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EFFECT OF MAIZE-COWPEA CROPPING PATTERNS ON SOIL MOISTURE CONSERVATION IN MERU AND THARAKA NITHI COUNTIES

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ABSTRACT

Given the frequent drought pressure caused by the unpredictable and limited precipitation concurrent with global climate change, highly efficient cultivation technologies have been increasingly recognized by various levels of scientific communities. Maize (*Zea mays* L.) based intercropping systems are widely practiced in Kenya, but only a few studies have focused on cowpea (*Vigna unguiculata* L.) as the companion intercrop in moisture conservatory strategy. This study was conducted during the 2018 long rains of March-April at the Kenya Agricultural and Livestock Research Organization (KALRO) Igoji Research Station and Magutuni Primary school in Meru and Tharaka-Nithi Counties, respectively. The objective of the study was to assess the effect of incorporating cowpea into the maize production pattern on crop cover and soil moisture content. The experiment was laid in a randomized complete block design with three replications in 3 x 4 m plots. The treatments comprised of pure maize stand, maize intercropped with inoculated cowpea, maize intercropped with non-inoculated cowpea and pure non-inoculated cowpea. A generalized linear model was used to determine the effects of cropping patterns on ground cover, leaf area index and soil moisture content, using GenStat 19th edition. Means were separated using Fischer's protected least significant difference (LSD) test, with differences considered significant at $P \leq 0.05$. Significantly ($P \leq 0.05$) higher (82%) crop cover was exhibited at kernel development stage in maize intercropped with inoculated cowpea compared to 78, 64 and 53% in maize intercropped with non-inoculated cowpeas , sole stand of non-inoculated cowpeas and sole maize stand, respectively. Similarly, the highest soil moisture content was recorded at kernel development stage: 210.3, 209.3, 200.2 and 196.4 mm in maize intercropped with inoculated cowpea, maize intercropped with non-inoculated cowpeas, sole stand of non-inoculated cowpeas and sole maize stand, respectively. Relative to sole maize stand and sole stand of non-inoculated cowpeas, maize intercropped with inoculated cowpea recorded the peak leaf area index of 3.75 at 70 days after planting at Igoji and 3.16 at 63 days after planting in Magutuni. The study showed that cowpea is a promising legume crop that could be integrated into maize cropping patterns to improve moisture conservation.

Keywords: maize-cowpea intercropping, soil moisture content, maize development stages, canopy cover, cropping patterns

INTRODUCTION

Maize (*Zea mays* L.) is one of the crops that are grown in many parts of the world. The United States is the lead producer accounting for 40% of the world's harvest (Morris, 2014). However, in the developing world, Argentina, Brazil and China produce about 60% of total maize output (Dowswell, 2019). In addition to that, white maize cultivation accounts for less than 1% of the total maize produced (Morris, 2014). Maize was first brought to Africa by the Portuguese in the 16th-18th centuries. Since then, maize has become a staple food in Africa with small-scale farmers producing it under very difficult conditions, with challenges varying from environmental and climatic conditions, poor soils and poor quality seeds.

In Kenya, maize is a major food crop and source of income for smallholder farmers, accounting for about 14% of farm household income (Nyoro *et al.*, 2004) and is wholly produced under rain fed conditions. Maize production is a key sub-sector in the agricultural sector in Kenya. The country's area under maize production stood at 2.3 million ha in 2016 with an annual production of approximately 3.3

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million metric tons (FAOSTAT, 2017). Olwande
(2012)

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reported that maize productivity in Kenya is low (1.0–2.1 t/ha) compared to other sub-Saharan countries (1.1−4.9 t/ha). This could be attributed to the high cost and increased adulteration of inputs, declining soil fertility, decreasing land sizes, limited access to affordable capital and low absorption of modern technology (Chebet *et al*., 2018). Besides, the low moisture availability as a result of the frequent drought pressure caused by the unpredictable and limited precipitation due to climate change, contributes to low rain-fed maize yield (Lu *et al*., 2017).

