapa.

Cowpea root nodule number

Cropping system, crop residue management and their interactions had significant effect on the number of cowpea root nodules (Table 7). Surface mulching and incorporation of crop residue into the soil significantly reduced the number of root nodules in both cropping systems in Mtwapa and DH04–cowpea intercrop at Kilifi. Crop residue incorporation into the soil had a lower number of root nodules than surface mulching in both cropping systems in Mtwapa. Cowpea intercropped with DH04 maize had significantly higher number of cowpea root nodules than cowpea intercropped with Lamu maize under all the crop residue management options in Mtwapa and under control (no residue incorporation and no surface mulch) in Kilifi. Kilifi had 151.6% higher average number of root nodules than Mtwapa.

Pods per plant and grains per pod of cowpea

Cropping system, crop residue management and their interactions had significant effects on cowpea number of pods per plant and grains per pod of cowpea (Table 8). Incorporation of crop residue significantly increased the number of pods per plant in both cropping systems in Mtwapa and in Lamu-cowpea intercrop in Kilifi. Surface mulching increased the number of pods per plant only in DH04-cowpea intercrop at Mtwapa. Incorporation of crop residue into the soil had higher number of pods per plant than surface mulching at both sites. Cowpea intercropped with DH04 maize had significantly higher number of pods per plant than cowpea intercropped with Lamu maize under control and surface mulch options. The average number of pods per plant in Kilifi was 183.3% higher than in Mtwapa. Surface mulching increased the number of grains per pod only in Lamu-cowpea intercrop at Kilifi.

Table 7: Effect of cropping system and crop residue management on number of cowpea root nodules per plant at kilifi and at mtwapa sites during July – October 2011/2012 season

Cropping system (CPS)	Kilifi				Mtwapa			
	R_0	R_1	R_2	CPS-means	R_0	R_1	R_2	CPS-means
Lamu - cowpea	14.53	12.53	10.30	12.45	6.40	4.60	3.80	4.93
DH04 - cowpea	25.47	13.63	12.17	17.09	9.60	5.70	5.10	6.80
CRM-mean	20.00	13.08	11.24		8.00	5.15	4.45	
P-value (CPS)	0.002				0.0001			

Vol. 3, No. 05; 2018

ISSN: 2456-8643

P-value (CRM)	0.008	0.0001
P-value (CPS x CRM)	0.0001	0.0001
$LSD_{0.05}$ CPS	2.43	0.14
$LSD_{0.05}$ CRM	2.97	0.18
$LSD_{0.05}$ CPS x CRM	4.45	0.27
CV (%)	15.65	2.33

Crop residue management (CRM) levels: R_0 = No crop residue; R_1 = crop residue on the soil surface; and R_2 = crop residues incorporated into the soil

Incorporation of crop residue into the soil significantly increased the number of cowpea grains per pods in both cropping systems and sites. Incorporation of crop residues into the soil had higher number of grains per pod than surface mulching in DH04-cowpea intercrop at Kilifi and Lamu-cowpea at Mtwapa. Cowpea intercropped with DH04 maize had significantly higher number of grains per pod than cowpea intercropped with Lamu maize under control plots in both sites, and crop residue incorporated plots at Kilifi. The average number of pods in Kilifi was 168.3% higher than in Mtwapa.

Table 8: Effect of cropping system and crop residue management on number pods per plant and grains per pod of cowpea at kilifi and at mtwapa sites during July – October 2011/2012 season

