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INTERSEEDING TIMING OF COWPEA (*Vigna unguiculata* L. Walp.) LIVING MULCH ON WEED DIVERSITY, PHYSICAL SOIL PROPERTIES AND PERFORMANCE OF MAIZE (*Zea mays* L.)

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BY

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DISSERTATION/THESIS SUBMITTED TO THE DEPARTMENT OF AGRONOMY, FACULTY OF AGRICULTURE, UNIVERSITY FOR DEVELOPMENT STUDIES, IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE AWARD OF MASTER OF PHILOSOPHY DEGREE IN CROP SCIENCE

JUNE, 2019

DECLARATION

Student

I hereby declare that, except for the work by others, which I have duly acknowledged, this dissertation/thesis is the outcome of my own research and that neither a part nor whole of it has been presented for another degree in this university or elsewhere.

Signature: …………………………. Date: …………………………….

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I hereby declare that the preparation and presentation of the dissertation/thesis was supervised in accordance with the guidelines on supervision of dissertation/thesis laid down by the University for Development Studies.

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ABSTRACT

This trial was conducted to determine cowpea living mulch and maize maturity type effect on soil physical properties, maize yield and weed management. The study was a 3 x 4 factorial experiment laid out in Randomised Complete Block Design with 3 replications. Three maize maturity types: extra early Abontem, early Omankwa and medium Obatanpa and four living mulch systems: cowpea living mulch interseeded same day with maize (SDWM), cowpea living mulch interseeded 1 Week after planting maize (WAPM), cowpea living mulch interseeded 2 WAPM and sole maize (control) were used as treatments. The maize was planted at a spacing of 75 x 40 cm and interseeded with cowpea living mulch planted in between maize rows at an intra-spacing of 20 cm, resulting in a 1:1 row arrangement. Data was collected on soil physical properties, maize growth, yield and yield components, weed biomass and diversity. Planting cowpea as mulch in maize reduced ($p < 0.05$) soil temperature and increased ($p < 0.05$) soil moisture content than the control at vegetative, tasselling and harvest growth stage of the maize. Maize plant height at harvest, leaf area index of maize at 6 WAPM and days to 50% tasselling were significantly affected by cowpea living mulch and maize maturity type interaction. Cowpea living mulch significantly increased maize grain yield, with cowpea living mulch at 1 WAPM recording the highest grain yield of 2285.9 kg/ha. Cowpea living mulch significantly reduced weed biomass at 6, 9 and 12 WAP. Maize maturity type affected ($p < 0.05$) parameters such as plant height, leaf area index, 50% tasselling and silking, stover yield and harvest index. Cowpea interseeded SDWM and 1 WAPM best improved soil physical properties, maize yield and reduced weed diversity and biomass. Therefore, for enhanced maize yield and optimum weed control, farmers with enough labour can inter-seed maize with cowpea live mulch on the same day (SDWM). Alternatively,

those face with labour scarcity could adopt maize with cowpea interseeded at 1 WAPM.

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DEDICATION

This is dedicated to the memory of my late mother Mrs. Beatrice Yeboah, who passed away exactly 2 months before I defended this thesis.

MAY HER SOUL REST IN PEACE!!!

And to my brother, Yaw Agyeman Prempeh (Scott), that He should always remember, even though our mother is gone, our **GOD IS NOT DEAD**.

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CHAPTER ONE

1.0 Introduction

Maize (*Zea mays* L) is the third most important cereal after wheat and rice in the world and chief sources of energy in human diet (Pingali, 2001). According to FAO (2018) estimate, 187 million hectares of maize are harvested worldwide of which sub-Saharan Africa harvest 36 million hectares. In Ghana, it is produced in all five agro-ecological zones, namely Coastal, Forest, Transitional, Guinea and Sudan savannas (Sallah et al., 2004). Maize is primarily used as food for man, secondly for livestock feed and raw materials for industries. Despite its importance, the average yield of maize in Ghana is estimated to be 1.7 metric tons/hectare, whereas achievable yields (on-farm trials) are between 4 and 6 tons/hectare (Ragasa et al., 2013). Several biotic and abiotic factors are often cited as the major causes of the low yield of maize, two (2) of which are low and declining soil fertility and weed infestation.

Low and declining soil fertility in smallholder farms has been described as the fundamental biophysical factor responsible for the declining per-capita food production in Sub-Saharan Africa (Sanchez & Leakey, 1997). Accordingly, several studies on soil nutrient balance have reported negative balance of nitrogen, phosphorus, and potassium in most Sub-Saharan African countries (Stoorvogel et al., 1993). Thus, to effectively reverse the trend of declining soil fertility, soil fertility replenishment would be required.

Weeds are one of the greatest limitation factors to efficient maize production and account for about 40 – 60% maize yield loss (Thobatsi, 2009). Among the weed management technologies applied predominantly in Sub-Saharan Africa are hand weeding and chemical weed control. However, it is a common observation that smallholder farmers find hand weeding difficult to practice due to lack of labour, drudgery and insufficient time as critical weed management periods coincides with other farming activities, while herbicides use are associated with high cost, weed resistance and negative effects on environment. Therefore, there is the need for research in the area of low-input cropping systems that can increase soil fertility as well as reduce drudgery associated with weeding, weeding frequency and increase grain yield in a small-scale maize based cropping system. And one cropping system that embodies and expands upon such an idea is that of a living mulch.

Living mulches are cover crops planted either before, after or with a main crop and maintained as a living ground cover throughout the growing season or longer (Hartwig & Ammon, 2002). The main task of living mulches in crop production systems is to enhance soil properties as well as to improve the growing conditions for the main crop (Brainard & Bellinder, 2004). Leguminous living mulches offer the greatest potential for fertility improvement (Beahm, 2011) and weed management (Silva et al., 2008). Improvement in soil organic carbon content (Groody, 1990), soil macro aggregation stability (Shennan, 1992), soil moisture, total porosity, lower soil bulk density have also been found by many authors when using legumes (Borowy, 2012; Boyd et al., 2001; Jędrszczyk et al., 2005). In addition to improving soil properties, reductions in weed diversity have been widely reported in studies of hairy vetch (*Vicia villos*) as a live mulch in corn (Mohammadi, 2012), subterranean clover (*Trifolium subterranean* L.) in soybean (Enache & IInicki, 1990) and cowpea as a live mulch in maize (Talebbeigi & Ghadiri, 2012). Incorporating leguminous living mulches can significantly improve yield of main crop (Decker et al., 1994). Yield advantages have been recorded in many main-crop – living mulch systems, including maize – cowpea (Talebbeigi & Ghadiri, 2012) and pepper – cowpea (Hutchinson & McGiffen, 2000).

Despite the widely acclaimed potential of leguminous living mulches, results from various studies on the best timing for interseeding the mulch with maize proves to be inconsistent. For instance, studies by Zemenchik et al. (2000) indicated no yield reduction when corn was planted into an established kura clover mulch. Conversely, Brainard & Bellinder (2004), reported a substantial reduction of corn yield when interseeded with legume, 5 weeks before corn planting. In another study, Nordquist & Wicks (1974) found grain yield reduction of 3% when corn was interseeded with alfalfa as a live mulch at the time of corn establishment. In addition, there is inadequate information regarding the use of legume crop such as cowpea as a living mulch in a small-scale maize based cropping system.

The study was therefore aimed at evaluating cowpea as a living mulch in a small-scale maize based cropping system for improve soil physical properties, optimum weed control and enhanced maize yield.

The specific objectives were to determine the effect of:

i. Cowpea living mulch interseeding time and maize maturity type on soil physical properties.
ii. Cowpea living mulch interseeding time and maize maturity type on weed biomass and diversity.
iii. Cowpea living mulch interseeding time on growth and yield of maize maturity type.

Hypotheses

The above specific objectives were formulated to test the following hypotheses

i. Soil physical properties may not be affected by cowpea living mulch interseeding time and maize maturity type.

ii. Weed biomass and diversity may not be affected by cowpea living mulch interseeding time and maize maturity type.

iii. Performance of maize in a cowpea living mulch system may not be influenced by cowpea interseeding time.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Origin, Classification and Botany of Maize

Despite conflicting views still existing as to maize origin, the generally accepted view is that primitive maize was selected by man either directly from its closest living relative, teosinte (*Zea Mexicana*) or from a common ancestor (Iltis, 2000).

Zea is genus of the family Graminae (Poaceae), commonly known as the grass family. Maize (*Zea mays* L.) is a tall monoecious annual grass with a robust and erect stem. Plants have staminate (male) spikelets borne on long spike-like racemes that form large spreading terminal panicle (tassels), terminating the main axis of the stem. The female inflorescence (pistillate), which mature to become the edible ears, bears paired spikelets in longitudinal rows; each row of paired spikelets normally produces two rows of grain. The seed contains two structures, which are the germ from which new plants develop and the endosperm which serve as source of food for germinating seed. The kernels vary in colour ranging from white, red and blue. On the basis of endosperm of kernels, Dickerson (2008) classified maize as,

i. Flint corn (*Zea mays* indurate Sturt): The soft and starchy portion of the endosperm is protected by a hard-outer layer. This is early maturing, white or yellow coloured and is more resistant to storage insects like weevil than the dent and floury corn.

ii. High endosperm corn: These are hybrid corn with dry milling or alkaline cooking properties, and is used for snack foods, breakfast cereals etc. This can be further classified into:

- High amylose corn: It contains larger volume of amylose starch (55 – 60%) and is used in materials where good film-forming properties are required, as in the coating of glass fibres.
- High oil corn: Has higher levels of oil, protein and essential amino acids. It is good for poultry, swine and dairy cows that requires feed with high calorie levels.
- High starch corn: In this type, limited hybrids are available currently. These hybrids have found special application in industries such as the production of ethanol and biodegradable plastics.
- Floury maize (*Zea mays var amylaceae*): The seed has a soft starch and while drying, the endosperm uniformly shrinks and results in no denting on the kernel.
- Dent corn (*Zea mays indentata*): It is a cross between floury and flint maize. The rapid drying of the soft starch in the kernels leads to formation of dent or depression in the crown of the seed.
- Popcorn (*Zea mays averta*): The endosperm surrounds a small area of soft starch. This soft starch contains a significant amount of moisture which when heated generates steam and pressure resulting in swelling and bursting giving a pop sound
- Sweet corn (*Zea mays var saccharata*): It has very high sugar content, creamy texture, low starch content and a pleasant aroma than any ordinary maize. This is also known as Indian corn, sugar corn or pole corn.
- Waxy corn (*Zea mays ceretina* Kulesh): In terms of both molecular structure and pasting characteristics, this is distinct from regular maize.

Pastes made from waxy starch are long and cohesive, whereas pastes made from regular maize starch are short and heavy bodied.

- Pod corn (*Zea mays tunicata*): Each kernel is enclosed in pod or husk in an ear which is enclosed in husks like other types of corn. It is a primitive type of corn not grown commercially.

2.2 Origin, Classification and Botany of Cowpea

Cowpea is believed to have originated from two independent centres: Africa and Asia. However, Asia as a centre of origin has been questioned due to the lack of wild ancestors (Marechal & Ng, 1985). To further cast doubt on Asia as a centre of origin, Flight (1970) reported that the oldest archaeological evidence of cowpea was found in Africa in the Kintampo rock shelter remains in central Ghana dating about 1450 – 1000 BC, suggesting Africa as centre of origin.

Cowpea (*Vigna unguiculata* L. Walp.) is a member of the phaseoleae tribe of the leguminosae family. It is a very diverse, usually glabrous, annual herb with twinning stems varying in erectness and bushiness. It has a deep taproot system with many numerous root nodules of about 5mm in diameter (Chaturvedi et al., 2011). Leaves are alternate and trifoliate with petioles of about 2.5 – 12.5 cm long. Like many flowers, those found on cowpea plants are hermaphroditic, containing both the stamen and pistil. This according to Weaver (2003), makes the plants self-fertile, meaning that an individual plant is able to reproduce by itself which can have the effect of limiting genetic diversity. The fruit is a dehiscent pod with varying shape and length which usually shatter when dry. It is pendulous, smooth, 10 – 23 cm long with a thick curved back and 10 -15 seeded. Seed of cowpea ranges in length from 4 – 8 mm and 3 – 4 mm broad (Allaire & Brady, 2010). The pod is green at early stage and when maturing it becomes usually yellow, light brown, pink or purple (Bediako, 2012).

2.3 Living Mulches

Maintaining a mulch layer and building soil organic matter are primary motivations for adopting practices like conservation tillage. However, surface residues in conservation tillage may decompose too quickly to provide adequate weed suppression later in the season (Stivers-Young, 1998). Also coupled with this, intensive cultivation has led to decrease in soil fertility and build-up of weeds, increasing the need for cost effective soil and weed management strategies that addresses these interconnected challenges.

When cover crops are inter-planted within a main crop, acting chiefly as ground cover to protect and build soil structure while simultaneously suppressing weed germination and growth, they are defined as 'living mulch' (Hessler, 2013). Living mulch system were first practice with perennial crops, e.g. Vineyards and Orchards (Buckerfield & Webster, 1995; Neilsen & Hogue, 2000), but it has since being introduced with annual crops such as maize (Hartwig & Ammon, 2002) and small-grain cereals (Hiltbrunner & Liedgens, 2008; Jones & Clements, 1993). In line with cover crops, living mulch have the potential to decrease soil erosion (Zemenchik et al., 2000), increase the self-regulation of pests and diseases (Brandsetter et al., 1998; Ramert, 1996), supress weeds (Hutchinson & McGiffen, 2000; Kitis et al., 2011; Mohammadi et al., 2012) , improve soil structure (Duda et al., 2003) and hinder the leaching of N. However, in cases where excessive competition leads to poor plant quality in living mulch systems, the advantages of achieving adequate weed suppression and enhanced soil properties may be lost because of poor yields (Liebman & Staver, 2001).

2.3.1 Characteristics of living mulch species

An effective living mulch specie must conserve soil, provide balance between competition against weeds and not diminish the accessibility for the main crop with respect to available resources: light, water and nutrients (Leary & DeFrank, 2000). The success of living mulch – crop system is largely determined by the selection of the most appropriate species that suits the local climate and crop management system intended for. The presence of living mulches comprehensively affects the micro climate in which crops grow and, therefore, species selection should be considered from the point of view of different fields of knowledge and practice. In a review, Paine & Harrison (1993) cited four (4) characteristics that are deemed important for a living mulch species; 1) rapid establishment of the living mulch is needed to provide early weed control and to prevent soil erosion, 2) adequate wear tolerance and persistence is needed for entrance into the field, 3) tolerance to drought and low soil fertility, 4) low maintenance budget associated with weeding intervals and fertilize needs. Species as living mulches are distinct, in terms of their capacity to establish well, adequately suppress weed growth and contributes meaningfully to affect crop yields in an interseeding situation. For example, Ennin et al., (2004) found that, cowpea and mucuna contributed more than 90 kg N/ha to maize whiles no appreciable N contribution was measured from soybean and groundnut with maize.

The competitiveness against weeds is also a major trait influencing the suitability of a plant species as living mulch. In a study of weed suppression abilities of some legumes (cowpea, groundnut and soybean), Lawson et al. (2013) found that, the highest corn yield and weed suppression were realised from maize plots interseeded with cowpea as compared to maize plots interseeded with groundnut and soybean. Ideally, in a maize – living mulch system, the living mulch should suppress weed growth during the sensitive period to weed competition at 3 and 6 WAP (Akobundu, 1987) i.e., the stage when competing weeds will result in maize yield loss.

In general, potential crop specie as living mulch for weed suppression and soil conservation should have the following attributes:

i. The ability to suppress weeds without stressing the crop as a result of quick emergence.
ii. Fast soil coverage and short height to reduce aerial competition
iii. Tolerance to drought and low soil fertility.
iv. Low N demand or leguminous plant species.
v. Non-rhizomatous spread is also desired to minimize competition by keeping the mulch from growing into crop rows (Newenhouse & Dana, 1989; Muller-Scharrer & Potter, 1991; Paine & Harrison, 1993; Leary & DeFrank, 2000 & Teasdale, 2003).

2.4 Effect of living mulch on resource use efficiency

2.4.1 Water Use Efficiency

Soil water availability is one of the cardinal principles determining productivity in cropping systems. When water is a limiting factor and the goal is to conserve water, it is imperative to cultivate crops with high water-use efficiency (WUE), variously defined as:

1. Harvested yield per unit evapotranspiration (ET) (Evans, 1976),
2. Dry matter produced per unit area per unit of ET (t ha^{-1} mm^{-1}) (Jensen et al., 1980),
3. Photosynthesis per unit of water transpired (Sinclair et al., 1984)

4. Yield of dry matter as a function of the total water used to produce a crop (Iqbal et al., 2003).

Factors that influence crop water use efficiency, includes crop physiological characteristics, genotype, soil characteristics such as soil water-holding capacity, meteorological conditions and agronomic practices (Huang et al., 2006). Studies have found that multiple cropping system involving two crop species such as legume and cereal may use water more efficiently than a monoculture of either species through exploring a larger total soil volume for water, especially if the component crops have different rooting pattern (Willey, 1979). However, other authors have also reported differently, stating that having different root system in the soil may increase uptake of water and increased transpiration (Carlson, 2008). Tolk et al. (1999), reported a 14% increase WUE by comparing mulch soil with bare soil treatment. Gabriel & Quemada (2011), reported an increase WUE after three years of cover crop addition in maize cropping system. Results found by Wiggans et al., (2012), indicated that living mulch may increase soil water content and utilize water more effectively, particularly when combined with strip till. Furthermore, the presence of living mulches on the soil surface may provide positive soil water effects late in the growing season when the main crop relies on stored soil water during end-of-season drought (Wiggans et al., 2012).

2.4.2 Nutrient Use Efficiency (NUE)

Cropping systems that improves NUE is an essential pre-requisite for expansion of crop production into marginal lands with low nutrient availability and also a way to reduce use of inorganic fertilizer (Meena et al., 2015). A possible advantage of interseeding legume living mulch into a main crop may be a higher nutrient use efficiency. Nutrient use efficiency can be expressed in several ways. Mosier et al.

(2013) described four agronomic indices commonly used to describe nutrient use efficiency: partial factor productivity (PFP, kg crop yield per kg nutrient applied); agronomic efficiency (AE, kg crop yield increase per kg nutrient applied); apparent recovering efficiency (RE, kg nutrient taken up per kg nutrients applied) and physiological efficiency (PE, kg yield increase per kg nutrient taken up).

Many different agronomic options have been proposed as a means of improving NUE in cereal crops, two of which are: 1) Use of cover crops, to retain organic matter and soil N in the soil and 2) Identifying the best sowing rate, spacing and depth for the best use of soil water and nutrients (Faraj, 2011). Acknowledging this, higher total N-uptake in wheat-sub clover living mulch system compared to monoculture systems was reported (Radicetti et al., 2018). Tittarelli et al. (2014) also found that, the time of sowing living mulch using Burr medic influenced the nutrient use efficiency through higher N-uptake among cauliflower and the living mulch. While most of the focus on nutrient efficiency is on N, phosphorus efficiency is also of interest because it is one of the least available and least mobile nutrients (Ghosh et al., 2015). For potassium use efficiency, there is little available information, however it is generally considered to have a higher use efficiency than N and P because it is immobile in most soils and is not subject to the gaseous losses that N is or the fixation reactions that affect P.

It is however unclear, if better nutrient uptake is the cause of higher yield potential (Willey, 1979). This relationship between yield and nutrient use efficiency was ably described by Ghosh et al. (2015), stating that efficient does not necessarily means effective. Much higher nutrient efficiencies could be achieved simply by sacrificing yield, and that would not be economically effective or viable for the farmer.

2.4.3 Radiation Use Efficiency

Solar radiation is essential to all green plants because of its primary role in photosynthesis (Keating & Carberry, 1993; Roberts et al., 1985). Different type of radiant energy, including light, differs in several ways, most important of which are irradiation (intensity), quality and duration (Kiseve, 2012). Under natural conditions differences in irradiance influences plant growth more significantly than differences in light quality (Kiseve, 2012). Radiation interception varies from seedling emergence to crop harvest (Natarajan & Willey, 1980; Watiki et al., 1993) and depends largely on the canopy leaf area (Karimian et al., 2015). Therefore, understanding how the differences occurs within the plant canopy is important within a cropping system, especially when considering various crop - living mulch combinations.

Solar radiation captured by plants during growth is converted to more useful forms of chemical potential energy located in the harvestable plants parts (Hall et al., 2013). According to Azam-Ali & Squire (2002), this energy transformation is achieved through the conversion of the intercepted radiation energy (conveniently expressed in terms of plant dry matter) and partitioning of the dry matter produced between the harvested parts and the rest of the plant (Azam-Ali & Squire, 2002). As a result plant dry matter production often shows a positive correlation with the amount of radiation intercepted (Kiniry et al., 1989; Sinclair & Muchow, 1999).

Studies on mixed cropping systems, such as living mulch and crop/weed interactions have emphasized on competition for light between one species and another. This is because, as two morphologically dissimilar plant with different maturity periods are cultured together, radiation is the only environmental factor that determines the yield (Jeyakumaran & Seran, 2007). According to Lindquist & Mortensen (1998), leaf area index (LAI), plant height, vertical leaf area and leaf angle distribution are factors that play key role in evaluating competition for light in mixed canopies. Acknowledging this, Matthieu et al. (2007) found that the light competitive ability of wheat under sown with a living mulch was the highest when wheat was much taller than living mulch, and also when wheat leaf area in the mixed canopy layer was greater than that of the living mulch. Karimian et al. (2015) after studying about radiation absorption and use efficiency in wheat under sown with canola reported a maximum radiation use efficiency in the mixed cultured stand than their respective soles.

Although optimal light interception can be reached in sole crops compared to intercropping, efficiency in light utilization is usually higher in intercropping. According to Kiseve (2012), taller plants in an intercrop dominate light interception at the upper layer while shorter ones utilized the light transmitted to the ground that otherwise may be wasted in sole cropping.

2.4.4 Knowledge gap

The above review points out the beneficial effects of main crop - living mulch systems on resource use efficiency. However, there is a prevailing gap in literature regarding the appropriate time for interseeding a cowpea living mulch with maize for improved resource use efficiency. Therefore, there is the need to fill this knowledge gap using the results from this study.

2.5 Effect of living mulch on soil properties

2.5.1 Chemical

2.5.1.1 Soil Organic Matter and Carbon

Soil organic matter (SOM) is one of the most important components included in the assessment of soil health. It represents the remains of roots, plant materials and soil organisms in various stages of decomposition and synthesis, and is variable in composting though occurring in relatively small amount (Ryan & Rashid, 2013). Organic matter is considered one of the main agents favouring soil structure, soil stability, buffering capacity, moisture retention, biological activity and nutrients reserve and it availability (Broughton, 2010). Improvements in the physical structure of the soil reduces erosion and facilitate tillage, water storage capacity, and deeper plant root system (Vachon, 2008). In general, soil moisture content increases by 1 to 10 g for every 1g increase in SOM content which helps to maintain crop growth between periods of rainfall (Emerson, 1995). Soils low in organic matter and nutrients exhibit increased susceptibility to degradation upon cultivation especially if management of these soils is inappropriate (Burt et al., 2001)

Soil organic matter (SOM) is closely related to soil organic carbon (SOC) because SOM constitutes the largest terrestrial reservoir of carbon (Abu-Khader, 2006; Blanco-canqui & Lal, 2004). According to Berg & Laskowski (2006), organic matter contains approximately 55% SOC and 45% other essential elements. Therefore any management practices aimed at enhancing SOC must increase the input of organic matter to the soil (Vachon, 2008). Living mulches contributes organic matter to the soil through the addition of mulch residues. However, the rate of change in SOM would depend not only on the mulch species and residue input but also on soil type and climatic conditions (Sanchez, 2016). Several studies have shown that even a grass mulch can add over a dry ton of organic matter per year to the soil just from the root mass (Ferguson, 2001). Verhulst et al. (2010), observed that, mixed cropping systems was still more effective in retaining carbon (C) and nitrogen (N) in soil than a monoculture system. The effect of mixed cropping systems on SOC contents can be due to increased biomass input as a result of greater biomass production, diverse quality of the residue and the different mechanism of capturing carbon in stable and long-term forms by different crop species (Verhulst et al., 2010). For instance, crop-legume living mulch system produce greater amount of aromatic carbon content (a highly biologically resistant form of carbon) below the plough layer than continuous maize (Gregorich et al., 2001). Studying the effects of a legume crop (*Mucuna puriens* var *utilis*) on a sandy loam ultisol in Benin, Barthes et al. (2004), found that total carbon content increased from 5.2 to 11.6 g kg^{-1} in the 0 – 10 cm layer when corn was planted into a mucuna mulch that was sown each year 1 month after corn. While reports have shown that living mulches have a positive effect on soil carbon content, complementing it with additional soil management practices such as no-tillage can likewise increase the quantity of organic carbon in the soil (Sanchez, 2016). In a three year study carried out in the Ajuno basin in mexico, Roldán et al. (2003) did not find significant difference in total organic carbon by planting a legume cover crop in addition to maintaining a 33 % residue cover, supporting the notion that better soil quality is best achieved through the adoption of several conservation management practices.

