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EFFECTS OF PEARL MILLET (*Pennisetum glaucum* L.)–COWPEA (*Vigna unguiculata* L.) INTERCROP ON *Striga hermonthica* (DEL.) BENTH, YIELD COMPONENTS AND GRAIN YIELD IN THE SUDAN SAVANNAH ZONE OF GHANA

BY

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DECLARATION

I hereby declare that this thesis is my original work and that no part of it has been presented for another degree in this university or elsewhere. Work of others which served as useful information has been duly acknowledged by references to the authors.

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

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ABSTRACT

Field experiment was conducted on naturally *Striga hermonthica* infested field in the Kassena-Nankana East District of the Upper East Region during the 2018 cropping season. This was to investigate effects of *Striga* tolerant pearl millet varieties intercropped with cowpea on *S. hermonthica,* crop yield and yield components. The study was a 4 x 3 factorial experiment consisting of four pearl millet varieties (Akad-kom, Kaanati, Naad kohblug and Waapp naara) and three cropping patterns (Sole millet, Millet-cowpea (1:1) and millet-cowpea (2:1) laid out in a Randomized Complete Block Design with three replications. Results showed that Naad kohblug gave the highest plant height of 171 cm whilst Waapp naara gave the shortest at 9 WAP. Highest leaf area index was obtained with Naad kohblug (5.5) whilst Waapp naara gave the lowest leaf area index of 2.6 at 9 WAP. Grain yields of Akad-kom (1892 kg/ha) was the highest with millet-cowpea (1:1) as the best cropping pattern. *S. hermonthica* emergence and shoot biomass was highest with Waapp naara variety, which also gave the lowest grain yields (1778 kg/ha) and 1000 grain weight (8.3 g). Millet-cowpea (1:1) cropping pattern had the lowest *Striga* numbers and shoot biomass. Longest panicle length was obtained by Naad kohblug (31.1cm). Shortest days to 50% heading were found in Kaanati (40) and Akad-kom (42). Naad kohblug variety and MC (1:1) cropping pattern gave best total LER of 1.44 and 1.41 respectively. Grain yield was negatively correlated with *Striga* count (r = -0.42). Millet-cowpea (1:1) cropping pattern exhibited suicidal germination of *Striga* seeds, enhanced soil fertility and promoted *Striga* seed bank depletion of 46%. Resource poor farmers in *Striga* endemic areas could plant Akad-kom and Naad kohblug varieties as sole crops or intercropped with cowpea (1:1) to manage *Striga hermonthica* and maximize grain yields.

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DEDICATION

This research work is dedicated to the Almighty God, to whom all hearts are open, all desires known and from whom no secrets are hidden, to my parents, dear wife and children (Abel Akanfah, Peace Akanfah and Faith Awinbono Akanfah) and to my siblings.

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CHAPTER ONE

1.0 INTRODUCTION

Pearl millet (*Pennisetum glaucum* (L.) R. Brown) is a major cereal grown primarily in Africa and Asia in tropical semi-arid regions of the world (Vanisha *et al.*, 2011). It ranks after maize, rice and sorghum as the fourth most significant tropical cereal crop in the world (FAOSTAT, 2015). It is particularly crucial in marginal agricultural cultivation areas in sub-Saharan Africa where it offers food, feed and fodder to millions of individuals and animals (Camara *et al.*, 2005; Angarawai *et al.*, 2008; Nambiar *et al.*, 2011). India and Africa are the most important producers with more than 85% of the world's production (FAOSTAT, 2015).

Pearl millet is an important crop in Niger, Mali, Burkina Fasso and Nigeria where it is either ranked first, second or third most important cereal crop (FAOSTAT, 2016). Pearl millet is a staple food crop for more than 90 percent of the population and ranks third as a staple crop in northern Ghana after maize and sorghum (Asungre, 2014). It is harvested earlier than other crops to mark the end of the "Hunger gap" for most subsistence farmers of the north when the previous year's grain stock is exhausted. For millions of poor people in the areas where it is produced, it is a source of protein, vitamins, minerals and carbohydrates. Pearl millet is a dual purpose crop as it provides human food, poultry feed and livestock feed (Mati and Rodriquez, 2010). The composition of millet grain is approximately 62-72% carbohydrates, 11% protein, 4-8% fat, 1.5-2.7% Ash, 3.68 mg/g Lysine and 270-390 ppm Phosphorous (Asungre, 2014).