Therefore, crop production under rain-fed agriculture requires a focus on conserving soil moisture (Gitari *et al*., 2018; Nyawade *et al*., 2018). Supplemental irrigation, use of plastic film and mulching are common practices among the interventions that are applied to conserve soil moisture in rain-fed agriculture (Shah and Wu, 2020). On the other hand, the challenge of using crop residues as moisture conservation strategy is their availability, since it is coupled with their competitive uses as fuel and fodder (Mohammed *et al*., 2018). In addition, organic mulches decompose rapidly besides being susceptible to termite infestation under tropical conditions (Ambele *et al*., 2018; Bayala *et al*., 2018). Therefore, integration of legume crops in cereal production systems could be a viable option for addressing these challenges. According to Gitari *et al*. (2017), Nelly *et al*. (2018) and Nyawade *et al*. (2018), legumes enhance soil moisture conservation by covering the soil surface thereby reducing water loss through run-off and direct evaporation from the soil surface.

Various crops such as common bean, soybean and groundnuts have been intercropped with maize, resulting to increased water use efficiency (Choudhary and Choudhury, 2016; Masvaya *et al*., 2017; Miriti, 2018). However, most of these studies focused on maize-bean intercropping systems. In Kenya, intercropping of maize with cowpea (*Vigna unguiculata* L.) has been reported to reduce run-off and soil loss compared with the pure stand of maize (Nyawade, 2015), however, the soil moisture dynamics in the intercropping patterns were not monitored. Kernel and grain filling maize development stages are very critical (Siebers *et al*., 2017) and water stress occurring during these stages may reduce maize yield more than when it occurs at any other growth stage. Technologies for improving plant available water rain-fed cropping patterns are critical for sustainable crop production and food security. Hence, integration of cowpea into maize production pattern may be an effective way to address moisture stress and improve grain yield and income. The objective of this study was therefore to assess soil moisture content under different maize cowpeas intercropping patterns.

MATERIALS AND METHODS

Description of the Experimental Site

The experiment was conducted during the 2018 long rains of March-April at the Kenya Agricultural and Livestock Research Organization (KALRO) Igoji Research Station (0^o 10’26.54 S, 37^o 42’21.23 E) and Magutuni Mautini Primary School (0^o 12’44.03 S, 37^o 44’32.50 E) in Meru and Tharaka-Nithi Counties, respectively. The altitude range is 700-1000 m above local sea level. The climate of both sites is semi-arid with a mean annual minimum and maximum temperature of 18 and 25.9 °C, respectively. Rainfall is bimodal with mean annual rainfall ranging between 500-700 mm (Recha *et al*., 2017). The predominant soils in the study areas are deep, well drained and are classified as Rhodic Nitsol (FAO-UNESCO, 1994). Agriculture is the main source of livelihood in the areas, growing millet (*Pennisetum glaucum*), sorghum (*Sorghum* spp.), cowpeas (*Vigna unguiculata* L*)*, maize (*Zea mays* L.), cassava (*Manihot esculenta*) and vegetables in small-scale.

Measurement of rainfall and temperature Data

The amount of rainfall and temperature (Figure 1) received during the experimental period was recorded immediately after every rainfall and temperature event using a manual rain gauge and thermometer installed at the experimental sites.

Experimental design

The maize and cowpea varieties used in the experiment were SC Duma 43 and Katumani 80 (K80), respectively. The experiment was laid out in a randomized complete block design replicated three times. There were a total of 12 experimental plots in per site. Each treatment plot was 4 x 3 m in size. The distance between the replications was 1 m while the distance between treatment plots was 0.5 m. The four treatments were as in Table I.