2.5.2 Physical

2.5.2.1 Soil moisture

Soil moisture conservation is one of the cardinal principles of soil management in rainfed areas with considerable potential for increased productivity (Sebetha, 2015). According to Gunes et al. (2007), lack of moisture in soils could be a significant limiting factor for agricultural productivity, because it inhibits plant growth through reduced water absorption and nutrient uptake. While water stress at all times of the growing season may be detrimental to yields, crops have different responses to water deficit according to their developmental stages (Cakir, 2004). In living mulch systems using maize, this period would be roughly from 2 weeks before tasselling to 2-3 weeks after silking (Muchow, 1989; Sebetha, 2015). During this stage, there is rapid growth (leaves and stem elongation), requiring adequate supplies of water to sustain rapid organ development. Therefore, it is important to maintain soil moisture, especially at this growth stage.

Various studies on living mulch systems, have reported a reduced evapotranspiration from the mulch layer compared to evaporation of water from a bare field (Greyson, 1998), but this according to him, will depend on many factors, including: rooting depths of competing species, the leaf area index (LAI) of the mulch and the main crop, the difference in albedos of the mulch-covered ground and bare soil and levels of soil organic matter. In a study evaluating the use of water by different mulch species, Nicholson & Wien (1983) reported that, grasses used less water than legumes.

Living mulch systems conserves and use water more efficiently than mono-cropping cereal systems (Morris & Garrity, 1993). This is achieve through a two-fold service; 1. extensive canopy cover, which shades soil surfaces form radiation making it less exposed than bare soils (Hsiao & Xu, 2005), 2. Minimizing raindrop impact on soil surface, thereby enchancing water infiltration into the soil. Living mulch systems improves yield of companion crops by conserving soil moisture (Nedunchezhiyan et al., 2012) and can therefore be a sustainable option for smallholders in adapting to dryland cropping conditions (Walker & Ogindo, 2003).

2.5.2.2 Soil temperature

Soil temperature can affect the absorption of water and nutrient by plant root, soil biological activity, the decomposition of soil organic matter as well as soil nutrient availability (Bot & Benites, 2005; Kirschbaum, 1995). For most crops, optimum soil temperature ranges for successful seed emergence and plant growth is very narrow (Pregitzer & King, 2005). To maintain such optimal temperature ranges for crops, cropping systems that aimed at optimizing soil temperatures should be pursued.

Soil temperatures can be significantly influenced by cropping systems (Nyobe, 1998; Odjugo, 2008), difference in energy as a result of incoming and surface emitted solar radiation (Verhulst et al., 2010) and soil physical properties such as bulk density and moisture content (Dalmago et al., 2004; Flerchinger, 2002; Licht & Al-kaisi, 2005). Most of these factors are in tend influenced by mulching practices.

Mulching aids in control of diurnal temperature fluctuations (Dilipkumar et al., 1990). However, the effect of mulching on soil temperature depends on the type of mulch (Bhardwaj, 2013). Heat storage in the mulch layer is small, but the available energy at a mulch site will be affected by the heat storage in the mulch layer (Li et al., 2016). Therefore, the insulation effect of dead mulches on the surface may not be the same as living mulches due to differences in albedos. Kolota & Adamczewska-Sowińska (2013), observed that living mulches help to maintain the soil temperature more uniform by preventing it from excessive heating at intensive insulation and by reducing the rate of cooling during cooler periods. Ghanbari et al. (2010), also observed a decreased soil temperature in plots with cowpea acting as a cover in maize to those with sole maize stands. The researcher explains this as a result of extensive soil coverage of the two crops, which also minimized water evaporation from the soil surface.

2.5.2.3 Soil Structure and Aggregate

Each soil particles, be it clay, silt or sand, normally do not remain as individual particles in soils but they are bond together by a range of mechanisms to form soil structural units or aggregates (Murphy, 2014). Such range of mechanisms may include, the balance between compaction (by machine traffic and soil weight), agglomeration of aggregates (by climate and/or fauna), fragmentation (by climate, fauna and/or tillage) and displacement (by tillage) of soil (Roger-estrade et al, 2000). According to Foy (2003), biological processes and tillage accounts for most structural development. Soil aggregation provides pore spaces of different sizes providing water, gases and nutrients to plant roots and microorganisms (larger pores), and facilitating moisture retention and availability (smaller pores) (Adams, 2011).

Soil structure is important for plant productivity as the structure can influence soil strength and mechanical resistance to emergence and root growth, aeration, surface crusting, erosion, infiltration, water holding capacity and bulk density (Murphy, 2014). Increasing soil organic matter by planting living mulches promotes biological activity in the soil increasing aggregate stability. Living mulches serving as cover crops enhance pore structure and stability in the soil through increases in root biomass (Bronick & Lal, 2005; Nascente et al., 2013). Blanco-canqui et al., (2015), found water-stable aggregates to be 1.2 – 2 times more stable under cover crops than the control with the responsiveness of soil aggregation occurring within 30 years after cover crop introduction. Kong et al., (2005) observed an enhanced soil aggregate, when legumes was introduced into a cropping system. A strong correlation between crop yield and cover crop effect on soil physical and chemical properties was also observed by (Nicolau et al., 1996).

One aspect of living mulches, that is often ignored, is that it contributes root-deposited photosynthate, which is an important carbon source for microorganisms, especially earthworms and Arbuscular Mycorrhizae Fungi (AMF) to maintain soil structure, aggregate stability and overall restoration of degraded soil (Butler et al., 2003; Fonte et al., 2010). Earthworms through their feeding, burrowing and excretion activities, have been reported to play an important role in the formation of soil pores and stable macroaggregates (Fonte et al., 2009; Scullion & Malik, 2000). Additionally, Arbuscular Mycorrhizae Fungi (AMF) forms a symbiotic relationship with plant roots and consolidate such particles in aggregates through hyphal networks and through the production of glomalin, binding soil particles together (Adams, 2011).

2.5.2.4 Soil Bulk Density

Bulk density is often cited as an indicator of the amount of pore space available within individual soil layers or horizons. The specific bulk density that will adversely affect plant root growth and development depends on many factors including the parent material, soil texture, the crop being grown and management history (Logsdon & Karlen, 2004). A high bulk density above 1.5 indicate either high sand content or compaction (Adekiya et al., 2009; Adekiya & Ojeniyi, 2002). Compaction minimizes pore space and deforms soil structure resulting in limited percolation and increasing the potential for water runoff and subsequently soil erosion. To ameliorate effects of soil compaction, plant roots serving as "tillage tools" have been proposed (Chen & Weil, 2010). The growth and decomposition of roots leaves pores and root channels that could be later used as low resistance pathways for succeeding crop roots, in a process dubbed "biodrilling" (Lynch & Wojciechowski, 2015). This assertion was confirmed by Williams & Weil (2004), when they reported that soybean roots were able to grow through a compacted plowplan soil using channels made by decomposing canola cover crop roots.

Living mulches have been reported to also alleviate compacted soils (Dexter, 2004), providing a more uniform rupture of compacted layers than the common mechanical methods offering both economic and environmental benefits over subsoiling (Ritchey et al., 2012). With less compaction, living mulches providing soil cover, promote root growth, nutrient cycling and soil structure development leading to increase crop yield. Liedgens et al. (2004), observed 40 percent less deep percolation and 99 percent less leached nitrate beneath corn inter-planted with ryegrass as living mulch. Annual crops serving as mulch has been reported to be the most effective in disrupting compacted layer favouring the subsequent growth of soybean roots through the compacted layer (Rosolem & Da Silva, 2002). Under 15 years of cover crop management on a silt loam soil, a negative correlation was observed between increased crop yield and decreased soil bulk density (Blanco-canqui et al., 2012). Plots without cover crops had higher bulk densities and lower yields, suggesting cover crops decrease soil vulnerability to compaction (Blanco-canqui et al., 2012).

2.5.3 Biological

2.5.3.1 Biological nitrogen fixation (BNF)

Biological nitrogen fixation is a biochemical process by which the inert dinitrogen (N_2) gas of the atmosphere is converted to ammonia (NH_3) in the presence of a biological catalyst, nitrogenase (Brady & Weil, 2008). Nitrogenase is commonly produced by certain prokaryotic species referred to as diazotophs (Ronner & Franke, 2012). The common diazotoph include several species of symbiotic rhizobium, actinomycetes, cyanobacterium and free living prokaryotes such as Azospirillum, Herbaspirillum and Azotobacter (Santi et al., 2013). According to Berrada & Fikri-benbrahim (2014), the term rhizobium is retained historically but it represents a number of microbial groups, with current information indicating more than ten (10) genera that include: Allorhizobium, Azorhizobium, Bradyrhizobium, Burkholderia, Mesorhizobium, Methylobacterium, Microvirga, Ochrobacterium, Phyllobacterium, Rhizobium, Sinorhizobium (Ensifer) and Shinella.

Biological nitrogen fixation by legumes is a major component in low input cropping technologies such as crop-legume living mulch system, as it potentially enhances nitrogen addition to the system (Thobatsi, 2009). The movement of the fixed N could be direct; that is, from the legume to the component crop during the same growing season or indirect N transfer; that is, from the legume to the succeeding crop (Stern, 1993). When the live mulch used is an annual specie, direct transfer of N from legume to non-legume might not be a rapid or spontaneous phenomenon (Peoples et al., 1995).

In living mulch system, biological nitrogen fixation by the associated crop (when it is a legume) is another benefit that has been reported in several studies (Costello, 1994; Ditsch et al. 1993). Frye et al. (1988), observed an increase availability of nitrogen to companion crops when hairy vetch was used as a living mulch. Seo et al. (2000) observed that hairy vetch serving as a live mulch can contribute approximately 50 – 150 kg N ha^{-1} to either companion or succeeding crop. Velvet bean (*Mucuna pruriens*) was also reported, as contributing 50 to 200 kg N ha^{-1} from biological fixation in west Africa (Carsky et al., 2001). Although cover crops have shown the capacity to recover N in soils, others tends to immobilize it (Mpheshea, 2014). Clark et al. (2007), stated that a ryegrass cover crop will need approximately additional fertilizer of 10 – 50 kg

N ha^{-1} for establishment. However, because the recovery and immobilization of N by living mulches and/or cover crop species are not always direct and obvious, considerable effort has been put into the development of methods for measuring N_2-fixation (Bergersen et al., 1989; Boddey et al., 1995)

2.5.4 Knowledge gap

The review indicates that living mulch exerts a controlling influence on soil properties (physical, chemical and biological). However, little is known about the controlling effect of cowpea when use as a live mulch with different maize maturity types, on physical, chemical and biological soil properties.

2.6 Effect of living mulch on growth of maize

Interseeded live mulch play an important role in main crop growth as it exerts a controlling influence on the micro-climate. Liedgens et al. (2004), reported a reduced growth of maize, because of its inability to establish a competitive rooting system when interseeded with a living mulch. Similarly, Weston (1996) observed a decreased in sweet corn height as a result of competition for water and nutrients with its living mulch component. According to Magani & Kuchinda (2009), this maize – living mulch competition, starts from the time the corn has developed about ten (10) leaves. Jędrszczyk & Poniedziałek (2007) also reported that mulched corn height were 13 – 31 cm lower than those of the control and concluded that, when interseeded with a live mulch, corn height significantly depends on its live mulch component. Norman et al. (2002), stated that the magnitude of living mulch effect on corn height depends on the mulch specie. Conversely, he observed sweet corn height to be increased by grass mulch species.

In another study to evaluate mulching practices on crop growth, live mulching significantly influenced all growth parameters (plant height, leaf area index and crop growth rate) than no mulch treatments (Das et al., 2018; Liedgens et al., 2004). Leaf area index, beside plant height, is another important growth variable characterizing the development of a crop (Andrieu et al., 1997). Several authors have reported on the significant influence of living mulch on maize leaf area index (Faget et al., 2012). In the presence of bean (*Phaseolus vulgaris* L.) live mulch interseeded at different times, the highest value of maize leaf area index was observed in treatments where bean was interseeded 21 days after maize sowing (Rezvani & Salehian, 2016). Similarly, interseeding times of soybean in maize, did not significantly affect leaf area and leaf area index of maize (Abdul-Rahman, 2010)

Tasselling and silking is another good indicator of the commencement of the reproductive growth stage of maize. Consequently, several studies have reported on the effect of living mulches on maize tasselling and silking (Hussein, 1997; Zemenchik et al., 2000). Maximum days to maize tasselling in live mulched plots was observed to be due to the interspecific competition between maize and living mulch (Gul et al., 2014). While delayed silking of maize interseeded with a live mulch was attributed to lower soil temperature under the denser cover of living mulch. According to Hussain et al. (2003), days to tasselling and silking increase with a living mulch in maize.

2.6.1 Knowledge gap

From the review, several studies have reported on the controlling effect of living mulches on maize growth. However, there is inadequate information on the effect of living mulch on growth performance of maize belonging to different maturity types. Therefore, there is the need to fill this knowledge gap.

2.7 Effect of living mulch on maize yield

In general, greater diversification of cropping systems have been demonstrated to be more productive than mono-cropping. Living mulches, that accompany a main crop during its growing season affects the micro-climate to lower weed infestation, eliminates pests amd improves main crop yield (Masiunas, 1998). However, living mulches can also compete with the main crop for nutrients and water, and this can lead to yield reduction (Echtenkamp & Moomaw, 1989). In most cases, a living mulch that is competitive enough to control weed growth will in addition, supress crop growth and yield (Mohammadi et al., 2012). In confirming this, Jeranyama et al. (1998) reported a grain yield reduction of 13 to 18% when corn was interseeded with legumes. Similarly, Martin et al. (1999) reported a 39 – 72 % corn yield reduction in plots with living mulch in relation to their control plots. As a result, several studies have focused on providing main crops with optimal growing conditions by the choice of interseeding time for living mulches (Kolota & Adamczewska-Sowińska, 2013), as well as the selection of proper main crop and living mulch species suitable as component crops (Jędrszczyk & Poniedziałek, 2007).

In evaluating the impact of three (3) living mulch species (white clover, Lucerne and ryegrass) on sweet corn yield, Jędrszczyk et al. (2005) reported a decreased yield by all the live mulches. In a similar study, white clover mulch was favourable for eggplant yield, while conversely in the case of perennial ryegrass mulch. Zemenchik et al. (2000) indicated no yield reduction when corn was planted into an established kura clover mulch. Conversely, Brainard & Bellinder (2004), reported a substantial reduction of corn yield when interseeded with legume, 5 weeks before corn planting. In another study, Nordquist & Wicks (1974) found grain yield reduction of 3% when corn was interseeded with alfalfa as a live mulch at the time of corn establishment.

2.7.1 Knowledge gap

From the review, information on the yield performance of different maize maturity types when interseeded with a cowpea live mulch proved to be scarce. Studies are therefore needed to fill this knowledge gap.

2.8 Effect of time of planting living mulch on growth and yield of maize

Living mulches can be established before, after or concurrently with the planting of the main crop (Hessler, 2013). Probably the main way that complementarity in such system can occur is when growing pattern of the component crops differ in time so that the crop make their major demand on resources at different times (Willey, 1979). Marandus (1977) also supported this accession by stating that, varying sowing time of component crops may be a way to improve yield advantage because it improves land productivity and minimizes competition for growth limiting factors. For example, no grain yield reduction was recorded when living mulch planting was delayed until the corn was 15 to 30 cm in height (Scott et al., 1987). Velvet bean planted as living mulch 20 days after corn reduced weed biomass by 68% with no negative impact on corn yield (Caamal-maldonado et al., 2014), suggesting that delaying seeding date is a possible way of increasing the competitiveness of the main crop in relation to the living mulch crop. In another study, cover plants sown 5 weeks before or at the time of planting caused a substantial reduction of sweet corn yield while no detrimental effect was observed when it was done 5 weeks after planting (Kolota & Adamczewska-Sowińska, 2013).

The period of time after emergence until the plant canopy is established with no yield penalty by weeds is term as the critical weed free period (Knezevic et al., 2002). The length of the critical weed free period is a function of crop and weed growth rates , and will be augmented if interseeding is delayed (Liebman & Staver, 2001). Therefore, the time for sowing the living mulch should take into account the dual objectives of suppressing weeds quickly and continuously while minimizing adverse interaction with the main crop (Hessler, 2013).

2.8.1 Knowledge gap

The inconsistency in the appropriate time for interseeding a living mulch with maize for enhanced growth and yield, highlights the need for further studies to ascertain the best and appropriate time for interseeding a live mulch with a main crop such as maize.

2.9 Effect of living mulch on weed control

Weeds are a serious constraint on yield and economic returns of crop production, particularly in spaced row crops. Irrespective of the important role herbicide plays on weed control, increasing weed resistance to herbicide, high cost and especially, negative effects on environment and human life have increased the need for non-chemical weed control in cropping systems (Augustin, 2003;Spliid et al., 2004). Acknowledging this Stephenson (2000), reported the use of about three million tonnes of herbicides per year in most agricultural systems. This has led to an increased interest in sustainable cropping systems over the past decade (Martens et al., 2001). In sustainable agriculture, an alternative method to chemical and mechanical weed control in crops is the use of living mulches (Mohammadi, 2012).

An important property, which ensures positive effect of living mulches on weed population reduction, is their rapid growth and quick canopy cover (Kolota & Adamczewska-Sowińska, 2013). Teasdale et al., (1991) showed that when a cover crop produced more than 300 gm^{-2} biomass and had greater than 90% ground cover, weed infestation was reduced by 78% compared to treatment without cover crop. In another study, 94 percent reduction in weed biomass by living mulch treatments was recorded compared to its no – mulch treatments (Enache & IInicki, 1990). Due to living mulches the decrease in weed species diversity can range between 50 – 90% (Kolota & Adamczewska-Sowińska, 2013). Moreover, if weed emergence occurs after living mulch establishment, then the presence of green vegetation influences the micro-climate (radiation) that is unfavourable for weed growth. Acknowledging this, Brainard & Bellinder (2004) observed a twelve fold reduction in weed biomass when a living mulch (oat) was sown earliest in cabbage cultivation. Contrary to the earlier results, where living mulches were successful at suppressing weeds when sown earliest, Brainard & Bellinder (2004) suggested that later sowings of living mulches may provide better weed suppression than when sown earliest. According to Araki & Tamura (2005), in general terms, living mulches often suppress weeds when compared with untreated control, especially if sown in early terms.

The potential of various living mulches to supress weeds has been recognized (Araki & Tamura, 2005; Brainard & Bellinder, 2004; Broughton, 2010; Hessler, 2013; Mohammadi, 2012; Teasdale & Daughtry, 1993), but in all weed suppression by living mulches is thought to be based on competition for light, water and nutrients, physical impediment of germination and alleopathic properties.

2.9.1 Mechanisms by which living mulches can control weeds

2.9.1.1 Light

In a living mulch system, weeds and the mixed crop stand compete primarily for light. According to Mohammadi (2012), two component of light affect the outcome of the competition: quantity and quality. The quantitative component of light (i.e. intensity and amount intercepted by a plant) determines crop-weed photosynthesis, whereas light quality is a driving variable of crop-weed morphology. Germination of weed seed may be prevented due to complete light interception by the living mulches. Kruidhof et al., (2008) reported a strong positive linear relationship between weed suppression and early light interception by the living mulch which is sustained by the strong negative linear relationship between cumulative light interception and weed biomass. Similarly, according to Steinmaus et al., (2008) weed suppression was attributed to solar radiation interception by the mulch cover for most weed species. This effects of living mulch are achieved as a result of a rapid occupation of the open space between the rows of the main crop or generally, the niches that would normally be filled by weeds (Teasdale, 1998). Caamal-Maldonado et al. (2001) also reported that extensive canopy cover by velvet bean acting as a living cover suppressed weed growth as a result of a reduced light incident on the soil. Since most living mulch systems are satisfactorily supported by water and nutrients, light has become the most important resource influencing competition between living mulches and weeds (Mohammadi, 2013).

2.9.1.2 Allelopathy

Allelopathy can be defined as the beneficial or harmful effect that is caused by one plant on another thus releasing chemicals (allelochemicals) from plant parts through leaching, root exudates, volatilisation, residue decomposition and processes in both natural and agricultural systems (Ferguson & Rathinasabapathi, 2003). They are mostly categorized into plant phenolics and terpenoids, which exhibit enormous chemical diversity and influences a number of metabolic and ecological processes (Sung et al., 2010). According to Westra (2010), these phenolic and terpenoids naturally produces secondary compounds which can mimic synthetic herbicide's wide range of selectivity in weed control. A crop which is allelopathic should exhibit the following features: (i) influence the growth, productivity and yield of other crops, (ii) potentially affect same crop grown in succession (autotoxicity), (iii) causes soil imbalance, in terms of nutrients, microbial population and health (iv) able to be manipulated to selectively suppress weeds (Batish et al., 2001).

The allelopathic potential of living mulches in weed suppression have been recognized by many authors (Batish et al., 2001; Borowy, 2012; Fujii, 1999; Teasdale & Daughtry, 1993). In many studies, best results were obtained from vetch species as living mulch for weed control because of their allelopathic features (Batool & Hamid, 2006; Kaneko et al., 2011; Moonen & Bàrberi, 2002). In evaluating the allelopathic potential of 280 soybean cultivars on weeds, Rose et al. (1984), found twenty soybean cultivars with the greatest weed suppression. Wójcik-Wojtkowiak et al. (1998), stressed the role of rye living mulch in weeds suppression as a result of their allelopathic compounds, inhibiting germination of weed species. Major living cover crops that has been reported to possessed allelopathic properties include: barley (*Hordeum vulgare*), corn (*Zea mays*), cucumber (*Cucumis sativus*), velvet bean (*Mucuna pruriens*), crimson clover (*Trifolium incarnatum*), hairy vetch (*Vicia vilosa*) and sweet potato (*Ipomea batatas*) (Batish et al., 2001; Putnam & Duke, 1974). Therefore, introducing a living mulch into a cropping system can take an advantage of allelopathic potential where mulch specie suppresses the weeds. Weed control mechanism as a result of allelopathy has been shown to be specie specific, therefore the control of a diverse weeds community may be possible by cultivating different crop species, each contributing specific allelochemicals towards specific weed species (Creamer et al., 1997).

2.9.2. Knowledge gap

Several authors have confirmed the positive effect of living mulches on weed management. There is, however, a prevailing gap in literature regarding the best and appropriate time for interseeding a leguminous living mulch such as cowpea, with maize of different maturity types for optimum weed management.