In the Sahelian and Sudan savannah regions, where the average annual rainfall ranges from 650 to 1200 mm, pearl millet is mainly produced as a rainfed cereal crop. It is usually planted between May and June and sometimes July, and most times in mixed/intercropped with sorghum.

1.1 Problem statement

Pearl millet is the least researched crop in terms of improvement despite its importance in food security in northern Ghana (Dawud *et al.*, 2017). Although this crop is indigenous and exceptionally adapted to the region, pearl millet yields are generally less than 1 ton per hectare (FAOSTAT, 2016), below yields of other major cereal crops. Factors responsible for this low yields include low soil fertility, low inputs and heavy infestation by parasitic weed *Striga hermonthica* (Del.) Benth (Fadelmola *et al.*, 2014; Dawud *et al.*, 2017).

S. hermonthica is a major biotic problem to pearl millet cultivation particularly in northern Ghana (Ayman *et al.*, 2014; Dawud *et al.*, 2017). In the Sudan savannah, *S. hermonthica* infestation appears to be spreading and it is gradually becoming a growing pandemic and a problem to subsistence farmers with small land holdings (Pennisi, 2010). *Striga hermonthica* can cause yield loss ranging from 20 to 100% when susceptible varieties are grown (Parker, 2012). Farmers sometimes are forced to abandon their land due to high infestation of the parasitic weed *S. hermonthica* (Atera *et al.*, 2012). *S. hermonthica* is observed in most pearl millet growing areas of northern Ghana.

Control of *S. hermonthica* has become a difficult task given the seed production rate of 10,000 to 100,000 seeds per plant (Ikie *et al.,* 2006), the longevity of the seeds in the seed bank (Ejeta and Gressel, 2007). Abunyewa *et al.* (2003) recorded an average count of 9384 plants m^{-2} on recultivated soil in the Sudan savannah area of Ghana after fallowing. Inherent low soil fertility and mono cropping have increased the *S. hermonthica* seed bank and infestation. Recommended methods of managing *S. hermonthica* control methods such as N application, use of trap crops, chemicals, cultural, use of resistant/tolerant varieties and biological control have not been adequately effective in managing the weed (Lagoke *et al.*, 1988).

Intercropping with legumes that induce suicidal germination of *Striga* has also been practiced, but reduction in infestation has been very low compared to seed bank. All the above challenges coupled by the fact that *S. hermonthica* emerges above the soil surface when it has already done extensive damage to a crop indicate the need to synergise *Striga* management technologies for a sustainable yield increase. Farmers have attempted to intercrop *Striga* tolerant millet varieties released by Savanna Agricultural Research Institute (SARI) with cowpea, but there is little information on its efficacy in reducing *Striga* infestation, as well as increased yield and economic productivity. Also, these genotypes were not commonly screened under *S. hermonthica* susceptible areas in Sudan savannah region of Ghana.

1.2 Justification

Several potential management strategies, including physical, cultural, chemical and biological, have been established against the parasitic weed. However, these practices only have a restricted effect on managing *S. hermonthica* and no single control technique is available today that can efficiently resolve this issue. Intercropping of *Striga* tolerant pearl millet and cowpea can serve as a means of maximizing the use of limited farm land; improve food security of farmers because higher yields can be obtained. Intercropping millet and cowpea can suppress the germination of *S. hermonthica* weeds, improve soil fertility, reduce the level of inorganic fertilizer requirement and reduce *Striga* seed bank (Sunda, 2014).

Using host plant resistance is considered to be the most economically feasible and sustainable approach to minimize the effects of the *S. hermonthica* weed (Badu-Apraku *et al.,* 2007). New *Striga* tolerant varieties of pearl millet bred and released by Savannah Agriculture Research Institute (SARI) Tamale-Ghana can be used in management of *Striga* seed bank and infestation.