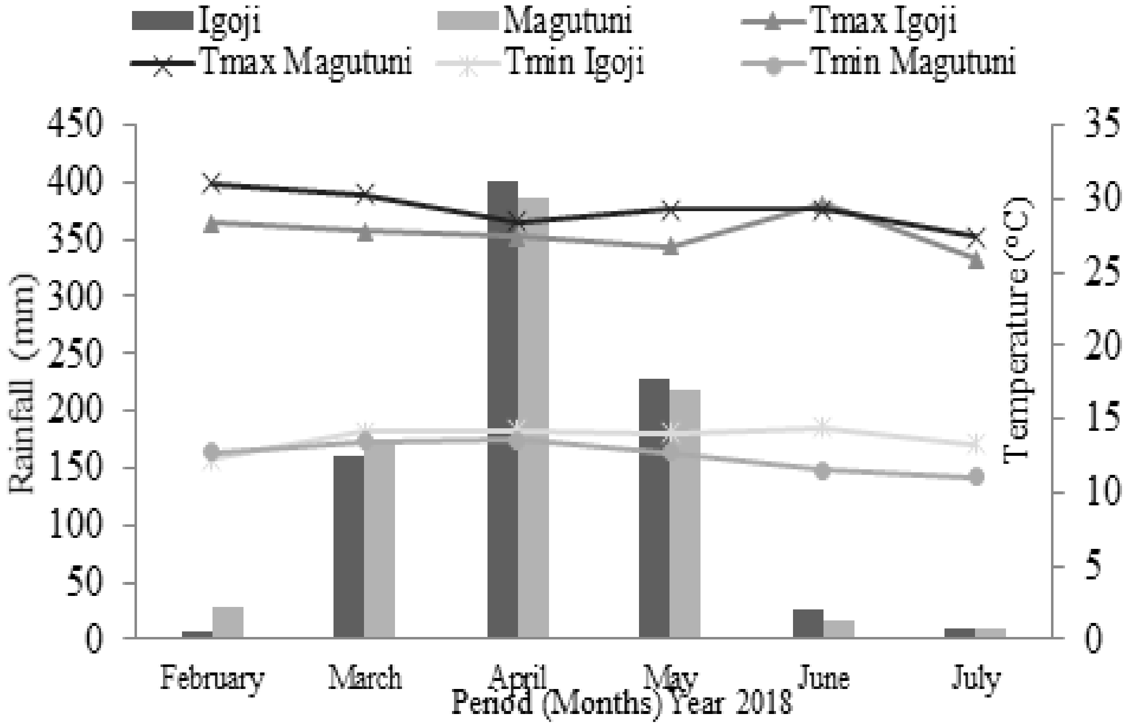

Figure 1: Rainfall, minimum (T min) and maximum (T max) temperatures recorded, during the study period

TABLE I -TREATMENT CODES USED

Code	Treatment
T1	Sole maize stand
T2	Maize intercropped with inoculated cowpea
T3	Maize intercropped with non-inoculated cowpeas
T4	Sole stand of non-inoculated cowpeas

Choice for SC Duma 43 and K 80 Varieties

Duma 43 variety is a very early white maize streak and mottle virus tolerant hybrid, with a relatively short, flinty ear and excellent yield stability over a range of environments (African Seed Company, 2017). It takes 90 days to mature with exhibited yields ranging between 4.5-6.5 t/ha (Ochami, 2021). It is compatible when intercropped with cowpeas Katumani 80 (K80) variety which assists in increasing yield. Cowpeas variety K 80 is a dual purpose variety grown for both leaves and grain. It flowers within 55-60 days where it requires a lot of light than maize during intercrop and it matures within 80-90 days. The average yield ranges from 1.7-2.1 t/ha (Kebede *et al*., 2020). It is tolerant to yellow mottle virus and scab and moderately tolerant to septoria leaf spot and powdery mildew. It has field tolerance to aphids and thrips (Shambaza, 2017).

Trial Management and Agronomic Activities

Previously the land was planted with maize but had been left furrow for one season. The land was cleared using a panga and ploughed using a fork jembe. After laying out the trial, hills were made at a spacing of 75 x 30 cm for maize and 40 x 20 cm for cowpeas. The four treatments were randomly assigned within each of the three replications. Each plot consisted of four rows of maize plants with each row having 16 plants (two seeds per hill), which were later thinned to one plant per hill at three weeks, giving eight plants per row. Thirty two plants were then left per plot giving a plant population of 44,444 plants/ha. Data was collected from the twelve inner plants in each plot.