Cropping system (CPS)								
	Kilifi				Mtwapa			
	R_0	R_1	R_2	CPS-means	R_0	R_1	R_2	CPS-means
	Number of pods per plant							
Lamu - cowpea	6.50	6.67	8.43	7.20	2.23	2.37	3.10	2.57
DH04 - cowpea	8.36	8.40	9.40	8.72	2.73	3.10	3.33	3.05
CRM-mean	7.43	7.54	8.92		2.48	2.74	3.22	
P-value (CPS)	0.0001				0.0001			
P-value (CRM)	0.0001				0.0001			
P-value (CPS x CRM)	0.0001				0.0001			
$LSD_{0.05}$ CPS	0.01				0.08			
$LSD_{0.05}$ CRM	0.12				0.10			
$LSD_{0.05}$ CPS x CRM	0.17				0.15			
CV (%)	1.14				2.81			
	Number of grains per pod							
Lamu - cowpea	10.67	13.50	13.53	12.57	4.00	4.80	5.50	4.77

Vol. 3, No. 05; 2018

ISSN: 2456-8643

DH04 - cowpea	13.33	13.53	14.63	13.83	4.80	5.07	5.33	5.07
CRM-mean	12.00	13.52	14.08		4.40	4.94	5.42	
P-value (CPS)	0.0001				0.0001			
P-value (CRM)	0.0001				0.0001			
P-value (CPS x CRM)	0.0001				0.0001			
$LSD_{0.05}$ CPS	0.26				0.06			
$LSD_{0.05}$ CRM	0.32				0.07			
$LSD_{0.05}$ CPS x CRM	0.40				0.09			
CV (%)	1.87				1.17			

Crop residue management (CRM) levels: R_0 = No crop residue; R_1 = crop residue on the soil surface; and R_2 = crop residues incorporated into the soil

Ears per plant and 100-grain weight of maize

Cropping system, crop residue management and their interactions had significant effects on the number of ears per plant and 100-grain weight of maize (Table 9).

Table 9: Effect of cropping system and crop residue management on number ears per plant and 100-grain weight (g) of maize at kilifi and at mtwapa sites during July – October 2011/2012 seasonn

Cropping system (CPS)	Kilifi				Mtwapa			
	R_0	R_1	R_2	CPS-means	R_0	R_1	R_2	CPS-means
	Maize number of ears per plant							
Lamu - cowpea	0.14	0.46	0.53	0.38	0.15	0.17	0.19	0.17
DH04 - cowpea	0.33	0.66	0.88	0.62	0.13	0.24	0.33	0.23
CRM-mean	0.24	0.56	0.705		0.14	0.21	0.26	
P-value (CPS)	0.0001				0.0001			
P-value (CRM)	0.0001				0.0001			
P-value (CPS x CRM)	0.0001				0.0001			
$LSD_{0.05}$ CPS	0.010				0.007			
$LSD_{0.05}$ CRM	0.013				0.009			
$LSD_{0.05}$ CPS x CRM	0.022				0.016			
CV (%)	2.05				3.64			
	Maize 100-grain weight (g)							
Lamu - cowpea	31.60	34.30	35.4	33.77	11.53	12.50	13.50	12.51

Vol. 3, No. 05; 2018

ISSN: 2456-8643

DH04 - cowpea	28.37	30.43	31.73	30.18	10.23	11.27	11.27	10.92
CRM-mean	29.99	32.37	33.57		10.88	11.89	12.39	
P-value (CPS)	0.0001				0.0001			
P-value (CRM)	0.007				0.0001			
P-value (CPS x CRM)	0.0001				0.0001			
$LSD_{0.05}$ CPS	0.32				0.19			
$LSD_{0.05}$ CRM	0.39				0.23			
$LSD_{0.05}$ CPS x CRM	0.58				0.34			
CV (%)	0.95				1.51			

Crop residue management (CRM) levels: R_0 = No crop residue; R_1 = crop residue on the soil surface; and R_2 = crop residues incorporated into the soil

Surface mulching and incorporation of crop residues into the soil significantly increased the number of maize ears per plant and also 100-grain weight. Incorporation of crop residues into the soil had higher number of ears per plant and 100-grain weight than surface mulching in at both sites. DH04 maize variety intercropped with cowpea had significantly higher number of ears per plant and lower 100-grain weight than Lamu maize variety intercropped with cowpea under the different residue management options. Average number of ears per plant and 100-grain weight at Kilifi, were 150% and 172.9% higher than at Mtwapa, respectively.