2.10 Summary of literature review

In the literature reviewed, information about maize and cowpea under origin, classification and botany has been investigated.

Living mulch and its characteristics, effect of living mulch on resource use efficiency, soil properties, maize growth and yield, effect of time of planting living mulch on growth and yield of maize and living mulch effect on weed control have been reviewed.

The literature reviewed, is aimed at assisting the researcher identify gaps in knowledge to create a direction for new research studies.

2.11 Knowledge gaps

From the literature reviewed the following knowledge gaps were identified:

i. The best and appropriate time for interseeding a cowpea living mulch with maize for improved resource use efficiency has been scarcely investigated.
ii. There is inadequate information on the effect of cowpea living mulch interseeded with maize maturity types, on soil properties.
iii. There is a scarcity of information on the effect of living mulch on growth performance of different maize maturity types.

iv. Data on yield performance of different maize maturity types with a cowpea live mulch proved to be scarce.

v. The best and appropriate time for interseeding a living mulch for enhanced maize growth and grain yield proved to be inconsistent.

vi. There is a prevailing gap, regarding the best and appropriate time for interseeding cowpea live mulch with different maize maturity types for optimum weed management.

CHAPTER THREE

3.0 Materials and methods

3.1 Description of the Experimental site

The trial was conducted under on-farm conditions in the Guinea Savanna agro-ecological zones of Ghana in three (3) communities during the 2017 cropping season. These were at Cheyohi No.2 (9° 44' N, 0° 99' W), Tibali (9° 66' N, 0° 84' W) and Tingoli (9° 22' N, 1° 00' W) (Figure 1).

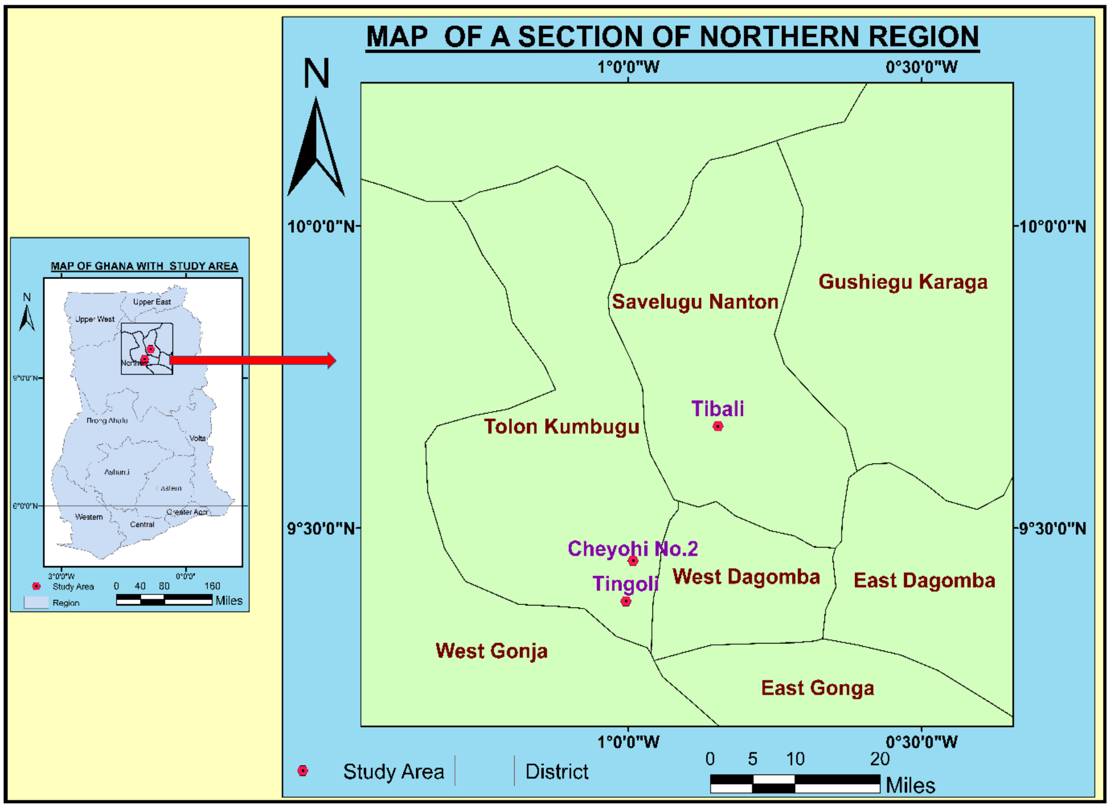

Figure 1. A map showing the location of study areas.

3.2 Climate

The three communities fall within the Guinea Savanna zone. The climate of this zone is warm, semi-arid tropical and has a mono-modal annual rainfall of 700 – 1100 mm, which increases gradually from March until a maximum is reached in

August/September. However, there is considerable variation between years in the time of onset, duration and amount of rainfall. This zone is also characterized by harmattan winds which starts from December to April.

The mean monthly temperature figures ranges from 25° C (December) to 38° C (April). Relative humidity during the wet season, ranges from 65 % - 85 % and as low as 10 % in the harmattan period (Abdulai, 2016).

3.3 Soil

The characteristics of soils in the study areas were described by Tetteh et al. (2016), as summarised below (Table 1).

Table 1. Chemical and physical analysis of soil in the study area.

Soil Parameters	Cheyohi No. 2		Tibali		Tingoli	
	0 – 15 cm	15 –30 cm	0 – 15 cm	15 –30 cm	0 – 15 cm	15 –30 cm
pH	5.6	5.7	6.1	6.2	5.9	6.5
[a] TN (g/kg)	0.9	0.5	0.9	0.6	0.5	0.4
[b] OM(g/kg)	12.4	11.9	16.6	12.9	9.5	8.1
[c] P (mg/kg)	9.2	7.2	6.7	2.39	7.81	5.9
Sand (%)	49.9	42.2	44.5	41.7	64.3	61.3
Silt (%)	41.1	47.8	44.5	44.3	29.5	30.7
Clay (%)	9	10	11	14	6.2	8.1
Texture	Loam	Loam	Loam	Loam	S. loam	S. loam

[a] TN = total nitrogen, [b] OM = organic matter, [c] P = available phosphorus

3.4 Experimental design

The study was a 3 x 4 factorial experiment laid in a randomised complete block design with three replications. The three sites were used as replications, thus one replication per community. A factorial treatment combination consisting of four (4) cowpea living mulch interseeding time; No living mulch (NLM) (control), Cowpea living mulch planted same day with maize (SDWM), Cowpea living mulch planted 1 week after maize (1 WAPM) and Cowpea living mulch planted 2 weeks after maize (2 WAPM) and three (3) maize maturity types (Abontem (extra-early maturing), Omankwa (early maturing) and Obatanpa (medium maturing) were used as treatments (Table 2) . There were twelve (12) plots (treatments) in each replication, each plot measuring 4.5 x 5.0 m., with an alley of 1m between plots (treatments).

Table 2. Field trial treatments arising from the combination of cowpea living mulch interseeding time by maize maturity type.

Code	Treatments
T1	No living mulch + Abontem
T2	No living mulch + Omankwa
T3	No living mulch + Obatanpa
T4	Cowpea living mulch, same day + Abontem
T5	Cowpea living mulch, same day + Omankwa
T6	Cowpea living mulch, same day + Obatanpa
T7	Cowpea living mulch, 1 week after maize + Abontem
T8	Cowpea living mulch, 1 week after maize + Omankwa
T9	Cowpea living mulch, 1 week after maize + Obatanpa
T10	Cowpea living mulch, 2 weeks after maize + Abontem
T11	Cowpea living mulch, 2 weeks after maize + Omankwa
T12	Cowpea living mulch, 2 weeks after maize + Obatanpa

3.5 Agronomic practices

3.5.1 Planting

The fields which was previously cropped to maize were prepared for planting by disc-ploughing and harrowing. For the current study, maize was then planted on 27^{th}, 29^{th} and 30^{th} June 2017 for Tibali, Tingoli and Cheyohi no.2 respectively. Accordingly, cowpea was interseeded with maize at these sites, on the same day, one (1) week after planting maize and two (2) weeks after planting maize. The maize was planted at a spacing of 75 x 40 cm and interseeded with cowpea at rows between the maize plants to make a ratio of 1:1 row arrangement. The maize was planted at 3 seeds/hill and thinned to 2 seeds/hill 10 days after planting while the cowpea was planted at 2 seeds/hill. The cowpea was planted at 20 cm intra-row spacing between the rows of the maize plants.

3.5.2 Fertilizer application

A compound fertilizer, NPK (15-15-15) was applied at 30 kg N/ha, 30 kg P_2O_5 and 30 kg K_2Oha^{-1} as a basal application to all maize plants 7 – 10 days after planting (DAP) and top dressed at 20 DAP with sulphate of ammonium at 30 kg Nha^{-1}.

3.5.3 Weeding

Weed was controlled manually by hoeing at 3 weeks after planting maize (WAPM) in all treatment plots and only in the no living mulch plants at 6 WAPM to controlled weeds build up to critical levels of infestation (Akobundu, 1987).

3.5.4 Pest control

From 4 WAPM, the field was sprayed at two (2) weeks interval to prevent incidences of pest especially fall armyworm (*Spodoptera frugiperda*). As required, such control measures were taken to prevent the infestation from reaching the economic threshold. At flower bud initiation and podding, cowpea was sprayed with sunhalothrin (contains 25 g lamda-cyhalothrin per litre), at the rate of 200 – 800 mls per hectare with water volume of 400 – 1000 litres.

3.6 Data collection

3.6.1 Weather

The WatchDog Weather Station (2000) was installed in each community to measure the following weather parameters: precipitation (mm) and temperature (°C) monthly during the 2017 cropping season.

3.6.2 Soil properties

3.6.2.1 Soil temperature

The temperature of the soil was measured with a HI 98501 Checktemp metre (Hanna Instrument Inc., USA) at the vegetative stage, tasselling stage and at harvest of the maize. Between 1 and 2 p.m. at each data collection stage day, the Checktemp metre probe was randomly immersed in the soil, three times in the middle of each plot along the diagonals. Temperature values were then recorded in degrees Celsius (°C) and the average calculated for each plot.

3.6.2.2 Bulk density

The metal core sampler method, as described by Blake & Hartge (1986) was used to determined soil bulk density, only at vegetative, tasselling and harvest growth stage. A core sampler of known volume of 98 cm^3 was pressed into a smooth "undisturbed" soil surface, three times in the middle of each plot along the diagonals at a depth of 0 - 5 cm. The sampler was carefully removed by excavating around it, so as to keep the soil within the sampler intact. Soils at both ends of the core sampler were trimmed, flushed with a straight-edged knife and emptied into a labelled plastic bag. Soil samples were oven dried at 105 °C to a constant weight. The weight of the dry soil sample were measured and recorded. The bulk densities of the samples were calculated by dividing the oven dry weight of each sample with the volume of the core sampler 98 cm^3.

Calculation:

Bulk density (gcm^{-3}) = $\frac{W}{V}$ ………………………………………………………….. (1)

Where:

W = Oven dry weight of soil samples

V = Volume of core sampler ($\pi r^2 h$), where:

$\pi = 3.142$

r = radius of core cylinder

h = height of the core cylinder

3.6.2.3 Soil porosity

Soil porosity at vegetative, tasselling and harvest growth stages were deduced from the values of bulk density at vegetative, tasselling and harvest growth stages respectively and particle size density of soil using the equation given by Chancellor et al. (1994).

$f = \left(1 - \frac{Pb}{Ps}\right) \times 100$ …………………………………………………………………… (2)

Where: f = soil porosity

P_b = soil bulk density

P_s = particle size density, with a value of 2.65 gcm^{-3}

3.6.2.4 Volumetric moisture content

Soil moisture content was determined on volume basis using the following equations suggested by Gardner (1986). The fresh and dry weights of soil samples used for the above bulk density calculations (3.6.2.2), were used in calculating the gravimetric moisture contents of samples,

$$\text{Gravimetric moisture content} = \frac{\text{Fresh soil weight - Dry soil weight}}{\text{Dry soil weight}} \dots\dots\dots\dots (3)$$

The volumetric moisture content of the samples were deduced from the values of gravimetric moisture content, bulk density and soil particle density, using the following:

$$\theta_v\ (cm^3/cm^3) = \frac{\theta_m}{P_s} \times P_b \dots\dots\dots\dots (4)$$

θ_v = Volumetric moisture content

θ_m = Gravimetric moisture content

P_s = Particle density, assumed as 2.65 gcm^{-3}

P_b = Soil bulk density

3.6.3 Growth parameters

3.6.3.1 Plant height

Five plants of maize from the two central rows of each plot, were randomly selected and tagged for height measurement. The measurement was taken at 3 WAPM, 6 WAPM, 9 WAPM and 12 WAPM. The average height of the five plants were then calculated for each plot.

3.6.3.2 Leaf area index

Data on leaf parameters including number of leaves/plant and leaf area were determined biweekly, starting from 4WAP to 8WAP, using the method suggested by Dugje (1992). Three randomly selected and tagged plants (maize and cowpea) in each plot had their three (3) fully expanded green leaves measured and removed across leaf positions (upper, middle and lower) for leaf area and leaf area constant determination. The outline of each leaf was traced on a graph to determine the actual leaf area (cm^2). The length and maximum width of each leaf outline on the graph were measured with a tape measure to obtain the estimated leaf area (cm^2). The leaf area constant for each leaf sample was then estimated by dividing the actual leaf area by the estimated leaf area. These were averaged over the number of leaf samples per plant. The single leaf area was then calculated using the formulae:

Single leaf area (cm^2) = L x W x K…………………………………………………...(5)

Where L = Leaf length (cm), W = Maximum leaf width (cm), K = Leaf area constant

From this the leaf area index was estimated using the formulae suggested by (Dugje, 1992):

LAI = (P x L x A)/ (GA)

Where LAI = Leaf area index, P = Plant population/ground area (ha), L = Number of fully expanded green leave/plant, A = Single leaf area (cm^2), GA = Ground area or hectare

According to Welles (1990), since leaf area index is defined as the relative area of crop foliage per unit area of ground, and since leaf area was measured in square centimetres (cm^2), hence;

$$LAI = (P \times L \times A)/ (10^7) \quad \ldots \quad (6)$$

3.6.3.3 Days to 50% tasselling and silking

Each plot was carefully monitored as to the number of days to which 50% of the plants (maize) in the two central rows tasselled and silked. The respective number of days to 50% tasselling/silking for each plot was then recorded.

3.6.4 Yield and yield components

3.6.4.1 Grain yield

The grain yield of maize was determined from the two central rows within a net plot area of (7.5 m^2). The cobs of the maize plants were harvested at physiological maturity, dehusked, oven dried at 65 °C to a moisture content of 13% before shelling to measure the grain weight. It was then expressed as kg/ha.

3.6.4.2 Stover weight

After harvesting the cobs from the plants in the harvest area, the plants were cut at ground level and oven dried at a temperature of 65 °C to a constant weight before measuring stover yield. It was then converted to $kgha^{-1}$.

3.6.4.3 Harvest index

The harvest index was determined as a ratio of grain yield ($kgha^{-1}$) and the total above ground biomass at maturity ($kgha^{-1}$).

3.6.4.4 Weed biomass

The weed biomass was measured with a 1 m^2 quadrat at 6 WAPM, 9 WAPM and at harvest. The quadrat was used to capture weeds by randomly placing it three times in the middle of each plot along the diagonals. The weeds were then cut at ground level, captured into envelope and oven dried at 70 °C to a constant weight to measure weed biomass.

3.6.4.5 Weed diversity

A 1 m^2 quadrat was used to determine weed species diversity. The quadrat was randomly placed three times in the middle of each plot along the diagonals. The weeds in each quadrat were identified and scored using a scale of 0 – 4 where 0 = no occurrence, 1 = 1 – 2, 2 = 2 – 5, 3 = 6 – 20 and 4 = > 20 plants of the weed species. The average weed occurrence in each treatment plot was calculated using the Summed Dominance Ratio (SDR) approach by Dangol (1991).

$$SDR\% = \frac{1}{2}\left[\left(\frac{F}{\sum F}\right) + \left(\frac{D}{\sum D}\right)\right] \text{ X } 100 \quad \ldots\ldots (7),$$

where F = frequency of occurrence of a weed species within a treatment plot and D = density of occurrence within a treatment plot.

3.7 Water productivity/use efficiency

Water use efficiency (WUE, kg mm^{-1}) was calculated after maize grain harvesting according to the formula used by (GRDC, 2009).

$$WUE\ (kg\ m^{-1}) = \frac{Y_{Grain}\left(kg\ ha^{-1}\right)}{TR\ (mm)} \quad \ldots\ldots (8)$$

Where Y_{Grain} is the grain yield of each treatment, and TR is the total rainfall recorded from the location of the weather stations at the time of harvest.

3.8 Statistical analysis

Data collected was subjected to the General Analysis of Variance (ANOVA) procedure of the statistix 10 analytical package (2013) for windows. The soil, growth, yield and yield component data were analysed using factorial treatment combination of cowpea living mulch interseeding time and maize maturity type in RCBD to determine whether there was significant difference among treatment. Least significant difference (LSD) was used to separate treatment means at 5% probability level.

Correlation analysis was performed to determine relationship among soil physical properties, growth, yield and yield components. Parameters with correlation values of 0.60 and above were considered to be best fitted and less than 0.60 considered non-best fit. Linear regression was used to establish predictive equations among correlated variables.

CHAPTER FOUR

4.0 RESULTS

4.1 Weather data

4.1.1 Rainfall and temperature variability in the study area

Figure (1) depicts the monthly variability in the pattern of rainfall and temperature in three locations within the study area, mainly; Cheyohi, Tibali and Tingoli during the period June – October 2017.

At Cheyohi No. 2, total rainfall and mean temperature recorded during the cropping season was 667.7 mm and 27.0 °C respectively. The month of August recorded the highest total monthly rainfall as well as the lowest mean monthly temperature whilst October received the lowest total rainfall and the highest mean temperature values (Fig. 2a).

At Tibali, total rainfall and mean temperature recorded during the cropping season was 686.7 mm and 26.9 °C respectively. Peak monthly rainfall amount and lowest mean monthly temperature value was recorded by the month of August whilst the lowest total rainfall and highest mean temperature value was recorded in the month of October (Fig. 2b).

At Tingoli, total rainfall and mean temperature recorded during the cropping season was 694.6 mm and 26.7 °C respectively. The month of July recorded the highest total rainfall, a deviation from the month of August recorded by both Cheyohi No. 2 and Tibali. However, a similar trend of temperature fluctuation was observed, with the month of August and October recording the lowest and highest mean temperature values respectively (Fig. 2c).

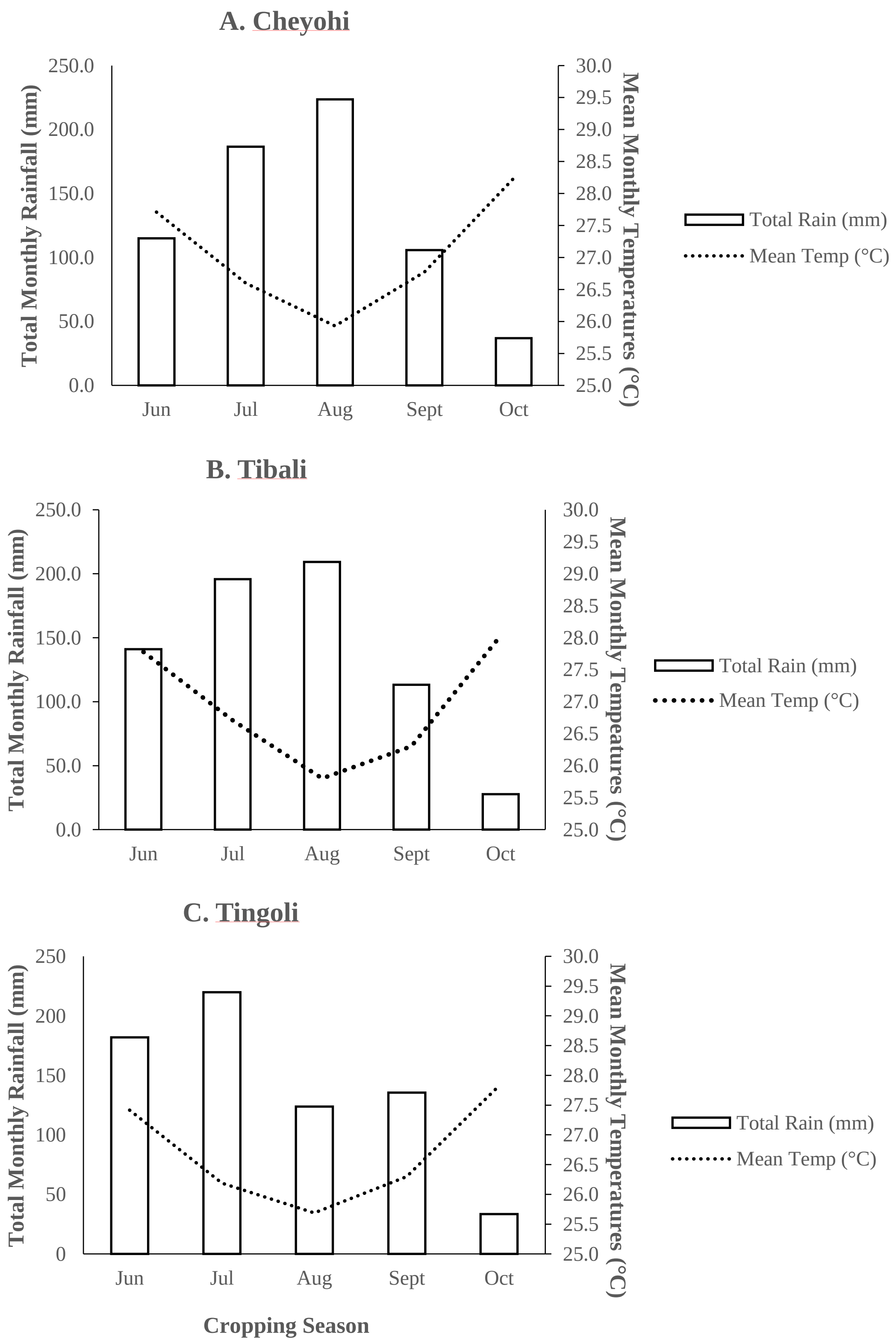

Figure 2. Rainfall and temperature variability at study sites (A. Cheyohi, B. Tibali and C. Tingoli) during 2017 cropping season.

4.2 Soil Physical Properties

4.2.1 Soil temperature

The interaction effect of cowpea living mulch interseeding time x maize maturity type did not significantly affect soil temperature at all growth stages (vegetative, tasselling and harvest), likewise maize maturity type effect (Appendix 1 - 3). However, living mulch interseeding time effect influenced ($p = 0.0001$, $p = 0.0002$ and $p = 0.0076$) soil temperature at the vegetative stage, tasselling stage and at harvest respectively, such that interseeding cowpea with maize on the same day (SDWM) gave the lowest soil temperature which was similar to cowpea interseeded 1 WAPM (Fig. 3).

4.2.2 Soil Bulk Density

The interaction effect of cowpea living mulch interseeding time x maize maturity type did not significantly affect soil bulk density at all growth stages, likewise maize maturity type effect. However, soil bulk density was significantly influenced by living mulch interseeding time at tasselling and harvest (Appendix 4 - 6).

At the tasselling stage, NLM recorded the highest bulk density, however it was statistically not different from bulk densities recorded by cowpea interseeded SDWM, 1 WAPM and 2 WAPM. At harvest, cowpea interseeded at 2 WAPM recorded the highest bulk density value which was significantly different from cowpea interseeded SDWM and NLM (Table 3).