Maize plots were established at a spacing of 75 x 30 cm and two rows of cowpea that had initially been inoculated with a commercial rhizobium bacterial strain was established in between the maize rows. The cowpeas spacing was 40 x 20 cm giving a plant population of 169,444 plants/ha. Plots with sole maize crop and non-inoculated cowpeas were also established at a spacing of 75 x 30 cm. Cowpea sole crop was established at the spacing of 40 x 20 cm. Each plot consisted of four rows with each row having 20 plants, later thinned to one plant per hill at three weeks leaving 40 plants per plot giving a plant population of 125,000 plants/ha. Data were collected from 16 inner plants in each plot.

This research was established without application of any mineral fertilizers to depict the farmers practice. The treatment plots were manually kept weed free to reduce competition for moisture and nutrients. Three weedings were done. Maize stalk borer was controlled by spraying with a pesticide (Pestox ® 100 EC) at a rate of 20 ml/20 litre knapsack spry at 45 cm high, and then repeated three weeks later.

Data Collection

Determination of moisture retention capacity

The *in situ* soil moisture was monitored weekly throughout the cropping season starting from the planting date up to 119th day after emergence (DAE) when the maize was harvested. Measurements were taken using a neutron probe from 41.25 mm (inside diameter) pre-installed polyvinyl chloride (PVC) access tubes that were installed in each plot with calibration of the probe done in the field before each sampling event and measurements taken at three depths; 0-20, 20-40 and 40-60 cm.

Before establishing the experiment, a hole for the access tube was carefully prepared by means of a soil auger sourced from University of Nairobi (UoN) which minimized soil disturbance. The enlarged top hole was back-filled to avoid water running down from the outside of the access tube. The access tubes were closed at the bottom by a tapered plastic cap. The probe was calibrated gravimetrically in the field on each measurement event. One point was randomly allocated in each plot from where depth-wise soil samples (0-20, 20-40 and 40-60 cm) were obtained and immediately sealed in plastic bags following procedures described by Okalebo *et al*. (2002). The samples were then transported to the soil chemistry laboratory at the UoN where they were weighed using a precision balance, oven dried at 105°C for 48 hours and soil moisture expressed as percent soil moisture content using equation 1:

$$\text{Gravimetric moisture content } (\%) = \frac{(\text{wet weight} - \text{oven dry weight})\ (\text{g})}{\text{Oven dry weight } (\text{g})} * 100$$

Equation 1

Moisture readings were later converted to volumetric water content (θ_v) (%) using equation 2

$$\mathit{Soil\ moisture\ content\ (mm)} = \theta v \ \times SD$$

:

Equation 2

Where: θ_v is the volumetric soil moisture content (%), SD is the sampling depth (600 mm).

Determination of plant cover

Percentage plant cover (PPC) was measured once every two weeks using a sighting frame from three points within each plot and expressed in percentages as described by Elwell and Wendelaar (1977). A sighting frame was placed on top of the vegetation then the tubes that sighted the vegetation were counted divided by the total number of the tubes on the frame. This method was then repeated three times in every treatment plot. Plant cover data was taken from seven to 119 days after emergence (DAE) when maize was harvested and was expressed following Equation 3.

$$\text{PPC } (\%) = \frac{\text{No.of tubes in where vegetation was sighted}}{\text{Total no.of sighted tubes}} \times 100$$

Equation 3

Determination of leaf area index

Leaf area index (LAI) was estimated from the second week after planting to physiological maturity using a leaf area meter at two weeks interval which was sourced from UoN.

Statistical analysis

A generalized linear model (GLM) was used to determine the effects of cropping patterns on soil moisture content, leaf area index and plant cover using GenStat 19th edition. Means were separated using Fischer's protected least significant difference (LSD) test, with differences considered significant at $P \leq 0.05$.