Cowpea 100-grain weight and grain yield

Cropping system, crop residue management and their interactions had significant effects on cowpea 100-grain weight and grain yield (Table 10). Crop residue incorporation into the soil significantly increased percent cowpea 100-grain weight in Lamu-cowpea intercrop in both sites and grain yield both cropping systesm and sites. Surface mulch had no effect on 100-grain weight in both cropping systems at Kilifi, but increased cowpea grain yield in DH04-cowpea intercrop. Incorporation of crop residue into the soil had higher grain weight than surface mulching in Lamu-cowpea intercrop. Cowpea intercropped with Lamu maize had significantly higher cowpea 100-grain weight than cowpea intercropped with DHO4 maize only under crop residue incorporation options at Kilifi. Cowpea intercropped with DH04 maize had significantly higher cowpea grain yield than cowpea intercropped with Lamu maize under all crop residue management options at Kilifi and under crop residue incorporation option at Mtwapa. Kilifi had 179.5% and 111.1% higher average cowpea 100-grain weight and grain yield, respectively, than Mtwapa.

Maize stover yield and grain yield

Cropping system, crop residue management and their interactions had significant effects on maize stover yield and grain yield (Table 11). Surface mulching and incorporation of crop residue into the soil significantly increased maize stover yield in both cropping systems. Crop residue incorporation had higher stover yield than surface mulching in Lamu-cowpea intercrop.

Vol. 3, No. 05; 2018

ISSN: 2456-8643

There was no significant difference between surface mulching and incorporation of crop residue into the soil in DH04-cowpea intercrop. In Kilifi, Lamu maize intercropped with cowpea had significantly higher maize stover yield than DH04 maize intercropped with cowpea.

Incorporation of crop residue into the soil significantly increased maize grain yield in both cropping systems at Kilifi. DHO4 maize intercropped with cowpea had significantly higher maize grain yield than Lamu maize intercropped with cowpea under the control (no-surface mulch + no-crop residue incorporation) and surface mulched plots. On average, DHO4-cowpea intercrop had 30% higher maize grain yield than Lamu-cowpea intercrop. Average maize grain yield in Kilifi was 440.5% higher than at Mtwapa.

Table 10: Effects of cropping system and crop residue management on cowpea 100-grain weight (g) and grain yield (t/ha) at kilifi and at mtwapa sites during July – October 2011/2012 season

Cropping system (CPS)	Kilifi				Mtwapa			
	R_0	R_1	R_2	CPS-means	R_0	R_1	R_2	CPS-means
	Cowpea 100-grain weight (g)							
Lamu - cowpea	13.64	13.67	17.44	14.92	4.83	5.17	5.23	5.08
DH04 - cowpea	13.35	13.66	14.05	13.69	5.07	5.20	5.20	5.16
CRM-mean	13.50	13.67	15.75		4.95	5.19	5.22	
P-value (CPS)	0.0001				0.101			
P-value (CRM)	0.0001				0.023			
P-value (CPS x CRM)	0.0001				0.002			
$LSD_{0.05}$ CPS	0.29				Ns			
$LSD_{0.05}$ CRM	0.36				0.12			
$LSD_{0.05}$ CPS x CRM	0.54				0.17			
CV (%)	1.95				1.78			
	Cowpea grain yield (t/ha)							
Lamu - cowpea	0.15	0.15	0.26	0.19	0.13	0.13	0.33	0.20
DH04 - cowpea	0.44	0.61	0.66	0.57	0.13	0.13	0.23	0.16
CRM-mean	0.295	0.38	0.46		0.13	0.13	0.28	
P-value (CPS)	0.0001				0.087			
P-value (CRM)	0.0001				0.0001			
P-value (CPS x CRM)	0.001				0.604			
$LSD_{0.05}$ CPS	0.01				Ns			
$LSD_{0.05}$ CRM	0.01				0.01			