4.2.3 Soil Porosity

Soil porosity at all growth stages was not significantly enhanced by the interaction effect of cowpea living mulch interseeding time x maize maturity type as well as the effect of maize maturity type (Appendix 7 - 9); however, at the tasselling stage, the effect of living mulch interseeding time influenced ($p=0.0449$) soil porosity. Cowpea interseeded SDWM, gave the highest porosity value of 0.58 which was significantly different from the lowest porosity value of 0.53 recorded in NLM (Table 4).

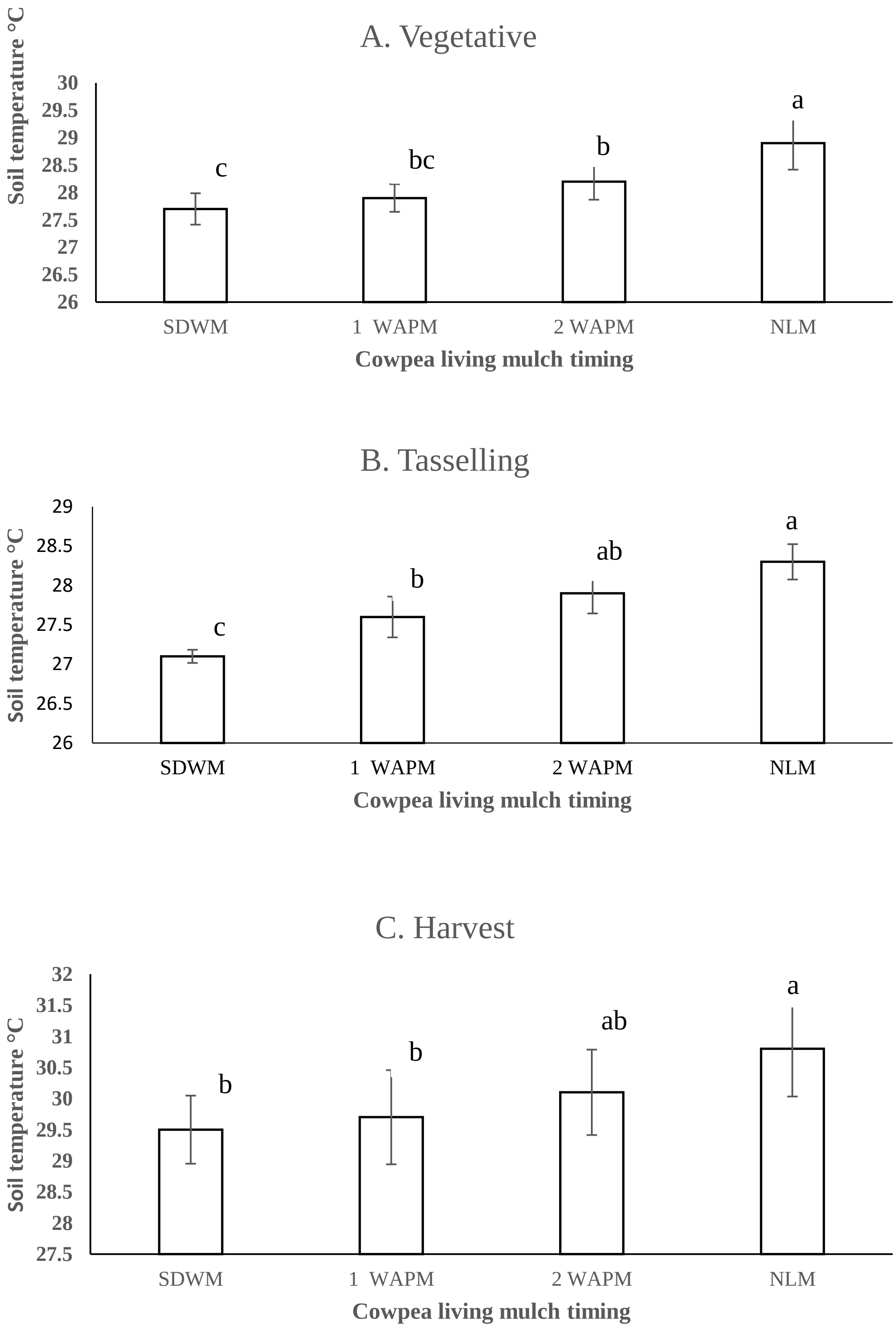

Figure 3. Effect of living mulch interseeding time on soil temperature at A. vegetative, B. tasselling and C. harvest. Bars represent S.E.M.

Table 3. Soil bulk density as affected by cowpea living mulch interseeding time

	Soil Bulk Density (g/cm^3)		
	Vegetative	**Tasselling**	**At Harvest**
Living mulch interseeding time (LMT)			
No living mulch (NLM)	1.25^{a}	1.24^{a}	1.17^{b}
Cowpea mulch same day with maize (SDWM)	1.29^{a}	1.12^{b}	1.19^{b}
Cowpea mulch 1 week after maize (1 WAPM)	1.29^{a}	1.18^{ab}	1.25^{a}
Cowpea mulch 2 weeks after maize (2 WAPM)	1.28^{a}	1.18^{ab}	1.26^{a}
LSD (0.05)	0.06	0.08	0.07
P-Value	**ns**	*	*

* $P < 0.05$, ^{ns} $P > 0.05$. Mean values followed by the same letters in each column are not significantly different from one another.

Table 4. Soil porosity as affected by cowpea living mulch interseeding time

	Soil Porosity		
	Vegetative Stage	**Tasselling Stage**	**At Harvest**
Living mulch interseeding time (LMT)			
No living mulch (NLM)	0.53^{a}	0.53^{b}	0.55^{a}
Cowpea mulch same day with maize (SDWM)	0.51^{a}	0.58^{a}	0.54^{ab}
Cowpea mulch 1 week after maize (1 WAPM)	0.51^{a}	0.56^{ab}	0.52^{b}
Cowpea mulch 2 weeks after maize (2 WAPM)	0.52^{a}	0.56^{ab}	0.52^{b}
LSD (0.05)	0.02	0.03	0.03
P-Value	**ns**	*	**ns**

* $P < 0.05$, ^{ns} $P > 0.05$. Mean values followed by the same letters in each column are not significantly different from one another.

4.2.4 Volumetric Moisture Content

The interaction effect of cowpea living mulch interseeding time x maize maturity type did not significantly contribute to the volumetric moisture content during the various growth stages likewise the main effect of maize maturity type (Appendix 10 – 12). However, the main effect of living mulch interseeding time significantly determined volumetric moisture content at tasselling stage and at harvest. Cowpea interseeded SDWM gave the highest moisture content but was not significantly different from both cowpea interseeded at 1 WAPM and 2 WAPM. NLM gave the lowest moisture content which was significantly different from all the other living mulch systems (Table 5).

Table 5. Volumetric moisture content as affected by cowpea living mulch interseeding time

	Volumetric Moisture Content (cm^3/cm^3)		
	Vegetative Stage	**Tasselling Stage**	**At Harvest**
Living mulch interseeding time (LMT)			
No living mulch (NLM)	0.09^{a}	0.06^{b}	0.06^{b}
Cowpea mulch same day with maize (SDWM)	0.10^{a}	0.10^{a}	0.09^{a}
Cowpea mulch 1 week after maize (1 WAPM)	0.10^{a}	0.09^{a}	0.08^{a}
Cowpea mulch 2 weeks after maize (2 WAPM)	0.10^{a}	0.10^{a}	0.07^{ab}
LSD (0.05)	0.01	0.02	0.01
P-Value	**ns**	**	*

** $P < 0.01$, * $P < 0.05$, ^{ns} $P > 0.05$. Mean values followed by the same letters in each column are not significantly different from one another.

4.3 Growth parameters

4.3.1 Plant height of maize

Appendix (13 - 16), shows the effect of cowpea living mulch interseeding time, maize maturity type and its interactions on maize plant height.

At 3 WAPM, plant height was significantly affected by maize maturity type, such that medium maturing maize type (Obatanpa) had higher plant height which was statistically similar to extra-early maturing maize type (Abontem) but statistically different from early maturing maize type (Omankwa) (Table 6).

At 6 WAPM, plant height was significantly influenced by cowpea living mulch interseeding time as well as maize maturity type. For maize maturity type levels, early maturing type (Omankwa) had the highest plant height whiles no living mulch gave the highest plant height among cowpea living mulch interseeding times (Table 6).

At 9 WAPM. Cowpea living mulch interseeding time, maize maturity type and its interaction had no significant effect on maize plant height. However, for all levels of cowpea living mulch interseeding time, cowpea interseeded SDWM promoted the highest plant height whilst early maturing maize type (Omankwa) gave the highest plant height for all levels of maize maturity type (Table 6).

At 12 WAPM, cowpea living mulch interseeding time and maize maturity type interaction had significant effect on plant height. Medium maturing maize type (Obatanpa) had higher plant height ($p < 0.05$) at all level of cowpea living mulch interseeding time compared with the other maturity types at all levels of cowpea living mulch interseeding time (Fig. 4).

Table 6. Maize plant height as affected by cowpea living mulch interseeding time and maize maturity type

	Maize Plant Height (cm)		
	3 WAPM	**6 WAPM**	**9 WAPM**
Living mulch interseeding time (LMT)			
No living mulch (NLM)	21.40^{b}	89.66^{a}	150.43^{ab}
Cowpea mulch same day with maize (SDWM)	24.85^{a}	88.72^{a}	154.40^{a}
Cowpea mulch 1 week after maize (1 WAPM)	24.81^{a}	71.65^{b}	141.04^{b}
Cowpea mulch 2 weeks after maize (2 WAPM)	24.32^{ab}	73.73^{b}	151.44^{ab}
LSD	3.36	8.30	12.86
P-Value	*	*	**ns**
Maize Maturity Type (MMT)			
Abontem (Extra-early)	25.05^{a}	83.35^{a}	150.28^{a}
Omankwa (Early)	20.81^{b}	85.24^{a}	144.68^{a}
Obatanpa (Medium)	25.67^{a}	74.23^{b}	153.02^{a}
LSD	2.91	7.19	11.14
P-Value	**ns**	**	**ns**
LM x MMT			
P-Value	**ns**	**ns**	**ns**

** $P < 0.01$, * $P < 0.05$, ^{ns} $P > 0.05$. Mean values followed by the same letters in each column are not significantly different from one another.

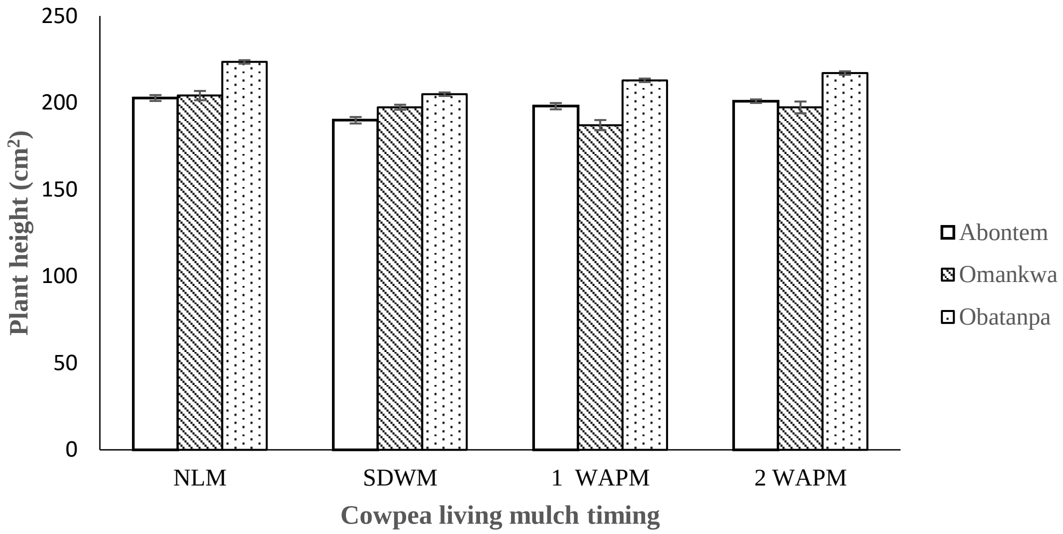

Figure 4. The interaction effect of living mulch interseeding time x maize maturity type on maize plant height (cm) at 12 WAPM. Bars represent S.E.M.

4.3.2 Leaf area index of maize

The effect of cowpea living mulch interseeding time, maize maturity type and its interaction on leaf area index of maize, are shown in Appendix (17 - 19).

At 6 WAPM, leaf area index was affected ($p < 0.05$) by cowpea living mulch interseeding time and maize maturity type interaction. Statistically, the highest leaf area index for maize maturity type levels was observed under the control – NLM (Fig. 5).

At 8 WAPM, leaf area index was significantly affected by maize maturity type (Appendix 18), such that early maturing maize type (Omankwa) had the highest leaf area index which was statistically different from the leaf area index of extra-early maturing maize type (Abontem) but statistically similar to the leaf area index obtained by medium maturing maize type (Obatanpa) (Table 7).

At 10 WAPM, leaf area index was significantly influenced by maize maturity type (Appendix 19), such that for all levels of maize maturity type, extra-early maturing maize type (Abontem) had the lowest leaf area index which statistically differed from the leaf area index obtained by early maturing maize type (Omankwa) and medium maturing maize type (Obatanpa) (Table 7).

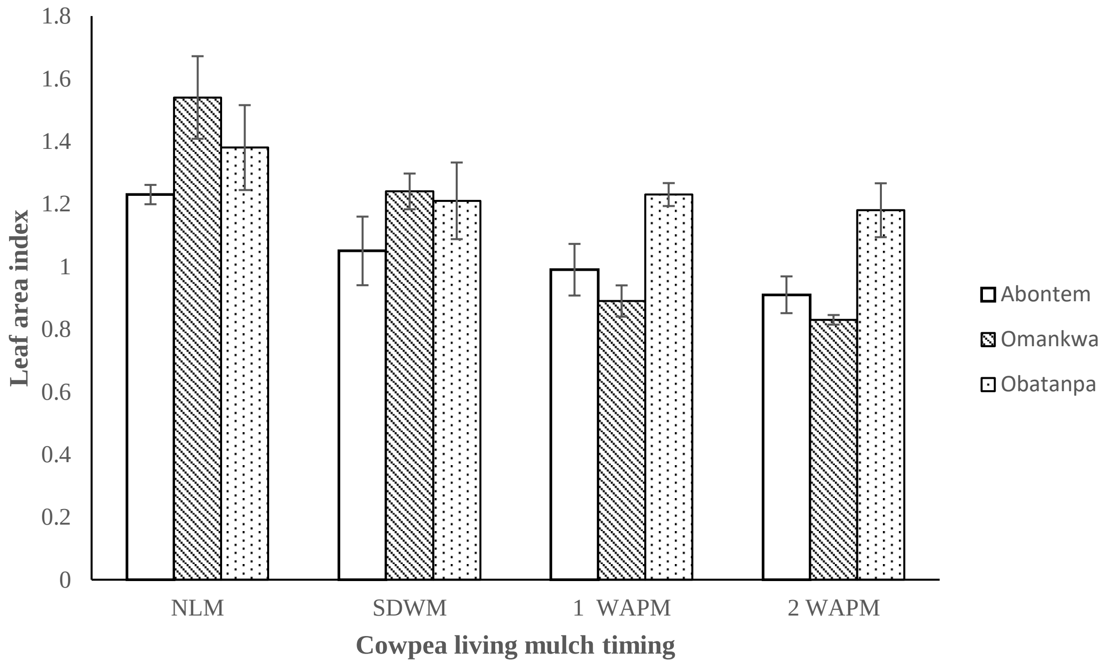

Figure 5. The interaction effect of cowpea living mulch interseeding time x maize maturity type on maize leaf area index at 6 WAPM. Bars represent S.E.M.

Table 7. Leaf area index of maize as affected by maize maturity type

	Leaf area index of maize	
	8 WAPM	**10 WAPM**
Maize Maturity type (MMT)		
Abontem (Extra-early)	2.0769^{b}	1.5971^{b}
Omankwa (Early)	2.4687^{a}	2.1080^{a}
Obatanpa (Medium)	2.0768^{ab}	2.3718^{a}
LSD (0.05)	0.3069	0.2988
P-Value	*	**

*** P < 0.01*, ** P < 0.05*. Mean values followed by the same letters in each column are not significantly different from one another.

4.3.3 Days to 50% tasselling of maize

Cowpea living mulch interseeding time, maize maturity type and its interaction had significant effect on days to 50% tasselling of maize (Appendix 20). Statistically, cowpea interseeded 2 WAPM promoted early tasselling for all levels of maize maturity type compared with the other cowpea living mulch interseeding times for all levels of maize maturity type (Fig. 6).

4.3.4 Days to 50% silking of maize

The interaction effect of cowpea living mulch interseeding time x maize maturity type as well as the effects of cowpea living mulch interseeding time were not significant on days to 50% silking. However, maize maturity type, had significant effect on days to 50% silking of maize (Appendix 21), with extra-early maize maturity type (Abontem) silking earlier among all levels of maize maturity type (Fig. 7).

4.3.5 Stover yield of maize

Cowpea living mulch interseeding time x maize maturity type interaction was not significant on maize stover yield likewise the effect of living mulch interseeding time ($p > 0.05$) (Appendix 23). However, maize maturity type had significant influence on the stover yield of maize. Medium maturing maize type (Obatanpa) had the highest stover yield which was statistically different from extra-early maturing maize type (Abontem) and early maturing maize type (Omankwa) (Fig. 8).

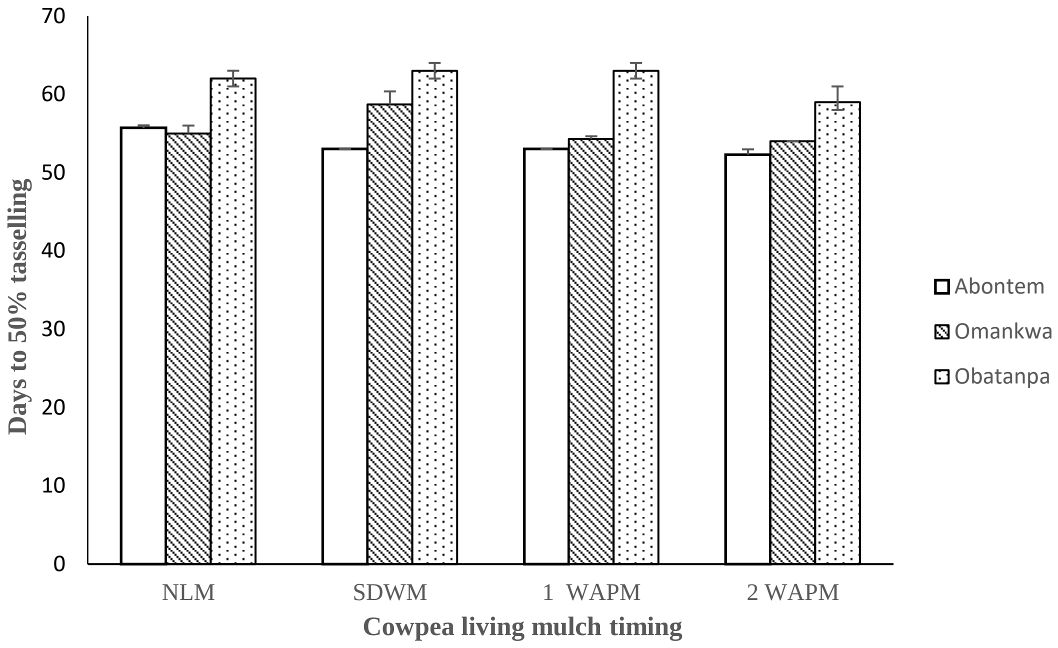

Figure 6. The interaction effect of cowpea living mulch interseeding time x maize maturity type on days to 50% tasselling of maize. Bars represent S.E.M.

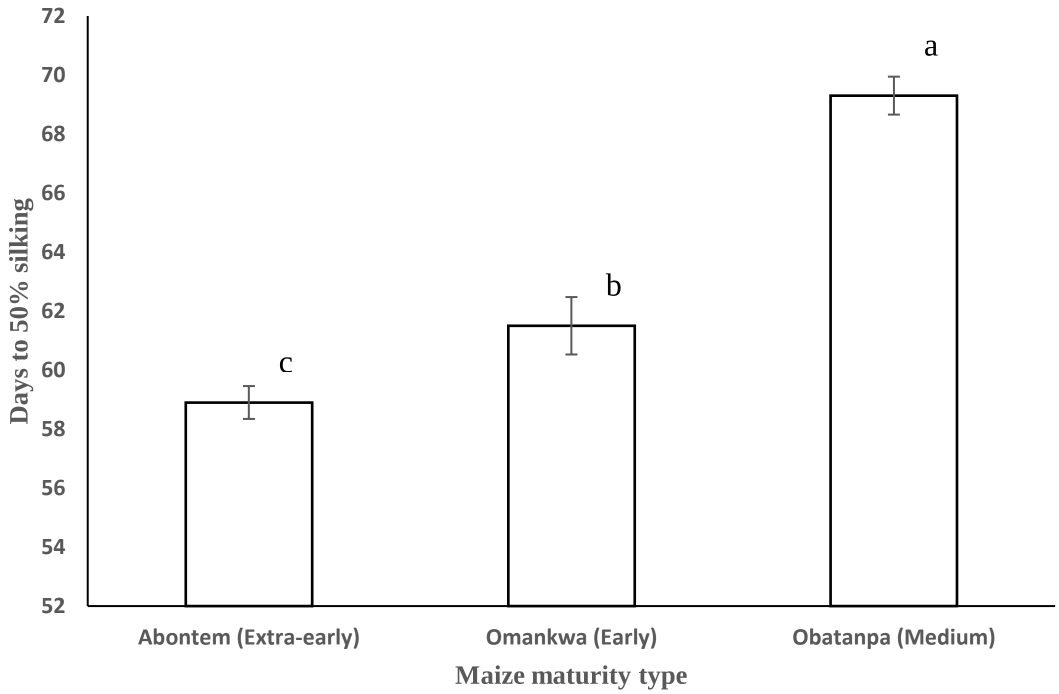

Figure 7. Effect of maize maturity type on days to 50% silking. Bars represent standard error of mean (S.E.M.)

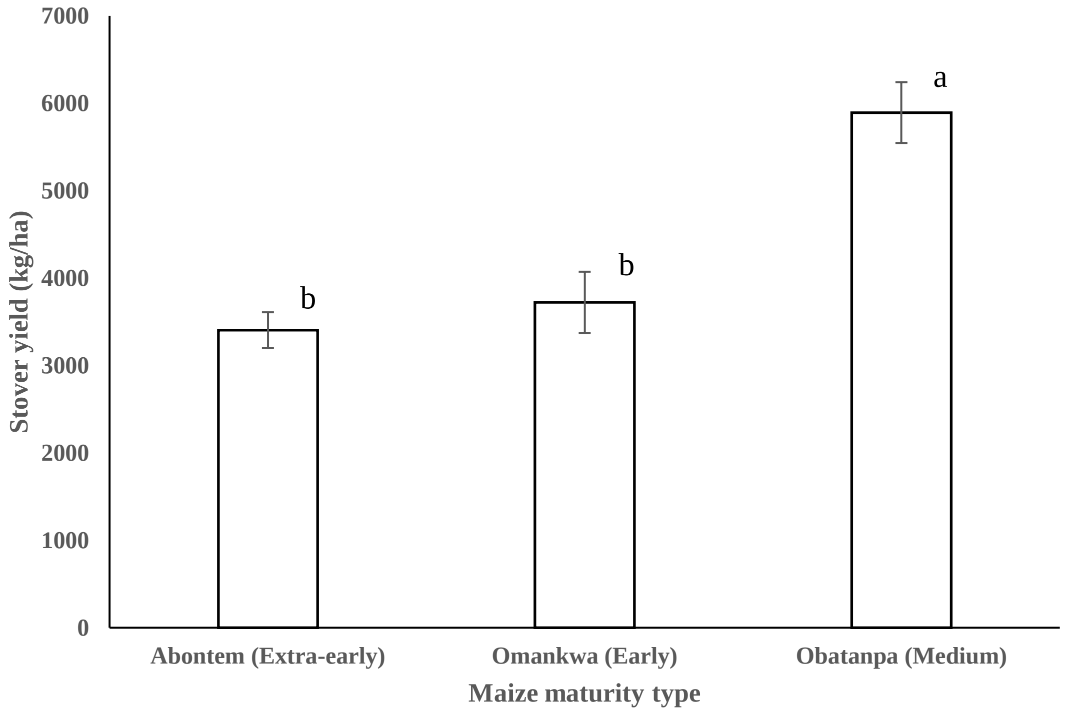

Figure 8. Effect of maize maturity type on stover yield. Bars represent standard error of mean (S.E.M.)