RESULTS

Effect of Cropping Patterns on Soil Moisture Content

The cropping patterns and maize development stages (MDS) exhibited significant differences on soil moisture content (SMC), with maize development stages having the greatest influence on soil moisture content than cropping patterns (Table II). Significant ($P \leq 0.05$) interactions were observed between cropping patterns and maize development stages. The highest values of soil moisture content (255.5 ± 3.7 mm and 253.0 ±1.9 mm) at Igoji and Magutuni, respectively, were observed at kennel development stage in maize intercropped with inoculated cowpea (T2) and lowest value recorded in Sole stand of non-inoculated cowpeas (T4), (96.6 ± 2.7 mm Igoji and 98.8 ± 5.4 mm Magutuni) at maturation stage. At kernel development stage, significantly ($P \leq 0.05$) higher soil moisture content was observed under intercropping patterns (T2 and T3) than in pure maize stand (T1), in Igoji and Magutuni.

TABLE II - EFFECT OF CROPPING PATTERN ON SOIL MOISTURE CONTENT (MM/M) AT DIFFERENT MAIZE DEVELOPMENT STAGES

Site	CP	Maize development stages					
		Planting	Post emergence	Cob devpt	Kernel devpt	Grain filling	Maturation
Igoji	T1	230.3a	235.2a	240.0b	245.3b	200.9b	117.8de
	T2	230.0a	240.5a	250.1a	255.5a	212.5cd	119.9d
	T3	232.2a	238.7a	245.9a	250.7a	205.2c	117.1de
	T4	229.2a	235.5a	243.8a	248.9a	190.2cd	96.6e
Mean		230.4	237.5	244.9	250.1	202.2	112.8
CV		26.8	25.1	23.6	23.9	20.4	19.3
LSD$_{(0.05)}$		10.3	11.4	12.4	30.1	10.5	26.8
Magutuni	T1	228.5a	230.2a	231.3a	230.8b	152.3c	102.7e
	T2	227.8a	233.7a	238.2a	253.0a	198.4b	118.9cde
	T3	225.7a	230.0a	235.2a	240.5a	185.2b	144.4.8cd
	T4	221.9a	228.4a	230.6a	233.7a	170.2b	98.8e
Mean		226.0	230.6	233.8	239.5	176.5	106.8
CV		30.6	24.6	23.4	22.3	18.2	17.7
LSD$_{(0.05)}$		11.4	15.9	20.3	12.6	7.1	30.9

Means in a column with same letter are not significantly difference from each other at 5% level. T1 = pure maize stand, T2 = maize intercropped with inoculated cowpea, T3 = maize intercropped with non-inoculated cowpea and T4 = pure non-inoculated cowpea stand

Cropping pattern (CP) had significant effect (P≤ 0.001) on canopy cover in both sites (Figure 2a and b). Despite the canopy cover in Igoji being slightly higher than in Magutuni, the differences between the two sites were not significant (P> 0.05). Across the maize development stages and sites, ground cover was significantly (P≤ 0.001) higher under inoculated maize cowpea intercrop T2 (51%) and lowest under sole maize T1 (31%). In both sites canopy cover at kernel development (77 DAE) and grain filling stages (91 DAE) was significantly (P≤ 0.001) higher under T2 (82.7%), T3 (80.2%) and T4 (79.4%) than T1 (71.5%), although the diffe;rence between T2 and T3 was not significant. At maize maturation (105 DAE) and harvesting (119 DAE) stages, T2 and T3 had the highest percentage ground cover compared to T1 which had the lowest cover than T4 (Figure 2a and 2b).