Vol. 3, No. 05; 2018

ISSN: 2456-8643

$LSD_{0.05}$ CPS x CRM	0.02	Ns
CV (%)	3.052	4.43

Crop residue management (CRM) levels: R_0 = No crop residue; R_1 = crop residue on the soil surface; and R_2 = crop residues incorporated into the soil

Table 11: Effects of cropping system and crop residue management on stover yield (t/ha) and grain yield of maize (t/ha) at kilifi and at mtwapa sites during July – October 2011/2012 season

Cropping system (CPS)	Kilifi				Mtwapa			
	R_0	R_1	R_2	CPS-means	R_0	R_1	R_2	CPS-means
	Maize stover yield (t/ha)							
Lamu - cowpea	4.87	6.67	7.43	6.32	2.43	2.63	2.90	2.65
DH04 - cowpea	3.52	4.79	5.24	4.52	1.27	1.83	1.73	1.61
CRM-mean	4.20	5.73	6.34		1.85	2.23	2.32	
P-value (CPS)	0.022				0.0001			
P-value (CRM)	0.380				0.001			
P-value (CPS x CRM)	0.115				0.0001			
$LSD_{0.05}$ CPS	1.49				0.11			
$LSD_{0.05}$ CRM	Ns				0.14			
$LSD_{0.05}$ CPS x CRM	Ns				0.20			
CV (%)	26.10				4.92			
	Maize grain yield (t/ha)							
Lamu - cowpea	1.52	1.65	2.62	1.93	0.20	0.30	0.43	0.31
DH04 - cowpea	2.22	2.42	2.88	2.51	0.30	0.57	0.71	0.53
CRM-mean	1.87	2.04	2.75		0.25	0.44	0.57	
P-value (CPS)	0.0001				0.0001			
P-value (CRM)	0.003				0.307			
P-value (CPS x CRM)	0.0002				0.0002			
$LSD_{0.05}$ CPS	0.25				0.07			
$LSD_{0.05}$ CRM	0.30				Ns			
$LSD_{0.05}$ CPS x CRM	0.45				0.37			
CV (%)	9.78				18.45			

Vol. 3, No. 05; 2018

ISSN: 2456-8643

Crop residue management (CRM) levels: R_0 = No crop residue; R_1 = crop residue on the soil surface; and R_2 = crop residues incorporated into the soil

4. DISCUSSION

Soil moisture content

Crop residue incorporation and surface mulch increased soil moisture content at 20 and 40 cm depths. Thobatsi (2009) reported that soils under maize mulch had higher soil water content than un-mulched soils in maize intercropped with cowpea. Other researchers have also demonstrated that retention of crop residues on the surface enhances water infiltration, protects the soil from sealing and crusting by rainfall, and conserves soil moisture (Thomas, 1996; McGuire, 2009). Crop residue incorporation had higher moisture content than leaving crop residue on the soil surface. Karuku et al., (2014) indicated that crop residue incorporation into the soil optimized the partitioning of the water balance components, increasing moisture storage. In a similar study, Lighourgidis et al., (2006) reported that incorporation of vetch crop residues significantly improved the quantity and frequency of deep water percolation. At 20 cm soil depth DH04-cowpea intercrop had higher soil moisture content than Lamu-cowpea intercrop while the converse was true at 40 cm soil depth. This observation supports a previous finding (see chapter six of this thesis) that suggested that Lamu maize variety exploited moisture in the top 20 cm soil better than DH04 maize variety which in turn exploited moisture better than the former at lower depths.

Chlorophyll content of cowpea and maize

The study has shown that surface mulch and incorporation of crop residue into the soil increased cowpea and maize chlorophyll content. Ramesh and Devasenapathy (2006) reported that mulching enhanced soil moisture gains in cowpea plots which led to favourable plant physiological parameters such as chlorophyll content. Boomsma et al. (2009) also reported that mulching increased maize chlorophyll content. These observations were attributed to availability of sufficient soil moisture and N for plants. Mulching enhances plant N-uptake efficiency and improves nutrient preservation over unmulched plots (Zamir et al., 2013). Chlorophyll content was higher at Mtwapa than at Kilifi possibly because Mtwapa had higher soil nutrients than the latter (Boomsma et al., 2009).