4.3.6 Grain yield of maize

Cowpea living mulch interseeding time x maize maturity type interaction were not significant on grain yield, likewise the effect of maize maturity type (Appendix 22). However, cowpea living mulch interseeding time effect, had significant influence on the yield of maize. Results obtained shows that maize interseeded with cowpea 1 WAPM produced the highest grain yield which was similar to maize interseeded with cowpea on the same day (SDWM), while the control – NLM performed poorly (Fig. 9).

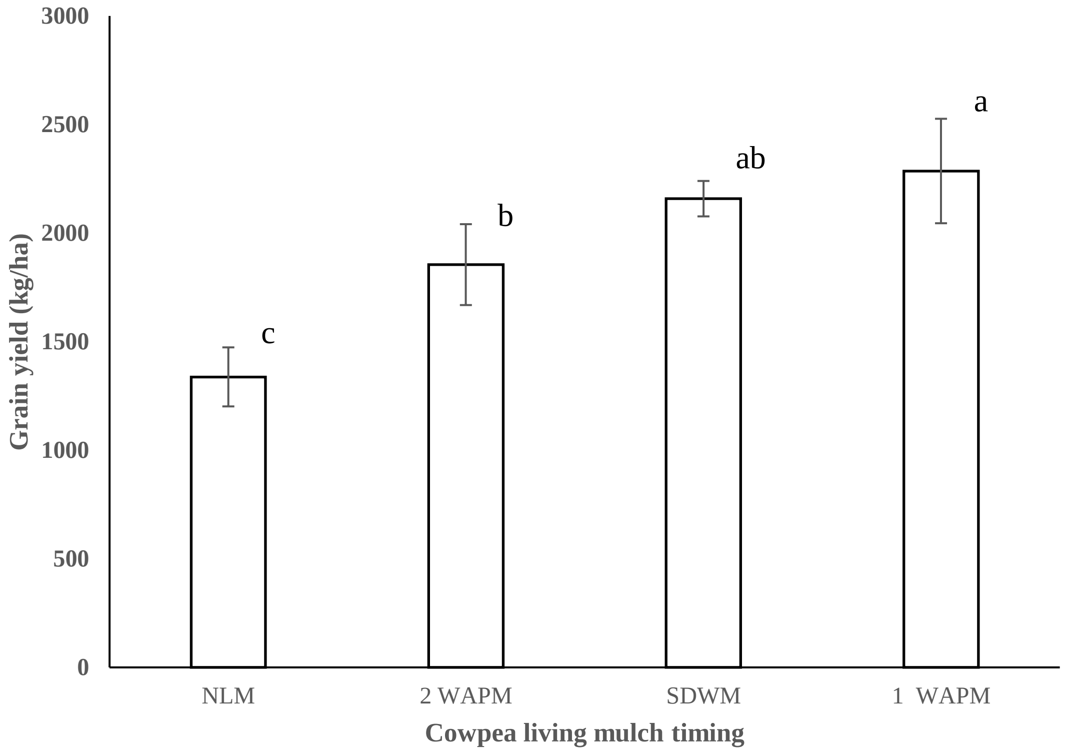

Figure 9. Effect of cowpea living mulch interseeding time on maize grain yield. Bars represent standard error of mean (S.E.M.)

4.3.7 Harvest index of maize

Harvest index of maize was not affected ($p > 0.05$) by cowpea living mulch interseeding time x maize maturity type interaction. However, the effect of cowpea living mulch interseeding time and maize maturity type contributed significantly to harvest index of maize (Appendix 24). In contrast to maize stover yield, it was observed that medium maturing maize type (Obatanpa) recorded the lowest harvest index which was statistically different from extra-early maturing maize type (Abontem) and early maturing maize type (Omankwa) (Table 8). Results obtained from the effect of living mulch interseeding time indicates that, maize interseeded with cowpea 1 WAPM recorded the highest harvest index similar to maize interseeded with cowpea on the same day (SDWM), while the control – NLM performed poorly (Table 8).

Table 8. Harvest index of maize as affected by cowpea living mulch interseeding time and maize maturity type

	Maize Harvest Index (%)
Living Mulch (LM)	
No living mulch (NLM)	36.7^{c}
Cowpea mulch same day with maize (SDWM)	55.2^{ab}
Cowpea mulch 1 week after maize (1 WAPM)	57.8^{a}
Cowpea mulch 2 weeks after maize (2 WAPM)	42.2^{bc}
LSD (0.05)	13.8
P-Value	*
Maize Maturity Type (MMT)	
Abontem (Extra-early)	53.0^{a}
Omankwa (Early)	56.8^{a}
Obatanpa (Medium)	34.1^{b}
LSD (0.05)	11.9
P-Value	**
LM x MMT	
P-Value	**ns**

** $P < 0.01$, * $P < 0.05$, ^{ns} $P > 0.05$. Mean values followed by the same letters in each column are not significantly different from one another.

4.3.8 Water Use Efficiency (WUE)

Cowpea living mulch interseeding time and its interaction with maize maturity type did not affect (p > 0.05) WUE likewise the effect of maize maturity type (p > 0.05). However, the effect of cowpea living mulch interseeding time significantly contributed to WUE (Appendix 25), such that the control – NLM had the lowest WUE compared with the other living mulch interseeding times (Fig. 10).

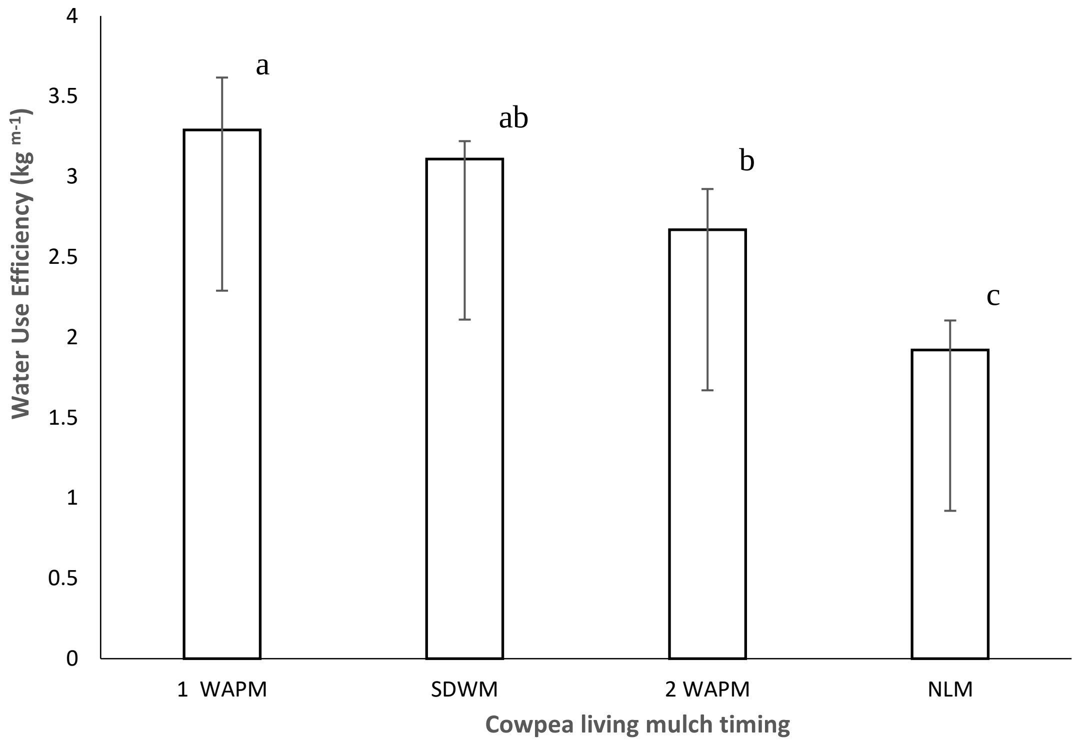

Figure 10. Effect of cowpea living mulch interseeding time on water use efficiency (WUE). Bars represent S.E.M.

4.3.9 Weed biomass

The interaction effect of cowpea living mulch interseeding time x maize maturity type as well as the effect of maize maturity type had no significant influenced on weed biomass at 6, 9 and 12 WAPM (Appendix 26 - 28). However, the effect of cowpea living mulch interseeding time contributed significantly to weed biomass (Appendix 26 - 28). At 6, 9 and 12 WAPM, it was observed that cowpea interseeded SDWM recorded the lowest weed biomass which did not differ statistically with cowpea interseeded 1 WAPM and cowpea interseeded 2 WAPM but however differed significantly over the control – NLM (Fig.11).

4.3.10 Weed species diversity

Thirty-three (33) dominant weed species were identified at 6 WAPM (Table 8). The weed species were classified into grasses, sedges and broadleaves. Six (6) weed species were grasses, three (3) were sedges and twenty-four (24) were broadleaves. Under grass species, *Bracharia alata* and *Paspalum scrobiculatum* were the least identified weed species for living mulch interseeding time x maize maturity type interaction. Under the broadleaves species, *Ageratum conyzoides, Hyptis spicigera* and *Ludwigia decurrens* were the only weed species observed under all living mulch interseeding time x maize maturity type interaction (Table 8). Interestingly, weed species diversity under control plots was higher than in live – mulch plots.

At harvest, thirty-six (36) weed species which include five (5) grasses, four (4) sedges and twenty-seven (27) broadleaves were identified (Table 10). Under grass species, *Hackelochloa granularis* was observed under all maize maturity types interseeded with cowpea 2 WAPM. Sedges showed more diversity at harvest, as the number of sedge species increased from four (4) at 6 WAPM to five (5) at harvest. Among the broadleaves, *Ageratum conyzoides, Hyptis spicigera* and *Ludwigia decurrens* continued to show more dominance as together with *Corchorus olitorius, Mitracarpus villosus* and *portulaca quadrifida* persisted under all living mulch interseeding time x maize maturity type interaction. However, *Aneilema beniniense, Bidens pilosa, Euphorbia hirta, Gomphrena celosioides, Hyptis saveolens, Leucas matinencensis, Tridax procumbens* and *Vernonia ambiqua* were drastically reduced by most maize maturity type x living mulch system interaction whilst *Desmodium tortuosum, Mollugo nudicalis, Portulaca quadrifida* and *Striga hermonthica* appeared at harvest (Table 10).

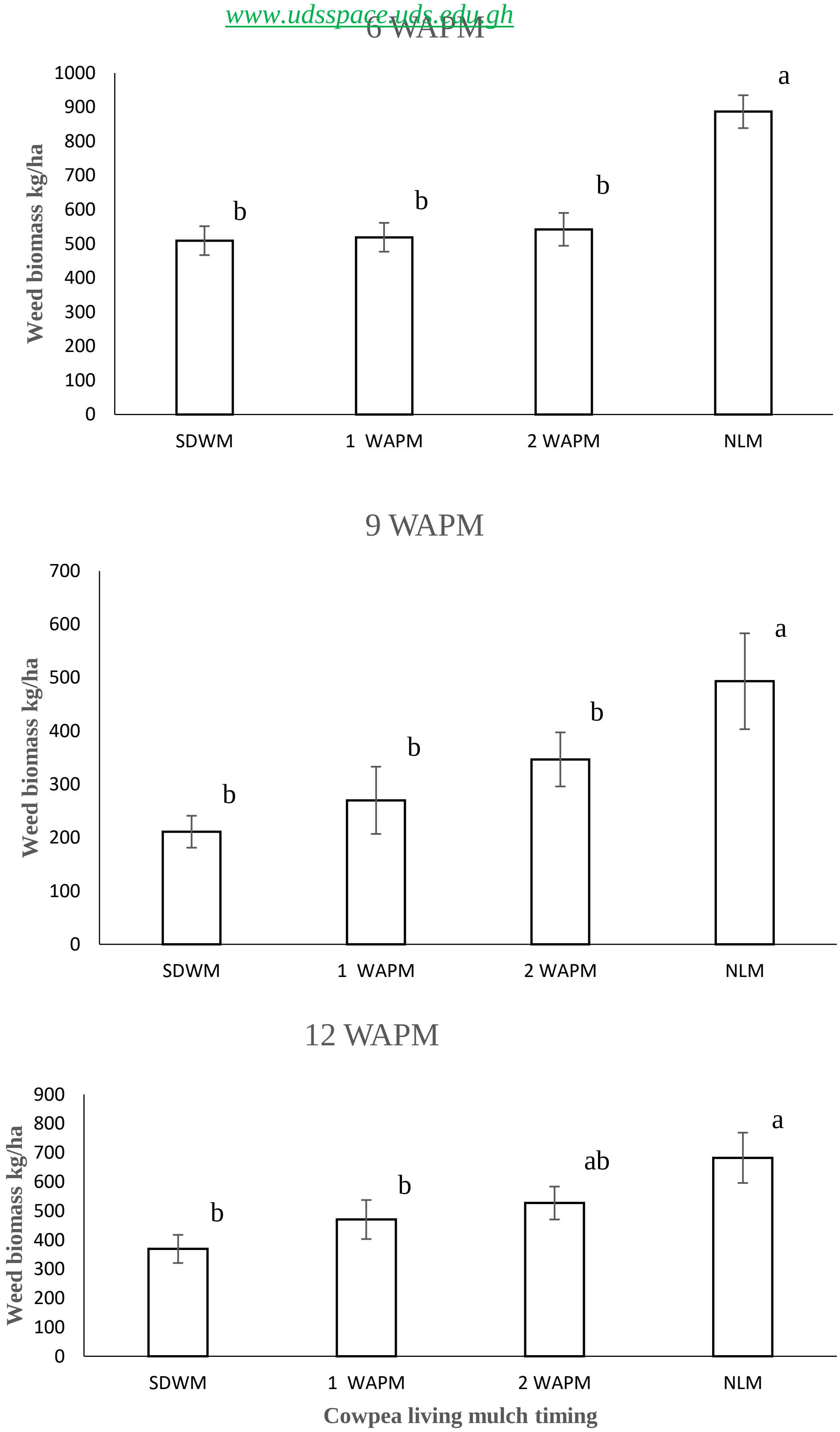

Figure 11. Effect of living mulch system on weed biomass at 6, 9 and 12 WAPM. Bars represent standard error of mean (S.E.M).

Table 9. Weed score and diversity as affected by maize maturity type and living mulch interseeding time at 6 weeks after planting maize (WAPM).

	Abontem				Omankwa				Obatanpa			
Weed species	NLM	SDWM	1 WAPM	2 WAPM	NLM	SDWM	1 WAPM	2 WAPM	NLM	SDWM	1 WAPM	2 WAPM
GRASSES	**3.6**	**3.8**	**6.8**	**6.7**	**4.8**	**6.1**	**6.0**	**10.6**	**7.1**	**14.7**	**17.8**	**6.5**
Bracharia alata (Schumach.) C.E Hubb.	-	-	1.8	-	3.0	-	-	-	2.0	2.8	4.2	3.3
Bracharia deflexa (Schumach) C.E Hubb	-	-	-	3.1	-	1.3	-	3.1	-	-	-	-
Dactelotenium aegyptium	-	1.9	3.2	1.8	-	1.3	3.6	4.4	3.2	4.6	5.9	-
Digtaria horizontalis Wil	1.8	-	1.8	1.8	-	3.5	-	3.1	-	4.6	7.7	-
Paspalum scrobiculatum	-	1.9	-	-	1.8	-	2.4	-	-	-	-	-
Setaria pumila (Poir.) Ro	1.8	-	-	-	-	-	-	-	2.0	2.8	-	3.3
SEDGES	**7.4**	**11.5**	**7.0**	**10.4**	**4.7**	**16.2**	**16.0**	**13.9**	**5.0**	**17.0**	**11.9**	**13.1**
Cyperus esculentus L.	1.8	2.9	4.7	7.3	2.4	9.6	6.3	5.6	5.0	7.8	5.9	-
Kyllinga bulbosa P. Beau	1.8	2.9	2.4	3.1	-	5.3	4.9	5.6	-	6.5	5.9	6.5
Killinga squamulata Tho	3.9	5.8	-	-	2.4	1.3	4.9	2.8	-	2.8	-	6.5
BROADLEAVES	**89.0**	**84.7**	**86.2**	**82.9**	**90.5**	**77.7**	**78.0**	**75.3**	**87.9**	**68.3**	**70.3**	**80.3**
Agerantum conyzoides L.	2.8	4.5	7.1	7.3	9.4	7.3	8.6	8.7	9.1	7.8	4.2	5.5
Aneilema beniniense (P. I	2.8	2.2	2.4	2.5	1.8	1.3	-	4.4	2.0	2.8	-	4.6
Bidens pilosa L.	2.8	3.0	1.8	2.5	3.0	3.5	5.0	3.1	2.0	-	-	-
Corchorus olitorius L.	7.0	4.3	3.0	3.1	3.0	4.2	6.3	-	9.1	3.9	7.7	6.5
Commelina bengalensis I	-	9.1	10.1	7.3	6.6	-	7.2	-	5.0	4.6	11.2	7.9
Euphorbia heterophylla I	3.9	-	2.4	5.4	2.4	4.2	3.6	6.3	7.1	-	-	-
Euphorbia hirta L.	-	2.4	3.2	3.1	1.8	2.7	-	-	2.0	3.9	-	-
Gomphrena celosioides N	5.0	-	5.4	6.2	4.7	-	3.6	-	1.8	4.6	3.0	4.6
Hyptis saveolens (L.) Poi	2.8	-	1.8	-	-	-	-	-	3.2	-	-	-
Hyptis spicigera Lam.	8.0	15.7	8.9	9.0	11.4	8.7	7.2	8.7	9.1	9.6	7.7	5.5
Ipomea tribola L.	2.8	-	-	2.5	-	-	1.8	-	-	-	-	-
Leucas martinicensis (Jac	5.6	3.0	5.1	6.2	3.0	-	-	2.8	5.0	-	-	-
Ludwigia decurrens Walt	10.0	15.7	13.2	10.0	14.2	14.3	11.8	12.5	10.4	9.6	12.7	11.0
Mitracarpus villosus (Sw	-	10.2	7.1	7.3	8.8	8.1	6.3	7.5	5.0	7.8	7.7	9.0
Oldenlandia corymbosa I	2.8	-	-	3.1	-	4.2	-	-	-	-	1.8	3.3
Phyllantus amarus Schur	1.8	4.5	1.8	-	4.7	3.5	2.4	3.1	3.2	-	4.2	-
Physalis anguculata Link	-	2.2	-	-	-	-	-	-	-	-	-	-
Portulaca quadrifida L.	3.9	-	-	-	2.4	-	-	-	-	-	-	1.8
Schwenckia americana L	7.6	-	1.8	-	2.4	2.7	4.9	6.3	2.0	4.6	3.0	6.0
Scoparia dulcis L.	8.0	-	-	-	-	-	-	-	-	-	-	-
Senna obtusifolia (L.)	4.0	5.2	8.3	3.1	5.1	5.3	-	-	3.2	2.8	-	7.9
Stachytarpheta jamaicens	2.8	-	-	-	1.8	-	2.4	3.1	2.0	-	3.0	3.3
Tridax procumbens L.	-	-	3.0	1.8	1.8	4.2	5.0	5.6	5.0	3.9	-	-
Vernonia ambiqua Kotschy & Peyr.	5.0	3.0	-	2.5	2.4	3.5	1.8	3.1	2.0	2.8	4.2	3.3

Table 10. Weed score and diversity as affected by maize maturity type and living mulch interseeding time at harvest.