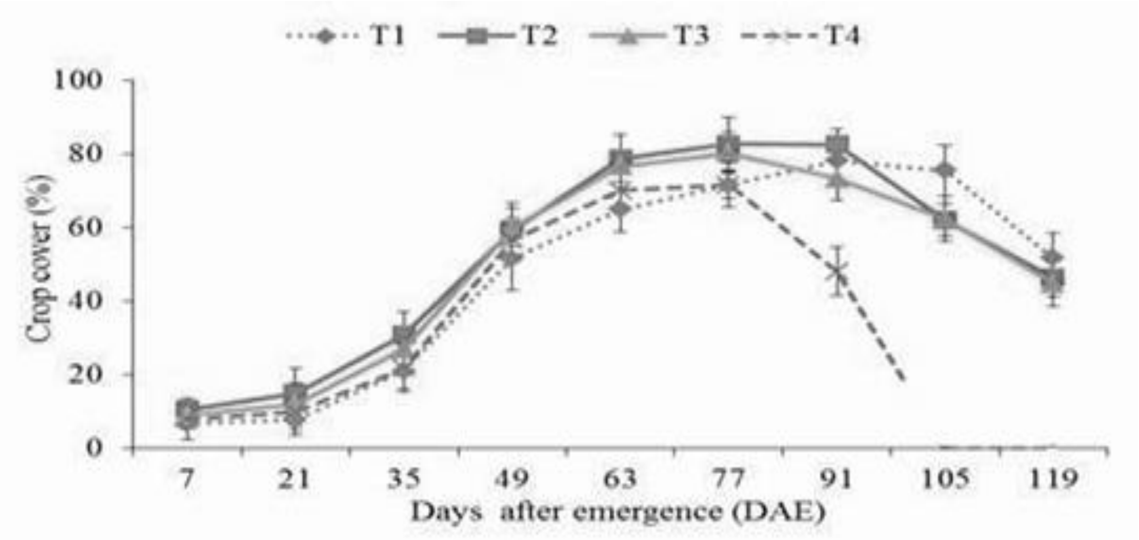

Figure 2a: Development of maize and cowpea cover under different cropping patterns at Ogoji.

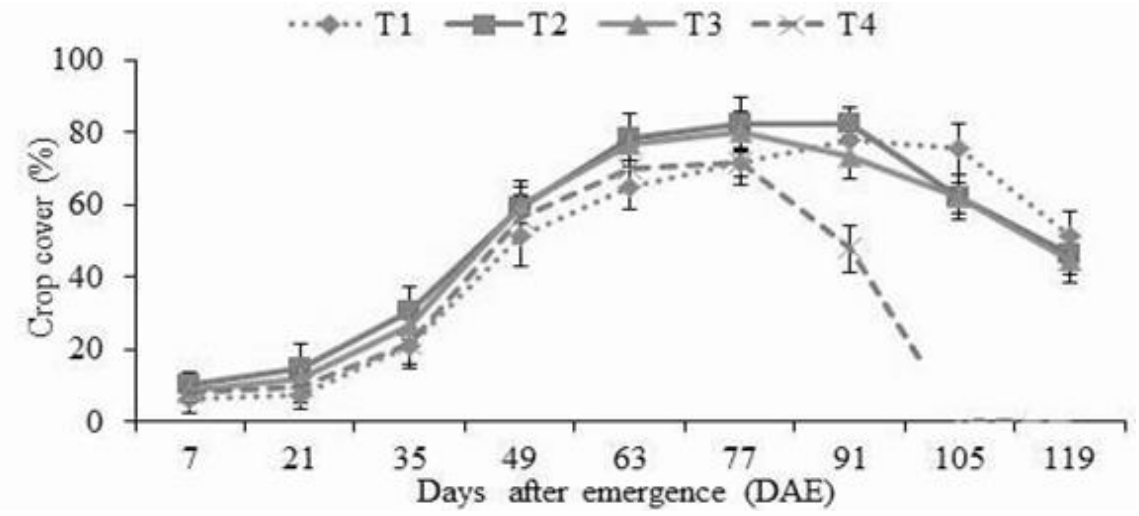

Figure 2b: Development of maize and cowpea cover under different cropping patterns at Magutuni.

T1=pure maize stand, T2=maize intercropped with inoculated cowpea, T3=maize intercropped with non-inoculated cowpea and T4=pure non-inoculated cowpea stand. Vertical bars represent standard error of the mean.

Leaf Area Index (LAI) development trend

Intercropping, significantly affected leaf area index (P≤ 0.05). The minimum peak LAI values across the sites and cropping patterns were recorded in controls (T1 and T4) at 63 to 70 DAE (Figure 3).