Canopy temperature

Surface mulch and incorporation of crop residue into the soil significantly reduced canopy temperatures of maize-cowpea intercrops. Turmel et al., (2015) attributed the reduction in canopy temperature under mulching to reduction in soil temperature, hence reduced moisture loss in the soil profile through evaporation. Availability of moisture in soil ensures continued transpiration and precludes the need for stomatal closure which is a common strategy by plants to reduce moisture loss. Lamu-cowpea intercrop had lower canopy temperature than DH04-cowpea intercrop, suggesting that Lamu maize variety transpired more leading to reduction in temperature. The cropping system canopy temperature averages were higher at Mtwapa than at

Vol. 3, No. 05; 2018

ISSN: 2456-8643

Kilifi possibly due to water stress conditions, because Mtwapa received lower amount of rainfall than Kilifi.

Cowpea root nodule number

Surface mulch and incorporation of crop residues into the soil significantly reduced the number of cowpea root nodules per plant in both cropping systems. The findings are in agreement with the study by Ibewiro et al., (2001) and Singh et al., (2011) who reported significant reduction in the number of root nodules under mulching. The findings in the current study could be attributed to increased shading of cowpea by maize which increased in growth and ground cover under mulch and crop residue incorporation. Cowpea intercropped with Lamu maize variety had a lower number of root nodules than cowpea intercropped with DH04 maize variety. Kilifi had 151.6% more root nodules than Mtwapa. This could be attributed to the fact that Mtwapa received lower amount of rainfall and had higher soil nutrient content than Kilifi.

Ground cover, growth and yield parameters of cowpea and maize

The study has shown that surface mulch and incorporation of crop residue into the soil increased cowpea and maize ground cover, growth, grain yield and yield components at both sites. Dahmardeh, et al., (2010) and Scopel et al., (2004) reported significant increase in leaf number and plant height due to effective water conservation as a result of surface mulching and incorporation of crop residues into the soil. Salako et al (2007) reported increased cowpea and maize ground cover due to application of crop residues. Dahmardeh, et al., (2010) and Nyakatawa, (1997) reported that mulching increased yield and yield components of cowpea and maize. Mulches intercept raindrops, retard runoff promote infiltration and reduce surface evaporation, thereby enhancing moisture availability for plant uptake (Odhiambo and Bomke, 2001).

Incorporation of crop residues into the soil had significantly higher cowpea and maize ground cover, growth, grain yield and yield components than surface mulch. This may be attributed to decomposition of incorporated crop residues releasing nutrients for crop use and improving the soil physical and chemical properties that affect plant growth (van Donk, et al., 2012). Crop residues have significant effect on nutrient cycling; soil organic matter and soil organic carbon (van Donk, et al., 2012; Pieri, 1989). Yield and yield components of cowpea and maize in Kilifi were significantly higher than in Mtwapa. This could be attributed to the fact that Kilifi received higher amount of rainfall than Mtwapa.

5. CONCLUSION

Cowpea crop residue mulch and cowpea crop residue incorporation into the soil significantly increased soil moisture content, ground cover, cowpea and maize ground cover, growth and yield parameters, yield components of maize and cowpea, but decreased the canopy temperature. Incorporation of crop residues into the soil had significantly higher growth parameters, yield and yield components of intercrops than surface mulching. The performance of DH04-cowpea intercrop was significantly higher than Lamu-cowpea intercrop.

Vol. 3, No. 05; 2018

ISSN: 2456-8643

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Vol. 3, No. 05; 2018

ISSN: 2456-8643

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ISSN: 2456-8643

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