	Abontem				Omankwa				Obatanpa			
Weed species	NLM	SDWM	1 WAPM	2 WAPM	NLM	SDWM	1 WAPM	2 WAPM	NLM	SDWM	1 WAPM	2 WAPM
GRASSES	**5.4**	**3.1**	**2.2**	**7.0**	**2.3**	**2.9**	**2.4**	**5.2**	**11.5**	**10.1**	**3.8**	**7.0**
Bracharia alata (Schumach.) C.E Hubb.	3.0	-	2.2	-	2.3	2.9	2.4	3.0	3.6	3.7	-	2.8
Bracharia deflexa (Schur	-	3.1	-	1.9	-	-	-	-	-	2.8	-	-
Hackelochloa granularis	-	-	-	1.9	-	-	-	2.3	-	-	-	2.1
Panicum laxum Sw.	-	-	-	3.2	-	-	-	-	2.9	3.7	-	-
Paspalum scrobiculatum	2.4	-	-	-	-	-	-	-	5.1	-	3.8	2.1
SEDGES	**7.2**	**11.5**	**12.4**	**10.7**	**14.5**	**11.5**	**8.6**	**11.9**	**3.6**	**14.7**	**2.8**	**11.1**
Cyperus esculentus L.	-	6.2	7.3	8.2	7.0	2.9	3.1	8.9	-	9.2	2.8	5.6
Cyperus rotundus L.	-	-	-	-	2.3	-	-	-	-	-	-	-
Kyllinga bulbosa P.Beau	1.8	2.3	2.2	-	2.3	2.9	2.4	3.0	-	-	-	2.8
Killinga squamulata Tho	5.4	3.1	3.0	2.5	2.9	5.8	3.1	-	3.6	5.5	-	2.8
BROADLEAVES	**87.4**	**85.4**	**85.4**	**82.3**	**83.1**	**85.6**	**89.0**	**82.9**	**84.9**	**75.2**	**93.4**	**81.8**
Agerantum conyzoides L.	2.4	3.9	6.7	7.0	5.8	6.5	5.5	5.9	6.5	8.2	8.5	6.2
Aneilema beniniense (P. I	-	-	-	2.5	-	-	-	-	-	-	-	-
Bidens Pilosa L.	-	-	-	-	-	2.2	-	-	-	-	-	-
Corchorus olitorius L.	7.8	7.6	8.9	7.6	6.4	7.2	7.0	11.2	7.2	3.7	9.4	6.2
Commelina bengalensis I	2.4	7.6	7.3	1.9	4.7	5.0	6.2	3.0	7.9	2.8	9.4	-
Desmodium tortuosum (S	-	3.1	2.2	2.5	-	2.2	-	3.0	-	-	-	3.4
Euphorbia heterophylla I	2.4	3.1	3.0	1.9	2.3	2.2	3.1	-	3.6	4.6	4.7	2.8
Euphorbia hirta L.	-	-	-	-	-	-	-	-	-	-	-	2.8
Gomphrena celosioides M	2.4	-	-	-	3.5	-	2.4	2.3	-	-	-	-
Hyptis saveolens (L.) Poi	-	-	-	-	-	-	-	-	-	-	-	2.8
Hyptis spicigera Lam.	12.5	11.5	11.8	11.4	8.7	10.1	13.9	12.4	11.5	12.8	14.2	11.0
Ipomea tribola L.	1.8	2.3	-	-	-	-	-	-	-	-	-	2.1
Leucas martinicensis (Ja	3.6	-	-	-	2.3	-	-	-	-	-	-	-
Ludwigia decurrens Walt	11.3	14.8	14.9	12.7	9.3	14.4	16.1	10.3	10.7	13.7	18.0	9.7
Mitracarpus villosus (Sw	10.8	9.3	8.7	9.5	9.3	8.6	13.1	13.3	5.1	11.0	8.5	9.7
Mollugo nudicaulis Lam.	2.4	-	-	-	2.9	-	-	-	-	-	-	-
Oldenlandia corymbose I	2.4	2.3	5.1	2.5	2.3	2.9	2.4	3.0	-	2.8	2.8	2.1
Phyllantus amarus Schur	4.2	3.1	5.1	5.1	4.1	5.0	3.1	-	2.9	-	2.8	5.6
Physalis anguculata Link	-	-	-	-	-	2.2	3.1	-	2.2	-	-	-
Portulaca quadrifida L.	4.8	7.0	6.7	3.2	4.7	9.4	7.0	6.6	5.1	7.3	6.6	6.9
Schwenckia Americana L	4.8	5.4	-	1.9	6.4	2.9	6.2	-	2.2	2.8	2.8	2.8
Scoparia dulcis L.	2.4	-	-	4.4	2.3	2.9	-	3.0	2.2	2.8	-	-
Senna obtusifolia (L.)	3.0	2.3	-	-	2.3	-	-	-	3.6	2.8	-	2.1
Stachytarpheta jamaicens	4.2	2.3	3.0	8.2	4.1	-	-	8.9	5.8	-	-	5.6
Striga hermonthica (Delile) Benth.	-	-	-	-	-	2.2	-	-	2.9	-	-	-
Tridax procumbens L.	-	-	2.2	-	-	-	-	-	2.9	-	2.8	-
Vernonia ambiqua Kotschy & Peyr.	1.8	-	-	-	1.8	-	-	-	2.9	-	2.8	-

4.4 Correlation and regression analysis

4.4.1 Correlation and regression among soil physical properties and yield

Soil temperature at harvest (STH) was positively correlated with bulk density at harvest (BDH), soil porosity at vegetative (PSV) and negatively correlated with bulk density at vegetative (BDV), soil porosity at harvest (PSH) (Table 11). This means that when STH increase BDH and PSV also increases whilst BDV, PSH decreases. This could be predicted from the general linear regression model;

$Y_{STH} = 15.19 – 8.21_{BDV} + 12.67_{BDH} + 7.80_{PSV} – 10.72_{PSH}$, $R^2 = 0.53$

Figure (12), depicts the linear relationship between soil temperature at harvest (STH) and soil porosity at harvest (PSH), with regression (R^2) value of 42%. This indicates that 42% of the variation in soil porosity at harvest value can be explained by the linear relationship with soil temperature at harvest

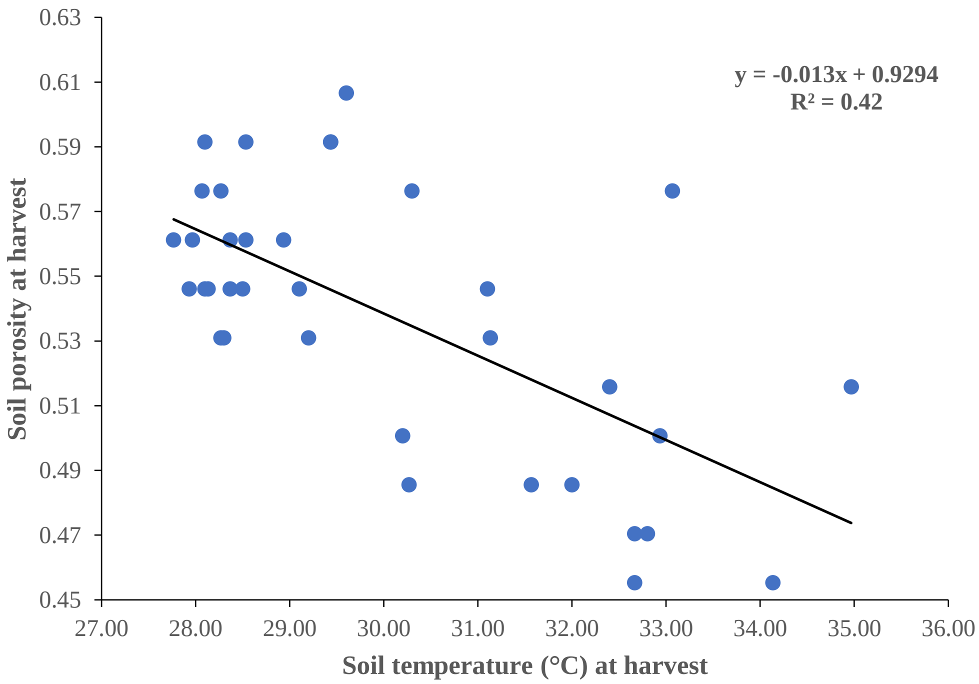

Figure 12. Linear relationship between soil temperature at harvest and soil porosity at harvest.

Bulk density at vegetative (BDV) was negatively correlated with soil porosity at vegetative (PSV) and positively correlated with soil porosity at tasselling (PST) (Table 11). This implies that when BDV values increases PSV value decreases whilst PST value increases. This could be predicted from the general linear regression model;

$Y_{BDV} = 2.567 – 2.433_{PSV} + 0.058_{PST}$, $r^2 = 0.96$

Figure (13), depicts the linear relationship between soil bulk density at vegetative growth stage and soil porosity at vegetative growth stage, with R^2 value of 97%. This indicates that 97% of the variation in soil bulk density value at vegetative growth stage can be explained by the linear relationship with soil porosity at vegetative growth stage.

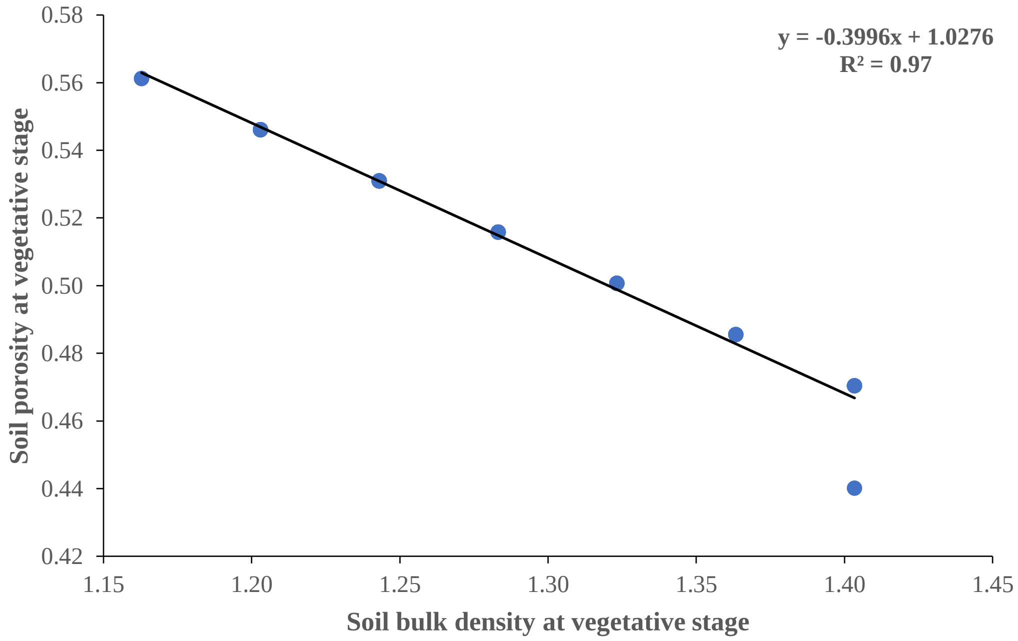

Figure 13. Linear relationship between soil bulk density at vegetative growth stage and soil porosity at vegetative growth stage.

Bulk density at tasselling (BDT) was negatively correlated with volumetric soil moisture content at tasselling (VMCT), soil porosity at tasselling (PST) and positively correlated with soil porosity at vegetative (PSV). This implies that when BDT value decreases VMCT and PST values increases whilst PSV values decreases (Table 11). BDT can therefore be predicted from the general linear regression model; $Y_{BDT} = 2.583 - 0.049_{VMCT} + 0.079_{PSV} - 2.595_{PST}$, $r^2 = 0.99$

Figure 14 depicts the linear relationship between BDT and VMCT, with R2 value of 35%. This implies that, 35 % of the variation in BDT value can be explained by its linear relationship with VMCT.

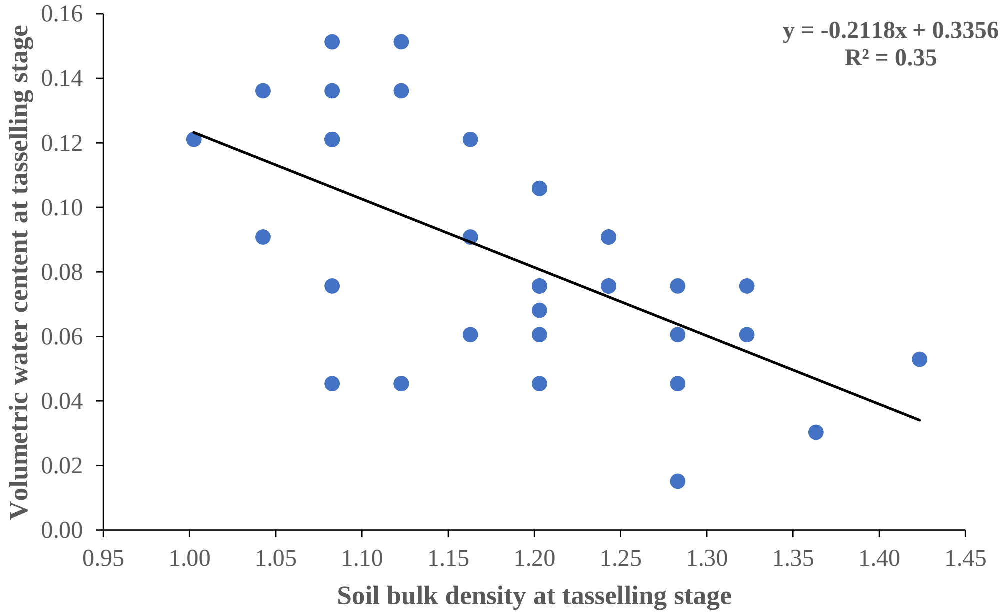

Figure 14. Linear relationship between soil bulk density at tasselling stage and volumetric water content at tasselling stage.

Bulk density at harvest (BDH) was negatively correlated with soil porosity at harvest (PSH). This implies that when BDH value increases PSH value decreases (Table 11). This could be predicted from the general linear regression model;

$Y_{BDH} = 2.651 – 2.649_{PSH}$, $r^2 = 0.97$

Figure 15 depicts the linear relationship between soil bulk density at harvest and soil porosity at harvest, with R^2 value of 97%. This indicates that 97% of the variation in soil porosity value at harvest can be explained by the linear relationship with soil bulk density at harvest (Fig.15)

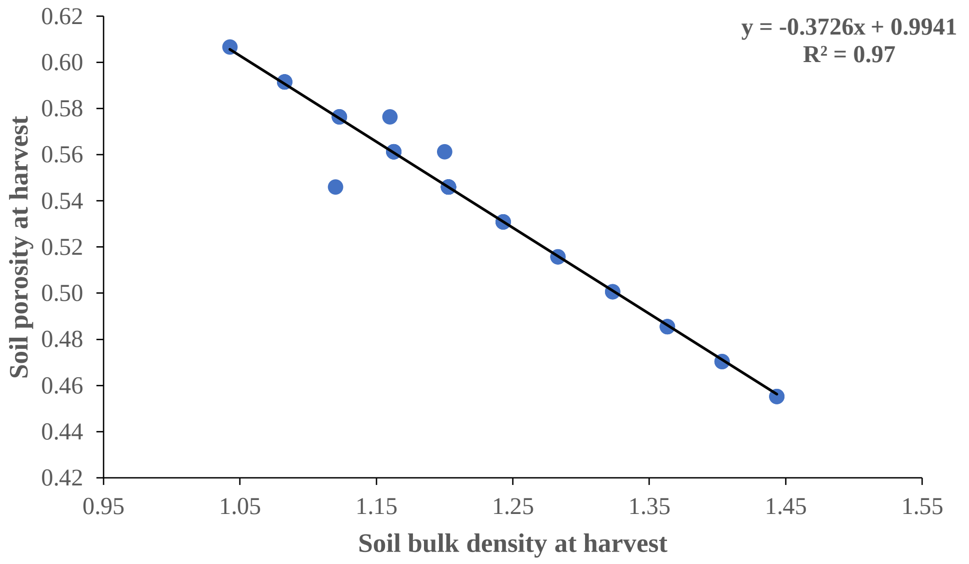

Figure 15. Linear relationship between soil bulk density at harvest and soil porosity at harvest.

Soil porosity at vegetative (PSV) was negatively correlated with soil porosity at tasselling (PST) (Table 11). This implies that when PSV value increases PST value decreases. This could be predicted from the general linear regression model;

$Y_{PSV} = 0.781 – 0.474_{PST}$, $r^2 = 0.38$

4.4.2 Correlation and regression among growth, yield components and yield

Plant height at harvest (PH 4) was positively correlated with days to 50 % tasselling (FPT), days to 50 % silking (FPS) and negatively correlated with harvest index (HI)

(Table 12). This implies that when PH 4 increases FPT and FPS also increases whilst HI decreases. This could be predicted from the general linear regression model;

$Y_{PH\ 4} = 152.677 + 0.206_{FPT} + 0.788_{FPS} – 0.234_{HI}$, $r^2 = 0.56$

Figure 16 depicts the linear relationship between plant height at harvest and harvest index with R^2 value of 41%. This indicates that 41% of the variation in harvest index value can be explained by their linear relationship with plant height at harvest.

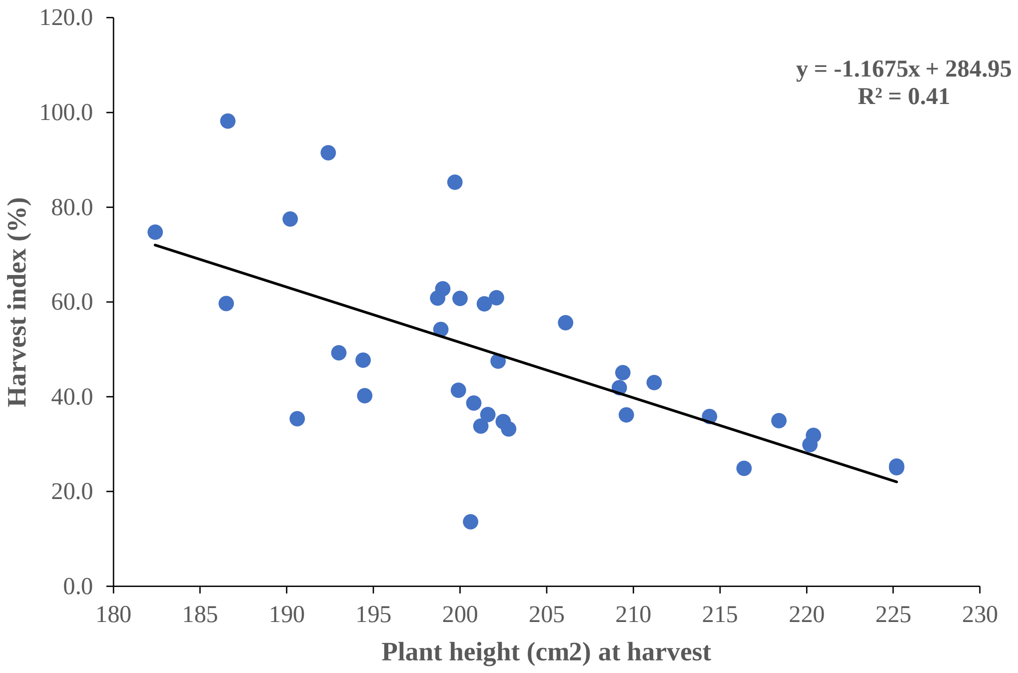

Figure 16. Linear relationship between plant height at harvest and harvest index (%).

Leaf area index at 10 WAPM (LAI 3) was positively correlated with leaf area index at 8 WAPM and days to 50 % silking (FPS) (Table 12). This implies that when LAI 3 increases LAI 2, and FPS also increases. This could be predicted from the general linear regression model;

$Y_{LAI\ 3} = -2.14 + 0.52_{LAI\ 2} + 0.04_{FPS}$, $r^2 = 0.60$

Figure 17 depicts the linear relationship between LAI 3 and FPS, with R^2 value of 42% respectively. This indicates that 42% variation in FPS value can be explained by their linear relationship with LAI 3.

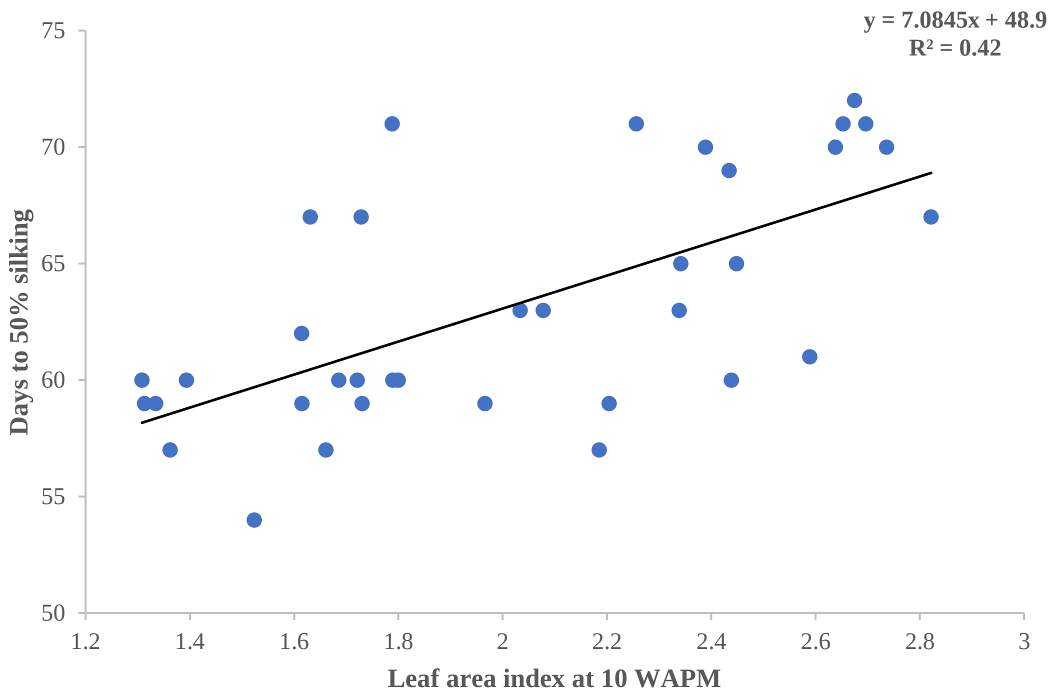

Figure 17. Linear relationship between leaf area index at 10 WAPM and days to 50% silking.

Days to 50 % tasselling (FPT) was positively correlated with days to 50 % silking (FPS) (Table 12). This implies that when FPT increases FPS also increases. This could be predicted from the general linear regression model;

$Y_{FPT} = 10.865 + 0.728_{FPS}$, $r^2 = 0.80$

Days to 50% tasselling influenced days to 50% silking significantly, R^2 values is 81%. This indicates that 81% of the variation in days to 50% silking value can be explained by the linear relationship with days to 50% tasselling (Fig. 18).

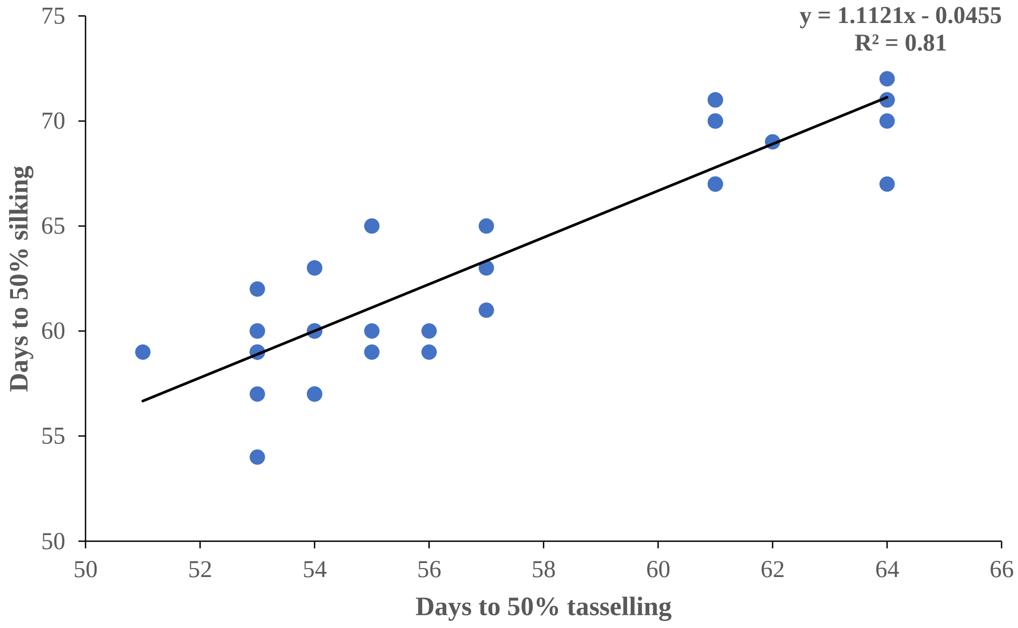

Figure 18. Linear relationship between days to 50% tasselling and days to 50% silking

Grain yield (GY) was negatively correlated with weed biomass at vegetative stage (WBV), meaning an increase in grain yield resulted in a decrease WBV (Table 12). This could be predicted from the general linear regression model;

$Y_{GY} = 3027.58 – 1.82_{WBV}$, $r^2 = 0.37$

Figure 19 depicts the linear relationship between grain yield and weed biomass at vegetative stage, with R^2 value of 37%. This indicates that 37% of the variation in grain yield value can be explained by the linear relationship with weed biomass at vegetative stage.