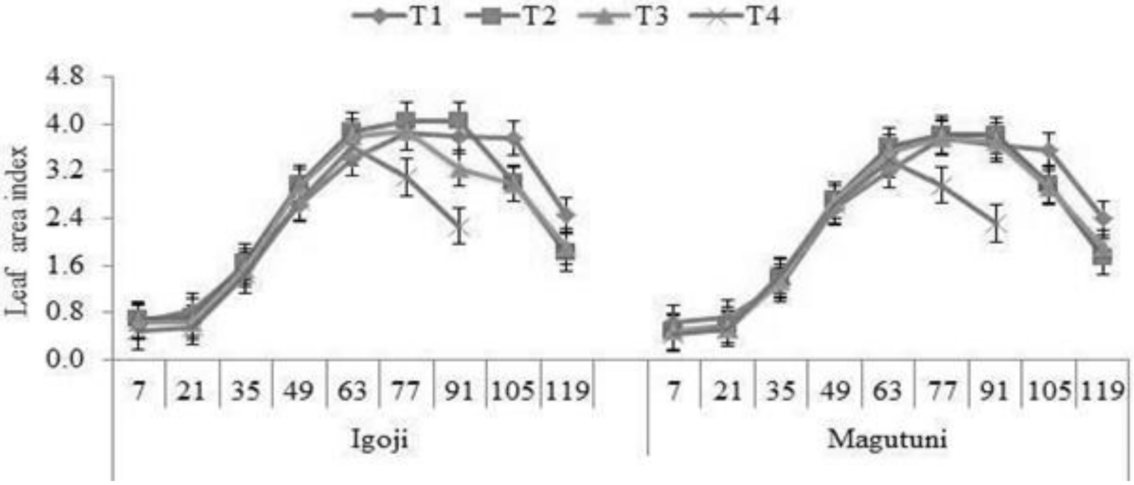

Figure 3: Leaf Area Index Development during the Experimental Period

T1=pure maize stand, T2=maize intercropped with inoculated cowpea, T3=maize intercropped with non-inoculated cowpea and T4=pure non-inoculated cowpea stand.

DISCUSSION

Effect of cropping patterns on soil moisture content

The similarity in soil moisture content during planting and post-emergence stages in both sites was attributed to the rainfall events that were experienced in the areas. Crops were in early stages of development and may not have formed enough ground cover to influence significant differences in soil moisture. However, at the later stages of maize development, the results indicated the potential role of intercropping in promoting soil moisture conservation in maize production patterns. The contents of soil moisture have been reported to increase under other intercropping systems such as potato-maize (Fan *et al.*, 2016), maize-cowpea (Ghanbari *et al.*, 2010) and dolichos-sweet potato (Chepkemoi *et al.*, 2014). Conversely, pure maize and cowpea stands which had relatively less dense canopy cover than maize-cowpea intercropping probably experienced a greater loss of water through direct evaporation from the soil surface leading to lower soil moisture content.

Compared to sole maize (T1), the maize-cowpea intercropping had consistently higher soil moisture content with inoculated cowpea (T2), (255.5 mm, 253.7 mm) and non-inoculated cowpeas (T3), (250.0 mm, 240.2 mm) at maize kernel development and pod formation (cowpeas) stage at both Igoji and Magutuni, respectively (Table I). This stage coincided with the period when the LAI in the intercropping plots was also higher than in sole maize plots (between 49 and 77 DAE) in both sites (Figures 2 and 3). Hence, low LAI in the sole maize plots exposed a greater surface area than the intercrop plots which could have increased direct evaporation of soil moisture from the surface. Maize-cowpea intercropping therefore increased soil water conservation by minimizing the losses due to surface evaporation. Moreover, the additional canopy cover provided by cowpeas in the intercropped plots could have helped in intercepting more rain water (Karuma *et al.*, 2011; Nelly *et al*., 2018; Nyawade *et al.*, 2018). This may have increased the amount of water infiltrating into the soil resulting in higher soil moisture content in intercropping patterns as compared to pure maize stand.

The results indicated the potential role of cowpea in promoting soil moisture conservation in maize production patterns (Sharma *et al*., 2017). The high ground cover in the two sites was attributed to high rainfall received during the cropping season in both sites. Crops used available soil water effectively, resulting in high canopy cover and eventually more biomass production. The higher ground cover in maize-cowpea intercropping relative to maize pure stand could be attributed to the ability of cowpea to provide a quick thick canopy. This may have increased the amount of water infiltrating into the soil resulting in higher soil moisture content in intercropping patterns as compared to pure maize stand. Additionally, the increased ground cover in maize-cowpea intercropping patterns could have created a microclimatic condition by preventing the escape of moist and cool air close, thereby reducing water loss through evaporation from the soil surface.

Leaf area index development during the experiment

Intercropping, significantly affected leaf area index ($P \leq 0.05$). The minimum peak LAI values across the sites and cropping patterns were recorded in controls (T1 and T4) at 63 to 70 DAP (Figure 3). This implied that the total plant canopy under intercropping patterns (T2 and T3) was higher compared to sole cropping patterns. The trend of LAI development exhibited in this study was typical of most crops that increase their LAI to a peak value, after which the LAI reduces as the crop senesces. The observed reduction in LAI by maize and cowpea under the sole cropping patterns could be a strategy by the crops to reduce water loss and maintain the soil water uptake at satisfactory levels. Stomatal conductance and morphological modifications by maize and cowpea may have achieved this. Absorption of soil water decreases with reduction in LAI (Dermody *et al*., 2006).

Relative to sole cropping patterns (T1 and T4), maize intercropped with inoculated cowpea (T2) recorded the peak LAI of 3.75 at 70 DAP at Igoji and 3.16 at 63 DAP in Magutuni (Figure 3). There was a significant decline in the LAIs immediately after the maximum LAIs were reached in the two sites and in all the treatments, with the fastest decline being observed under sole non-inoculated cowpea stand (T4) (Figure 3). Attaining the peak LAI of different cropping patterns at different times suggests that the spatial distribution of LAI in this study was influenced by the cropping patterns and site (Dermody *et al.*, 2006). The modification of the time of leaf senescence in response to availability in soil moisture could explain this variability between sole crops and intercrops. It has been reported by Haworth *et al*. (2015) that reduced stomatal conductance under limited water conditions cause interruption in CO_2 assimilation. Under such conditions, plants may consume own water reserves and may lead to early death of the plants or leaf senescence. Nutrient and water deficit in crops may shorten leaf longevity leading to decrease in LAI.

A better LAI distribution was achieved when maize was intercropped with inoculated cowpea. This was an indication that integration of inoculated component crop increased the development of LAI that led to an increased ground cover, which conserved soil moisture making the crop to utilize the moisture and increased surface area for CO_2 absorption to enhance the process of photosynthesis (Haworth *et al*., 2015). Significant differences in the peak LAI between inoculated (T2) and non-inoculated cowpea (T3), suggested that intercropping cowpea with application of rhizobium inoculant was sufficient to achieve optimal canopy cover depending on the population of native rhizobium in the soil. This was in agreement with Fituma (2015) who reported that the native rhizobial populations found in the soil increased the canopy cover of soybean when intercropped with sugarcane. The slightly higher rainfall in Igoji than in Magutuni during the experimental season could have contributed to a better LAI development as the improved moisture conditions could have led to enhanced assimilation of nutrients and accelerated leaf development.

CONCLUSION

There was increased soil moisture that was retained under inoculated cowpea maize intercrop than non-inoculated maize cowpea intercrop and sole crops of maize and cowpeas. Increased ground cover under intercropping patterns could be a potential water conservation strategy of intercropping maize with legumes. Integration of cowpea into maize cropping patterns could be essential to improve crop water productivity. Increased crop water productivity in smallholder farmers who depend on rain-fed agriculture is essential for improving their livelihoods.

RECOMMENDATION

There is need to increase the ground cover through intercropping patterns in order to conserve soil moisture in Meru and Tharaka Nithi Counties. Inoculation of cowpeas increased the forage cover which conserved more moisture than non-inoculated cowpea. Further research should be done on inoculation of different legume- cereal based intercrops in moisture conservation.

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