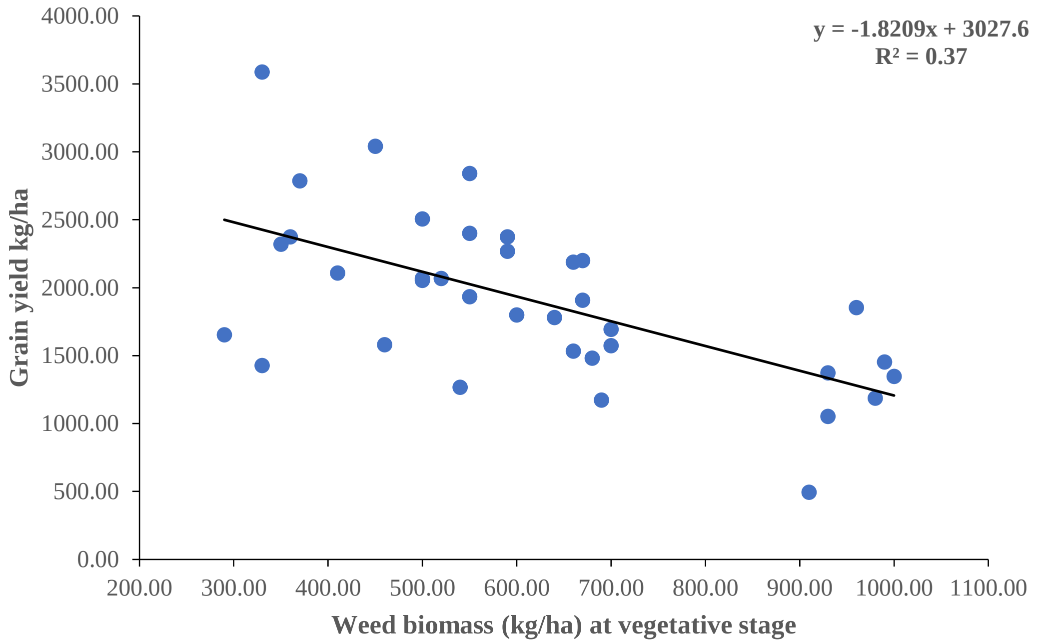

Figure 19. Linear relationship between grain yield and weed biomass at vegetative stage

Stover yield (STY) was positively correlated with days to 50 % tasselling (FPT), days to 50 % silking and negatively correlated to harvest index (HI). This means that when STY increases FPT and FPS also increases whilst HI decreases (Table 12). This relationship could be predicted from the general linear regression model;

$Y_{STY} = -3967.70 + 180.13_{FPT} - 8.66_{FPS} - 29.10_{HI}$, $r^2 = 0.52$

Figure 20 depicts the linear relationships between stover yield and days to 50% tasselling, stover yield and days to 50% silking and stover yield and harvest index, with R^2 value of 41%, 35% and 35% respectively. This indicates that 41%, 35% and 35% variation in FPT, FPS and HI values can be explained by their linear relationship with STY.

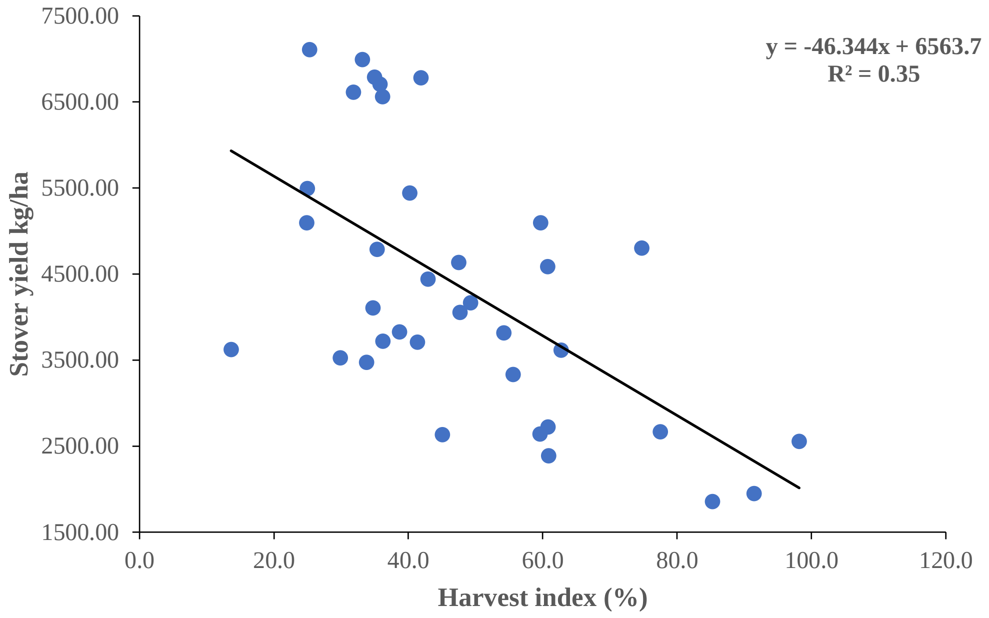

Figure 20. Linear relationship between stover yield and harvest index (%).

Weed biomass at tasselling (WBT) was positively correlated with weed biomass at harvest (WBH), meaning a decrease in WBT resulted in a decrease in WBH (Table 12). This could be predicted from the general linear regression equation;

$Y_{WBT} = -127.23 + 0.89_{WBH}$, $r^2 = 0.90$

Weed biomass at tasselling influenced weed biomass at harvest significantly, R^2 values is 90%. This indicates that 90% of the variation in weed biomass value at harvest can be explained by the linear relationship with weed biomass at tasselling.

Table 11. Correlation analysis among soil physical properties and yield

	STV	STT	STH	BDV	BDT	BDH	VMCV	VMCT	VMCH	PSV	PST	PSH	GY
STV	[illegible]												
STT	[illegible]	.00											
STH	[illegible]	.16^{ns}	1.00										
BDV	[illegible]	.14^{ns}	-0.61**	1.00									
BDT	[illegible]	.08^{ns}	0.51*	-0.60**	1.00								
BDH	[illegible]	.02^{ns}	0.65**	-0.48*	0.44*	1.00							
VMCV	[illegible]	.23^{ns}	0.11^{ns}	0.04^{ns}	0.11^{ns}	0.31^{ns}	1.00						
VMCT	[illegible]	.08^{ns}	-0.43*	0.53*	-0.60**	-0.08^{ns}	0.15^{ns}	1.00					
VMCH	[illegible]	0.19^{ns}	-0.48*	0.37*	-0.37*	-0.11^{ns}	-0.15^{ns}	0.58**	1.00				
PSV	[illegible]	0.13^{ns}	0.61**	-0.98**	0.63**	0.50*	-0.03^{ns}	-0.52**	-0.37*	1.00			
PST	[illegible]	0.07^{ns}	-0.48*	0.59*	-0.99**	-0.43*	-011^{ns}	0.59**	0.37*	-0.62**	1.00		
PSH	[illegible]	.02^{ns}	-0.64**	0.47*	-0.46*	-0.99**	-0.34*	0.06^{ns}	0.10^{ns}	-0.51**	0.44*	1.00	
GY	[illegible]	0.32*	-0.56*	0.48**	-0.46**	-0.19^{ns}	0.04^{ns}	0.30^{ns}	0.37*	-0.51**	0.46**	0.20^{ns}	1.00

* P ≤ 0. , ns = not significant, respectively. STV_ Soil temperature at vegetative stage, STT_ Soil temperature at tasselling stage, STH_ S at harvest, BDV_ Bulk density at vegetative stage, BDT_ Bulk density at tasselling stage, BDH_ Bulk density at harvest, VMCV_ ioisture content at vegetative, VMCH_ Volumetric moisture at harvest, PSV_ Soil porosity at vegetative stage, PST_ Soil porosity at tasselling stage, PSH_ Soil porosity at harvest, GY_ Grain yield.

Table 12. Correlation analysis among growth, yield components and yield

	PH 1	PH 2	PH 3	PH 4	LAI 1	LAI 2	LAI 3	FPT	FPS	GY	STY	HI	WBV	WBT	WBH
PH 1	1.00														
PH 2	[illegible]	[illegible]													
PH 3	[illegible]	[illegible]	1.00												
PH 4	[illegible]	[illegible]	0.21^{ns}	1.00											
LAI 1	[illegible]	[illegible]	0.24^{ns}	0.48**	1.00										
LAI 2	[illegible]	[illegible]	0.26^{ns}	0.18^{ns}	0.23^{ns}	1.00									
LAI 3	[illegible]	[illegible]	0.40**	0.43**	0.35*	0.61**	1.00								
FPT	[illegible]	[illegible]	0.16^{ns}	0.62**	0.48**	0.28^{ns}	0.55**	1.00							
FPS	[illegible]	[illegible]	0.17^{ns}	0.65**	0.46**	0.31*	0.65**	0.90**	1.00						
GY	[illegible]	[illegible]	-0.12^{ns}	-0.33*	-0.35*	-0.15^{ns}	0.10^{ns}	0.11^{ns}	0.04^{ns}	1.00					
STY	[illegible]	[illegible]	0.11^{ns}	0.48**	0.16^{ns}	-0.07^{ns}	0.37*	0.64**	0.59**	0.42**	1.00				
HI	[illegible]	[illegible]	-0.22^{ns}	-0.64**	-0.44*	-0.10^{ns}	-0.30^{ns}	-0.48*	-0.47**	0.41**	-0.59**	1.00			
WBV	[illegible]	[illegible]	0.06^{ns}	0.24^{ns}	0.38*	0.10^{ns}	0.01^{ns}	-0.02^{ns}	-0.08^{ns}	-0.61**	-0.31^{ns}	-0.26^{ns}	1.00		
WBT	[illegible]	[illegible]	0.28^{ns}	-0.01^{ns}	0.14^{ns}	0.04^{ns}	-0.01^{ns}	-0.27^{ns}	-0.40**	-0.10^{ns}	-0.20^{ns}	0.04^{ns}	0.45*	1.00	
WBH	[illegible]	[illegible]	0.22^{ns}	0.02^{ns}	0.13^{ns}	0.03^{ns}	0.01	-0.22^{ns}	-0.35*	-0.07^{ns}	-0.13^{ns}	-0.03^{ns}	0.42*	0.95**	1.00

* P ≤ 0.[illegible], ns = not significant, respectively. PH 1_ Plant height at 3 WAPM, PH 2_ Plant height at 6 WAPM, PH3_ Plant height at 9 W[illegible]ant height at 12 WAPM, LAI 1_ Leaf area index at 6 WAPM, LAI 2_ Leaf area index at 8 WAPM, LAI 3_ Leaf area index at [illegible] FPT_ 50% tasselling of maize, FPS_ 50% silking of maize, GY_ Grain yield, STY_ Stover yield, HI_ Harvest index, WBV_ Weed biomass at vegetative stage, WBT_ Weed biomass at tasselling stage, WBH_ Weed biomass at harvest.

CHAPTER FIVE

5.0 DISCUSSION

5.1 Rainfall and temperature variability

The amount and distribution of rainfall in a given cropping season determines the success or failure of crop production (Nhemachena & Hassan, 2007). With this in mind, farmers often pre-empt rainfall establishment thus exposing thier crops to the usual beginning and/or end-of- season drought. As shown in Figure (1), the lowest amount of rainfall was recorded towards harvest (September – October). With this trend of rainy period, growth of medium to late maturing crop varieties are affected, as grain filling mostly coincides with end of season drought. Farmers in this study area can take advantage of this trend and adopt the cultivation of extra-early maturing maize varieties as an adaptation measure. In corroborating this, Badu-Apraku et al. (2012) reported that extra-early inbreds and hybrids are not only drought escaping but also possess drought tolerant genes. Figure 1, also indicated that the total amount of rainfall varied between months. This is in line with the assertion by Amikuzino & Donkoh (2012) that, rainfall in the semi-arid regions of sub-Saharan Africa is highly variable.

Temperature may affect the rate at which plant releases carbon dioxide (CO_2) in the process of respiration and influencing the micro-climate for net growth (Ofori-Sarpong, 2001). According to Hatfield et al. (2011), decrease in minimum temperatures affects night time crop respiration rate which can lead to a reduction in crop yield, while higher minimum temperatures decrease crop growth and yield (Welch et al., 2010). It can be seen from Figure (1) that, the beginning (June) and end (October) of the cropping season months were relatively warmer than the mid-season months (July - September). Receiving of warmer temperatures means evapotranspiration can be accelerated. As an adaptation strategy, Kemausuor et al. (2012) reported that farmers can interseed their main crop with a live mulch such as cowpea to optimise the micro-climate.

5.2 Soil physical properties

5.2.1 Soil temperature

Soil temperature can be significantly influenced by different cropping systems (Nyobe, 1998; Odjugo, 2008), consequently from this study, interseeded cowpea plots significantly decreased soil temperature compared to non-interseeded maize plots at all growth stages (Fig. 2). This may be attributed to the protective effect of cowpea living mulch in absorbing solar energy via shading the soil surface, thus decreasing soil temperature during the growing season. Confirming this assertion, several authors have reported that soil temperature under mulching is different from that of non-mulched soils, with temperatures often being lower under mulched soils than in non-mulched soils (Bristow, 1988; Sarkar et al., 2007). Accordingly, Kolota & Adamczewska-Sowińska (2013), opined that living mulches help to maintain the soil temperature more uniform by preventing it from excessive heating at intensive insulation and by reducing the rate of cooling during cooler periods. In a similar study, Ghanbari et al., (2010), also observed a relatively lower soil temperature in plots with cowpea acting as a cover in maize than those with sole maize stands.

As expected, time of interseeding cowpea impacted significantly on soil temperatures, with cowpea interseeded with maize on the same day (SDWM) giving the minimum temperature values at all growth stages (Fig. 2). This indicates that early interseeding of cowpea living mulch may have allow for significant vegetative growth that provided a better soil cover to insulate the soil than late interseeding. Accordingly, in a study intended to determine what planting date gives the best cover crop performance, Darby et al., (2013) reported that, the amount of soil cover by winter rye cover crop decreased as the planting date was delayed. Similarly, soil temperatures during the day was observed to be lower in early seeded cover crop plots than in late seeded plots due to delayed canopy cover (Pehlivantürk, 1975).

5.2.2 Soil bulk density

Living mulches have been reported to alleviate compacted soils, by providing a more uniform rupture of compacted soil layers (Dexter, 2004). From this study, soil bulk density showed significant positive response to living mulch system. This is in line with the findings of Duiker & Hartwig (2004). However, this significant response was observed later in the growing season, that is, at tasselling and harvesting stage. This results is in line with the findings of Nabanita (2012), who reported that soil physical properties changes very slowly with time as compared to chemical and biological properties. Acosta-Martinez et al (1999) also proved, that the soil bulk density shaped during cultivation is not stable and therefore is subject to changes during the growing season. This explains why a significant difference was observed among living mulch system levels, stating from mid-growing season (tasselling stage). On the other hand, the lower bulk density value obtained from the control – NLM at the harvest stage, was in contrast to the findings by Blanco-canqui et al. (2012), that plots with cover crops had lower bulk densities than non- mulch plots, due to cover crops ability to decrease soil vulnerability to compaction.

5.2.3 Soil porosity

Soil porosity is the second parameter, apart from soil bulk density informing about the soil compaction (Sałata et al., 2017). From this study, cowpea living mulch interseeding times had significant effect on soil porosity at the tasselling growth stage and a total increased soil porosity at harvest (Table 3). At the tasselling stage, results indicate that, higher soil porosity characterized plots mulched with cowpea plants than in non – mulched plots. Higher soil porosity values obtained from cowpea living mulch plots might probably be due to (1.) the distinctive pores induced by the elongation and proliferation of maize and cowpea plant roots. Thus, increasing soil porosity through the creation of voids within the soil, in a process dubbed "biodrilling" and, (2.) the extensive canopy cover which aided in raindrop interception, thus, preventing physico-chemical dispersion of soil particles which can migrate into the soil with infiltrating water, clogging pores and subsequently creating a zone of decreased porosity. According to Tebrügge & Düring (1999), the size of macro-pores in conditions of destructive activity of rain drops in non-mulched soils, lowers to 40 cm and decrease by 38 %.

5.2.4 Volumetric moisture content

Generally, maize maturity type did not significantly influence volumetric moisture content at all growth stages (Table 4). Conversely, the volumetric moisture content among cowpea living mulch interseeding times were significantly enhanced at both the tasselling growth stage and at harvest. This might be due to an enhanced leaf area by the maize and cowpea live mulch at both growth stages which aided in a positive shading effect thereby reducing evapotranspiration. According to Greyson (1998), significant improvement in soil moisture content by living mulches, may be due to many factors, one of which is the leaf area index (LAI) of main crop and living mulch specie. Furthermore, the presence of living mulches on the soil surface might have provided a positive soil water effects late in the growing season when the main crop was experiencing end-of-season drought (Wiggans et al., 2012). However, at all growth stages the control – NLM experienced the lowest soil moisture content in comparison to mulched soils. These findings are in concurrence with Hsiao & Xu (2005), who reported that, extensive canopy cover aided by living mulches tends to shade soil surfaces from radiation making it less vulnerable to evapotranspiration than non – mulched soils. Similarly, Nedunchezhiyan et al. (2012) reported that living mulch systems effectively conserves soil moisture than non – mulch cropping systems. Conversely, this was in in line with the findings of Ochsner et al. (2010) ,who reported a lower soil water storage under maize - kura clover living mulch than the control (non-live mulch plots).

5.3 Yield and Yield Components

5.3.1 Maize plant height

The interactive effects of cowpea living mulch interseeding time with maize maturity type, significantly influence maize plant height at harvest (Appendix 16). The highest plant height for each maturity type was recorded from its interaction with the control – NLM. This may suggest that interseeded cowpea did influence the rate of competition between and among the system components, which resulted in lower plant heights of maize. The results of the present study corroborate the findings of Weston (1996) who reported that living mulches decreased corn height, probably in result of competition for water and nutrients as well as allelopathic. This also agrees with Bello et al. (2012), who reported that plant height does not only depend on the genetic composition of maize varieties, but it is also influence by competition for available resources such as nutrients and water. This may also suggest that none of the maize maturity types were suitable as a main crop in the cowpea living mulch system. This result was in line with the report of Muoneke et al. (2012) that, sometimes the best cultivars for mono-cropping might not be the most suitable for mixed cropping systems due to different microclimate within such crop mixtures. This is also in contrast to the findings of Magani & Kuchinda (2009) who attributed difference in plant height among varieties to genetic effect.

5.3.2 Leaf area index of maize

There was a significant interaction between cowpea living mulch interseeding time and maize maturity type on maize leaf area index at 6 WAPM. The interaction of maize maturity type levels with interseeded cowpea 2 WAPM produced the lowest LAI. This result may suggest that, interseeding cowpea late at 2 WAPM resulted in reduced photosynthetic active radiation (PAR) absorption by the cowpea which may have impacted negatively through limited N-fixation on edaphic conditions for growth of maize plants. Accordingly, in evaluating the effect of shading on dinitrogen fixation of three (3) pasture legumes, Fujita et al. (2012), reported a reduced N amount and fixation in one of the pasture legumes as a result of extensive shading by the main crop.

Leaf area index was influence significantly by maize maturity type at 8 WAPM and 10 WAPM. Extra-early maturing maize type (Abontem) had the lowest leaf area index among maize maturity levels. This observation might be due to the relatively smaller phenotypic traits associated with extra-early maturing crop types. In supporting this assertion, Tollenaar (1992) stated that extra-early maturing maize varieties are normally smaller, produce less leaves and have lower leaf area per plant. Similarly, Malone et al. (2002) also reported similar findings for early maturing soybean genotypes.

5.3.3 Days to 50% tasselling (maize)

Cowpea living mulch system interaction with maize maturity type significantly influenced days to 50% tasselling of maize. The trend for 50% tasselling of maize maturity type levels was similar under all cowpea living mulch systems levels (Fig.5). The linear response observed by maize maturity type levels at all levels of cowpea living mulch could be attributed to the different genetic constitution of the varieties. The attainment of reproductive phase has been reported to be a varietal characteristics (Muoneke et al., 2007).

Maize maturity types produced significantly different days to 50% tasselling. Extra-early maturing maize type (Abontem) took less number of days to 50% tasselling when compared with other maize maturity types under study. This could be attributed to the short plant height of extra-early maturing maize type (Abontem) arising from its genetic make-up. This agrees with the earlier finding of Troyer & Larkins (1985), who reported that, since internode extension terminates at floral initiation, early flowering maize varieties are usually characterized with short plant heights.

Days to 50% tasselling was significantly influence by cowpea living mulch interseeding time, with cowpea interseeded SDWM taking more days to 50% tasselling of maize. Under moisture stress tasselling development is delayed significantly (Du Plessis, 2003), but contrary to the finding from the present study days to 50% tasselling under the control – NLM was not delayed significantly under moisture stress, compared to cowpea interseeded SDWM and 1 WAPM.

5.3.6 Days to 50% silking

Maize maturity type optimized days to 50% silking, such that the trend reflected results from days to 50% tasselling in which extra-early maturing maize type (Abontem) took the least number of days to mid tasselling while medium maturing maize type (Obatanpa) took more days. This could be attributed to the difference in genetic make-up that exist among maize maturity types. Similar trend of results for association of 50% tasselling and 50% silking have also been reported by Vara Prasad (2014).

5.3.7 Maize stover yield

Maize maturity type exhibited significant variation in maize stover yield, with medium maturing Obatanpa recording the heaviest stover than the other maturity types (Fig. 7). This can be explained by the variation in maturity periods that existed between the varieties. In affirming this, Araus et al. (2008) stated that biomass accumulation in cereals is positively correlated to days to maturity. Again, the inversely proportional relationship exhibited between the stover and gain yield of Obatanpa is an indication that most of the dry matter accumulated by Obatanpa were translocated into the vegetative sinks instead of being translocated to the economic part (grains). This might be attributed to the drought intolerant nature of the Obatanpa variety. This agrees with previous research, which suggested that drought tolerant in maize is associated with a more efficient dry matter partitioning to grain production (Duvick, 1999; Nemali et al., 2015).

5.3.8 Maize grain yield

Legume living mulches have been reported to improve yield of crops (Singer, 2005). Consequently, from the present study living mulch interseeding times significantly increased grain yield of maize (Fig. 8). All maize plots interseeded with cowpea living mulch produced grain yield higher than the control – NLM. The difference in grain yield might have resulted from an enhanced nutrient (nitrogen and water) use efficiency (NUE), which was presumably improved by interseeding maize with cowpea live mulch. Accordingly, Kleinhenz et al. (1997) reported a better crop-N status in live-mulch plots than in no-mulch plots. Similarly, a higher total N-uptake by wheat was observed in a wheat-clover living mulch system compared to monoculture systems (Radicetti et al., 2018).

However, irrespective of the significant yield difference over the control – NLM, the time of interseeding cowpea living mulch at SDWM, 1 WAPM and 2 WAPM resulted in a different grain yield of 2.16 tons/ha, 2.29 tons/ha and 1.85 tons/ha respectively. This may suggest that cowpea live mulch interseeded 1 WAPM offered less competition to suppress grain yield of maize. These findings are generally in agreement with statement by other authors indicating that the efficiency of living mulch systems in terms of main crop yield is dependent on the live mulch's interseeding time (Muller-Scharrer & Potter, 1991; Vrabel et al., 1980).

5.3.9 Harvest index of maize

Harvest index is the ratio of harvested grain to the aboveground biomass of the crop expressed in percentage. The results shown that harvest index was significantly increased by maize maturity types (Table 6), with extra early Abontem producing significantly higher harvest index than early Omankwa and medium Obatanpa, in that order. This indicates a wide variation among maturity types in partitioning of photosynthates between the grain and vegetative parts. The findings of Worku et al. (2004) confirms this. However, the result from the present study was in contrast with Wnuk et al. (2013), who stated that a higher HI translates into a higher grain yield in cereal-legume cropping systems.

Living mulch interseeding time had significant effect on harvest index of maize. The results shown that, the control – NLM produced the lowest harvest index while interseeding cowpea SDWM produced the highest harvest index. This could probably be that interseeded cowpea significantly optimized the micro-climate to enhance the capacity of maize plants to allocate assimilate into the formed reproductive parts. This is in line with the results of Pierre et al. (2017), who reported similar findings on maize – soybean intercrop.

5.3.10 Water Use Efficiency (WUE)

Water use efficiency is an important yield determinant under water stress (Molden et al., 2010). Studies have found that living mulch systems involving two crop species such as legume and cereal may use water more efficiently than a monoculture of either species through exploring a larger total soil volume for water, especially if the component crops have different rooting pattern (Willey, 1979). Accordingly, from this study, a decrease in WUE for the control – NLM compared to interseeded cowpea live mulch plots was observed (Fig. 9). This might suggest that interseeded cowpea live mulch may have contributed significantly to efficient water use. Traits that might have conferred high WUE in interseeded plots were; extensive canopy cover (Huang et al., 2006) and effective utilization of available water (Singh et al., 2012), by component crops. In agreement with this results, several authors have reported high water use efficiency in maize - living mulch systems (Huang et al., 2006; Wiggans et al., 2012)

5.3.11 Weed biomass

Living mulches, apart from forming an important components in agroecosystems, can also be a useful approach for weed suppression in sustainable agriculture systems (Kruidhof et al., 2008). Consequently, from this present study, living mulch system reduced ($p < 0.05$) weed biomass at all growth periods (6 WAPM, 9 WAPM and at harvest). All the maize plots interseeded with cowpea living mulch produced weed biomass lower than the control – NLM. The significant reduction in weed biomass associated with live-mulch plots might be due to a number of mechanisms by which living mulches can supress weeds such as competition for light (Teasdale & Daughtry, 1993), moisture and nutrients (Mayer, 1986) and changes in physical soil properties such as temperature and soil porosity (Liebman & Davis, 2000; Yenish et al., 1995). Therefore, because weeds can be affected negatively through the above mechanisms, weed germination and growth will be supressed, as observed in the present study.

Furthermore, time of interseeding cowpea living mulch produced numerically different weed biomass, such that weed biomass increased with interseeding time of cowpea living mulch, in the order of cowpea interseeded SDWM < 1 WAPM < 2 WAPM. The difference might be due to the development of early ground cover which characterized the earlier interseeded cowpea living mulch, thus increasing its competitive ability against weeds. This result was similar to the observation by Kitis et al. (2011), who opined that a delay in weed species germination in relation to the living mulch will result in a reduced growth as the mulch species will shade and mechanically block growth of such weed species.

5.3.12 Weed species diversity

Resource use by maize – cowpea living mulch differed from that of maize – no living mulch systems and may have resulted in extensive canopy cover and weed species diversity. Results indicated that weed species diversity of no living mulch plots (control) was relatively lower than interseeded cowpea living mulch plots at both 6 WAPM and at harvest. This might probably be due to the live-mulch plot's ability to modulate solar radiation reaching weeds. This agrees with the reported lower diversity for mulch plots by Hassannejad & Mobli (2014). Similarly, as a result of shading, Tilman & Pacala (1993), reported thinning mortality effects on individual weed species, which consequently reduces weed species diversity. Out of the six (6) weed species of grasses identified at 6 WAPM, three (3) grass species *Bracharia alata*, *Bracharia deflexa* and *Paspalum scrobiculatum* shown consistent dominance while two (2) grass species *Hackelochloa granularis and Panicum laxum* appeared at harvest. The dominance shown might be due to the fast growth rate associated with grass weed species as reported by Li (1960). Similarly, Anele et al. (2013) reported that the growth of grass weed species, either sod-forming or bunch-forming is boosted when in association with legumes.

Sedge weed species diversity, on the other hand, did not usually differ among treatments. The experimental site used for the present study had been under continuous cultivation, and this might have affected the sedge weed specie richness and evenness over the years. According to Kone et al. (2013) these weed species are able to multiply rapidly through rhizome and/or tubers which can be greatly accelerated by soil tillage. Accordingly, Thomas (1985), reported that weed species diversity in a crop can be attributed to history of previous crops, cropping systems and cultural practices. Conversely, Gannon et al. (2012) indicated a chronically excessive soil moisture as the reason for increased dominance of sedge species.

Similarly, the dominance of broadleaves increased during cultivation. Out of the twenty-seven (27) broadleaves, the living mulch system suppressed and eliminated only eight (8) species. The most dominant broadleaves specie not suppressed were *Aneilema beniniense, Bidens pilosa, Euphorbia hirta, Gomphrena celosioides, Hyptis saveolens*, *Leucas matinencensis*, *Tridax procumbens* and *Vernonia ambiqua* . Once more resource use may also explain these results. The greater ability of broadleaves species to compete for resources under cowpea living mulch system might have been enhanced by canopy decay of both maize and cowpea plants. According to Satorre & Ghersa, (1987), open gaps created towards the end of crop's growing cycle, allows for the establishment and growth of weed species through increased light interception. Also Lawson et al. (2007) reported that, leaf fall and N – fixation of legume cover crops creates favourable edaphic conditions that encourages the growth and development of broadleaves. Akobundu (1987), reported that live-mulch (*Centrosema pubescens*) suppressed the growth of grasses but encouraged the growth of broadleaf weeds.

CHAPTER SIX

6.0 SUMMARY, CONCLUSION AND RECOMMENDATION

6.1 Summary

The effect of living mulch interseeding time by maize maturity type did not significantly influence soil physical properties at all sampling periods, likewise the effect of maize maturity type. Conversely, the effect of living mulch interseeding time was significant on soil physical properties (soil temperature, soil bulk density, soil porosity and volumetric moisture content) such that interseeding cowpea with maize same day improved soil physical properties than the other living mulch system.

Cowpea living mulch interseeding time and maize maturity type interaction had significant effect on maize plant height at harvest, maize leaf area index at 6 WAPM and days to 50% tasselling of maize; such that, medium maturing maize type (Obatanpa) with the control – NLM, early maturing maize type (Omankwa) with the control and medium maturing type (Obatanpa) with cowpea interseeded 1 WAPM gave the best maize plant height at harvest, leaf area index of maize at 6 WAPM and 50% tasselling of maize respectively. The effect of cowpea living mulch interseeding time had significant influence on maize plant height at 6 and 12 WAPM, maize leaf area index at 6 WAPM and 50% tasselling of maize; maize maturity type effect was significant on maize plant height at 3, 6 and 12 WAPM, maize leaf area index at 6, 8 and 10 WAPM, 50% tasselling and silking of maize.

Cowpea living mulch interseeding time and maize maturity type interaction did not significantly influence maize grain yield, maize stover yield and maize harvest index. Conversely, the effect of cowpea living interseeding time was significant on maize grain yield and harvest index, such that, cowpea interseeded 1 WAPM performed best for both grain yield and harvest index. Maize maturity type effect was significant on maize stover yield and maize harvest index, with medium maturing maize type (Obatanpa) and early maturing maize type (Omankwa) producing the best stover yield and harvest index respectively. However, the highest grain yield was realised from early maturing maize type (Omankwa).

The best weed suppressions was released from cowpea living mulch interseeded SDWM, which was statistically similar to cowpea interseeded 1 WAPM. Interseeding cowpea SDWM, however, gave the best weed suppression but a relatively lower yield than interseeding cowpea 1 WAPM.

6.2 Conclusion

This study has shown that, cowpea living mulch interseeding time by maize maturity type interaction and the effect of maize maturity type did not influence weed biomass, soil physical properties and grain yield of maize. However;

i. Cowpea living mulch interseeding time effect improved soil moisture and temperature at tasselling and harvest growth stages.
ii. For the best weed control, interseeding cowpea SDWM gave the lowest weed biomass and performed best in terms of weed species diversity.
iii. Interseeding cowpea at 1 WAPM gave the best maize performance by producing the highest maize grain yield, which was statistically similar to interseeding cowpea at SDWM.

Therefore, for enhanced maize yield and optimum weed control, farmers with enough labour can inter-seed maize with cowpea live mulch on the same day (SDWM). Alternatively, those face with labour scarcity could adopt maize with cowpea interseeded at 1 WAPM.

6.3 Recommendations

In this study, it is recommended that smallholder farmers in maize-based cropping systems take advantage of the weed suppression benefit of establishing cowpea living mulch either at the same day planting with maize (SDWM) or planting cowpea 1 WAPM. Nonetheless, further studies are required to investigate the effect of cowpea living mulch on soil chemical properties. Furthermore, long term experiments based on interseeding cowpea as a living mulch in maize are thus required to determine more positive effects on soil physical properties.

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APPENDICES

Appendix 1. Analysis of variance for soil temperature at vegetative stages

Source of	DF	SS	MS	F	P
Rep	2	28.6871	14.3435		
LMT	3	7.5632	2.5211	10.99	0.0001 **
MMT	2	0.6574	0.3287	1.43	0.2600 NS
LMT x MMT	6	0.7785	0.1298	0.57	0.7529 NS
Error	22	5.0456	0.2293		
Total	35	42.7319			

LMT_ Cowpea living mulch interseeding time, MMT_ Maize maturity type, ** Highly significant at $p < 0.01$, NS Not significant at $p > 0.05$.

Appendix 2. Analysis of variance for soil temperature at tasselling stage

Source of	DF	SS	MS	F	P
Rep	2	8.0608	4.03042		
LMT	3	6.5400	2.18001	10.74	0.0002 **
MMT	2	0.4408	0.22041	1.09	0.3549 NS
LMT x MMT	6	0.6453	0.10755	0.53	0.7795 NS
Error	22	4.4642	0.20292		
Total	35	20.1512			

LMT_ Cowpea living mulch interseeding time, MMT_ Maize maturity type, ** Highly significant at $p < 0.01$, NS Not significant at $p > 0.05$.

Appendix 3. Analysis of variance for soil temperature at harvest

Source of	DF	SS	MS	F	P
Rep	2	120.943	60.4716		
LMT	3	9.674	3.2245	5.15	0.0076 **
MMT	2	0.245	0.1223	0.20	0.8240 NS
LMT x MMT	6	4.094	0.6823	1.09	0.3992 NS
Error	22	13.777	0.6262		
Total	35	148.732			

LMT_ Cowpea living mulch interseeding time, MMT_ Maize maturity type, ** Highly significant at $p < 0.01$, NS Not significant at $p > 0.05$.

Appendix 4.Analysis of variance for soil bulk density at vegetative stage

Source of	DF	SS	MS	F	P
Rep	2	0.06142	0.03071		
LMT	3	0.00960	0.00320	0.96	0.4270 NS
MMT	2	0.01236	0.00618	1.86	0.1790 NS
LMT x MMT	6	0.01253	0.00209	0.63	0.7050 NS
Error	22	0.07298	0.00332		
Total	35	0.16889			

LMT_ Cowpea living mulch interseeding time, MMT_ Maize maturity type, * Significant at $p < 0.05$, NS Not significant at $p > 0.05$.

Appendix 5. Analysis of variance for soil bulk density at tasselling stage

Source of	DF	SS	MS	F	P
Rep	2	0.09082	0.04541		
LMT	3	0.06270	0.02090	3.38	0.0365 *
MMT	2	0.00802	0.00401	0.65	0.5326 NS
LMT x MMT	6	0.04593	0.00766	1.24	0.3256 NS
Error	22	0.13611	0.00619		
Total	35	0.34359			

LMT_ Cowpea living mulch interseeding time, MMT_ Maize maturity type, * Significant at $p < 0.05$, NS Not significant at $p > 0.05$.

Appendix 6. Analysis of variance for soil bulk density at harvest

Source of	DF	SS	MS	F	P
Rep	2	0.22729	0.11364		
LMT	3	0.05489	0.01830	3.63	0.0288 *
MMT	2	0.01342	0.00671	1.33	0.2844 NS
LMT x MMT	6	0.01431	0.00239	0.47	0.8207 NS
Error	22	0.11084	0.00504		
Total	35	0.42076			

LMT_ Cowpea living mulch interseeding time, MMT_ Maize maturity type, * Significant at $p < 0.05$, NS Not significant at $p > 0.05$

Appendix 7. Analysis of variance for soil porosity at vegetative stage

Source of	DF	SS	MS	F	P
Rep	2	0.01101	5.503E-03		
LMT	3	0.00149	4.963E-04	0.92	0.4472 NS
MMT	2	0.00227	1.136E-03	2.11	0.1454 NS
LMT x MMT	6	0.00179	2.991E-04	0.55	0.7612 NS
Error	22	0.01186	5.391E-04		
Total	35	0.02842			

LMT_ Cowpea living mulch interseeding time, MMT_ Maize maturity type, NS Not significant at $p > 0.05$.

Appendix 8. Analysis of variance for soil porosity at tasselling stage

Source of	DF	SS	MS	F	P
Rep	2	0.01194	5.969E-03		
LMT	3	0.00847	2.825E-03	3.16	0.0449 *
MMT	2	0.00091	4.528E-04	0.51	0.6094 NS
LMT x MMT	6	0.00732	1.219E-03	1.36	0.2723 NS
Error	22	0.01966	8.937E-04		
Total	35	0.04830			

LMT_ Cowpea living mulch interseeding time, MMT_ Maize maturity type, * Significant at $p < 0.05$, NS Not significant at $p > 0.05$.

Appendix 9. Analysis of variance for soil porosity at harvest

Source of	DF	SS	MS	F	P
Rep	2	0.03094	0.01547		
LMT	3	0.00650	0.00217	2.73	0.0685 NS
MMT	2	0.00191	0.00095	1.20	0.3200 NS
LMT x MMT	6	0.00169	0.00028	0.36	0.8988 NS
Error	22	0.01746	0.00079		
Total	35	0.05850			

LMT_ Cowpea living mulch interseeding time, MMT_ Maize maturity type, NS Not significant at $p > 0.05$.

Appendix 10. Analysis of variance for volumetric moisture content at vegetative stage

Source of	DF	SS	MS	F	P
Rep	2	0.00276	1.378E-03		
LMT	3	0.00016	5.463E-05	0.24	0.8685 NS
MMT	2	0.00069	3.444E-04	1.52	0.2403 NS
LMT x MMT	6	0.00144	2.407E-04	1.06	0.4132 NS
Error	22	0.00498	2.263E-04		
Total	35	0.01003			

LMT_ Cowpea living mulch interseeding time, MMT_ Maize maturity type, NS Not significant at $p > 0.05$.

Appendix 11. Analysis of variance for volumetric moisture content at tasselling stage

Source of	DF	SS	MS	F	P
Rep	2	0.01362	6.808E-03		
LMT	3	0.01073	3.578E-04	5.74	0.0047 **
MMT	2	0.00162	8.083E-04	1.30	0.2936 NS
LMT x MMT	6	0.00272	4.528E-04	0.73	0.6333 NS
Error	22	0.01372	6.235E-04		
Total	35	0.04240			

LMT_ Cowpea living mulch interseeding time, MMT_ Maize maturity type, ** Highly significant at $p < 0.01$, NS Not significant at $p > 0.05$.

Appendix 12. Analysis of variance for volumetric moisture content at harvest

Source of	DF	SS	MS	F	P
Rep	2	0.00277	1.386E-03		
LMT	3	0.00367	1.222E-03	3.24	0.0415 *
MMT	2	0.00057	2.861E-04	0.76	0.4801 NS
LMT x MMT	6	0.00098	1.639E-04	0.43	0.8477 NS
Error	22	0.00829	3.770E-04		
Total	35	0.01629			

LMT_ Cowpea living mulch interseeding time, MMT_ Maize maturity type, * Significant at $p < 0.05$, NS Not significant at $p > 0.05$.

Appendix 13. Analysis of variance for maize plant height 3 weeks after planting maize (WAPM)

Source of	DF	SS	MS	F	P
Rep	2	7.237	3.6186		
LMT	3	73.443	24.4810	2.07	0.1340 NS
MMT	2	167.661	83.83.03	7.07	0.0042 *
LMT x MMT	6	35.373	5.8955	0.50	0.8033 NS
Error	22	260.716	11.8507		
Total	35	544.430			

LMT_ Cowpea living mulch interseeding time, MMT_ Maize maturity type, * Significant at $p < 0.05$, NS Not significant at $p > 0.05$.

Appendix 14. Analysis of variance for maize plant height 6 weeks after planting maize (WAPM)

Source of	DF	SS	MS	F	P
Rep	2	3207.54	1603.77		
LMT	3	2473.69	824.56	11.42	0.0001 **
MMT	2	831.98	415.99	5.76	0.0097 **
LMT x MMT	6	438.85	73.14	1.01	0.4424 NS
Error	22	1588.49	72.20		
Total	35	8540.55			

LMT_ Cowpea living mulch interseeding time, MMT_ Maize maturity type, ** Highly significant at $p < 0.01$, NS Not significant at $p > 0.05$.

Appendix 15. Analysis of variance for maize plant height 9 weeks after planting maize (WAPM)

Source of	DF	SS	MS	F	P
Rep	2	1255.84	627.920		
LMT	3	900.39	300.131	1.73	0.1897 NS
MMT	2	433.84	216.920	1.25	0.3055 NS
LMT x MMT	6	1943.72	323.953	1.87	0.1317 NS
Error	22	3812.01	173.273		
Total	35	8345.80			

LMT_ Cowpea living mulch interseeding time, MMT_ Maize maturity type, NS Not significant at $p > 0.05$.

Appendix 16.Analysis of variance for maize plant height 12weeks after planting maize (WAPM)

Source of	DF	SS	MS	F	P
Rep	2	49.63	24.82		
LMT	3	901.28	300.43	21.70	0.0000 **
MMT	2	2437.74	1218.87	88.02	0.0000 **
LMT x MMT	6	380.11	63.35	4.58	0.0037 **
Error	22	304.64	13.85		
Total	35	4073.41			

LMT_ Cowpea living mulch interseeding time, MMT_ Maize maturity type, ** Highly significant at p < 0.01.

Appendix 17. Analysis of variance for maize leaf area index 6 weeks after planting maize (WAPM)

Source of	DF	SS	MS	F	P
Rep	2	0.04544	0.02272		
LMT	3	0.88308	0.29436	13.31	0.0000 **
MMT	2	0.25789	0.12895	5.83	0.0093 **
LMT x MMT	6	0.33378	0.05563	2.52	0.0500 *
Error	22	0.48658	0.02212		
Total	35	2.00677			

LMT_ Cowpea living mulch interseeding time, MMT_ Maize maturity type, ** Highly significant at p < 0.01, * Significant at p < 0.05.

Appendix 18. Analysis of variance for maize leaf area index 8 weeks after planting maize (WAPM)

Source of	DF	SS	MS	F	P
Rep	2	0.29535	0.14767		
LMT	3	0.41025	0.13675	1.04	0.3942 ^{NS}
MMT	2	1.00295	0.50148	3.82	0.0378 *
LMT x MMT	6	1.06154	0.17692	1.35	0.2794 ^{NS}
Error	22	2.89137	0.13143		
Total	35	5.66147			

LMT_ Cowpea living mulch interseeding time, MMT_ Maize maturity type, * Significant at p < 0.05, ^{NS} Not significant at p > 0.05.

Appendix 19. Analysis of variance for maize leaf area index 10 weeks after planting maize (WAPM)

Source of	DF	SS	MS	F	P
Rep	2	0.50320	0.25160		
LMT	3	0.39272	0.13091	1.05	0.3898 NS
MMT	2	3.72313	1.86156	14.95	0.0001 **
LMT x MMT	6	0.46484	0.07747	0.62	0.7107 NS
Error	22	2.73987	0.12454		
Total	35	7.82376			

LMT_ Cowpea living mulch interseeding time, MMT_ Maize maturity type, ** Highly significant at $p < 0.01$, NS Not significant at $p > 0.05$.

Appendix 20. Analysis of variance for 50% tasselling of maize

Source of	DF	SS	MS	F	P
Rep	2	6.500	3.250		
LMT	3	48.528	16.176	5.72	0.0047 **
MMT	2	444.500	222.250	78.65	0.0000 **
LMT x MMT	6	45.056	7.509	2.66	0.0430 *
Error	22	62.167	2.826		
Total	35	606.750			

LMT_ Cowpea living mulch interseeding time, MMT_ Maize maturity type, ** Highly significant at $p < 0.01$, * Significant at $p < 0.05$.

Appendix 21. Analysis of variance for 50% silking of maize

Source of	DF	SS	MS	F	P
Rep	2	33.500	16.750		
LMT	3	42.750	14.250	2.65	0.0744 NS
MMT	2	706.167	353.083	65.55	0.0000 **
LMT x MMT	6	25.833	4.306	0.80	0.5808 NS
Error	22	118.500	5.386		
Total	35	926.750			

LMT_ Cowpea living mulch interseeding time, MMT_ Maize maturity type, ** Highly significant at $p < 0.01$, NS Not significant at $p > 0.05$.

Appendix 22. Analysis of variance for maize grain yield

Source of	DF	SS	MS	F	P
Rep	2	2142049	1071025		
LMT	3	4802079	1600693	8.96	0.0005 **
MMT	2	905649	452824	2.53	0.1022 NS
LMT x MMT	6	1493618	248936	1.39	0.2613 NS
Error	22	39306625	178665		
Total	35	1.327E+07			

LMT_ Cowpea living mulch interseeding time, MMT_ Maize maturity type, ** Highly significant at p < 0.01, NS Not significant at p > 0.05.

Appendix 23. Analysis of variance for maize stover yield

Source of	DF	SS	MS	F	P
Rep	2	2.042E+07	1.021E+07		
LMT	3	2066776	688925	1.17	0.3445 NS
MMT	2	4.405E+07	2.202E+07	37.33	0.0000 **
LMT x MMT	6	2177429	362905	0.62	0.7159 NS
Error	22	1.298E+07	589878		
Total	35	8.169E+07			

LMT_ Cowpea living mulch interseeding time, MMT_ Maize maturity type, ** Highly significant at p < 0.01, NS Not significant at p > 0.05.

Appendix 24. Analysis of variance for maize harvest index

Source of	DF	SS	MS	F	P
Rep	2	993.8	496.89		
LMT	3	2785.6	928.53	4.66	0.0115 **
MMT	2	3537.7	1768.84	8.87	0.0015 **
LMT x MMT	6	1719.3	286.55	1.44	0.2453 NS
Error	22	4384.8	199.31		
Total	35	13421.1			

LMT_ Cowpea living mulch interseeding time, MMT_ Maize maturity type, * Significant at p < 0.05, NS Not significant at p > 0.05.

Appendix 25. Analysis of variance for water use efficiency

Source of	DF	SS	MS	F	P
Rep	2	4.4427	2.22136		
LMT	3	9.9493	3.31643	8.96	0.0005 **
MMT	2	1.8817	0.94086	2.54	0.1016 ^{NS}
LMT x MMT	6	3.1032	0.51719	1.40	0.2599 ^{NS}
Error	22	8.1438	0.37017		
Total	35	27.5207			

LMT_ Cowpea living mulch interseeding time, MMT_ Maize maturity type, ** Highly significant at $p < 0.01$, ^{NS} Not significant at $p > 0.05$.

Appendix 26. Analysis of variance for weed biomass at 6 weeks after planting maize (WAPM)

Source of	DF	SS	MS	F	P
Rep	2	84467	42233		
LMT	3	896342	298781	14.59	0.0000 **
MMT	2	12067	6033	0.29	0.7477 ^{NS}
LMT x MMT	6	43267	7211	0.35	0.9010 ^{NS}
Error	22	450533	20479		
Total	35	1486675			

LMT_ Cowpea living mulch interseeding time, MMT_ Maize maturity type, ** Highly significant at $p < 0.01$, ^{NS} Not significant at $p > 0.05$.

Appendix 27. Analysis of variance for weed biomass at 9 weeks after planting maize (WAPM)

Source of	DF	SS	MS	F	P
Rep	2	443739	221869		
LMT	3	402208	134069	6.01	0.0038 **
MMT	2	120439	60219	2.70	0.0895 ^{NS}
LMT x MMT	6	62717	10453	0.47	0.8241 ^{NS}
Error	22	490794	22309		
Total	35	1519897			

LMT_ Cowpea living mulch interseeding time, MMT_ Maize maturity type, ** Highly significant at $p < 0.01$, ^{NS} Not significant at $p > 0.05$.

Appendix 28. Analysis of variance for weed biomass at 12 weeks after planting maize (WAPM)

Source of	DF	SS	MS	F	P
Rep	2	377156	188578		
LMT	3	462919	154306	5.58	0.0053 **
MMT	2	92289	46144	1.67	0.2113 ^{NS}
LMT x MMT	6	183689	30615	1.11	0.3893 ^{NS}
Error	22	607911	27632		
Total	35	1723964			

LMT_ Cowpea living mulch interseeding time, MMT_ Maize maturity type, ** Highly significant at $p < 0.01$, ^{NS} Not significant at $p > 0.05$.