The potentials of cereal/legume intercropping and rotation to manage *S. hermonthica* infestation in cereal crops have been demonstrated under controlled conditions (Mbwaga, 2001). There is the need to intercrop *Striga* tolerant pearl millet with cowpea on a naturally infested field. Information on *Striga* tolerant pearl millet intercrop with cowpea is an important requisite for developing effective control protocol for *S. hermonthica*. The study was therefore undertaken with the following main and specific objectives:

1.3 Main objective:

To evaluate the effects of intercropping pearl millet and cowpea on *S. hermonthica* management, yield components and grain yield.

1.3.1 Specific objectives were to:

1. Evaluate four improved *Striga* tolerant pearl millet varieties in terms of yield components and grain yield,
2. Evaluate the performance of four varieties of pearl millet intercropped with cowpea in different cropping patterns in terms of yield components and grain yield,
3. Determine the most effective cropping pattern in pearl millet-cowpea intercrop for the control of *S. hermonthica* and reduction of *Striga* seed soil bank,
4. Determine the effect of pearl millet-cowpea cropping system on soil physico-chemical properties.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Pearl millet botany and morphology

Pearl millet (*Pennisetum glaucum,* (L.) R. Brown) is a member of the poaceae family with a relatively small diploid chromosome (2n=2x=14) and a deoxyribonucleic acid content (DNA) of 1 C 2.36 pg (Martel *et al.,* 1997). It is an extremely outcrossing species, with an outcrossing of more than 80% (Debieu *et al.,* 2017). As an open pollinated crop, pearl millets are extremely heterogeneous and therefore morphologically more feasible than single cross hybrid pearl millets (Rai *et al.,* 2009). Domestication of pearl millet started from the wild species, *Pennisetum glaucum* sub species *monodii* around northeast Mali to Lake Chad (Manning *et al.,* 2011). Burgarella *et al.* (2018) reported its origin to be Western Sahara by providing evidence of gene flow from wild to cultivated types.

Pearl millet is hardy cereals with high tillering capacity to enable it withstand harsh environmental conditions in regions where it is cultivated. It performs better than other cereals on saline and acidic soils where other cereal crops cannot produce seed (Jukanti *et al.,* 2016). Andrews *et al.* (1993) reported that pearl millet is a highly tillering, cross pollinated species with a perfect flower on each head. Numbers of tillers varies considerably in different varieties and are primarily from basal nodes. Plant height, panicle length, seed size and seed colour of pearl millet depends on the varieties and the condtion of the environments (Syngentafoundation, 2005).

2.2 Importance and uses of pearl millet

Locally known as "Naara," pearl millet is a very nutritious cereal. Globally, pearl millet is cultivated on an area of 34.6 million hectares with an annual production of 28.8 million tonnes, according to the Food and Agriculture Organization (2005). It is the main source of energy, protein, vitamins and minerals in the areas in which they are produced for millions of people. According to Alhassan (2017), pearl millet usually contain between 9 and 13 percent protein, with large variations between cultivars ranging from 6 to 21 percent. The calories in pearl millet are more than wheat, likely due to its 5% greater oil content, of which 50% are polyunsaturated fatty acids. It is rich in calcium, potassium, magnesium, iron, zinc, manganese, riboflavin, thiamine, niacin, lysine, and tryptophan (ICRISAT, 2013).

Pearl millet grains are gluten-free and retain their alkaline properties after cooking, making it ideal for people with allergies to gluten (ICRISAT, 2013). Pearl millet grain is used as starch in the alcohol industry for various industrial uses. It has a very elevated dietary importance for poultry and animal feed. Other uses of pearl millet grains show their elevated health food, bakery and poultry feed and brewing potential. Pearl millet is grown purposely as food crop in Ghana with the stalks used diversely as fodder, material for roofing and fencing or source of saltpeter for cooking local food (Asungre, 2014). It can also be harvested as a hay crop. Pearl millet is a short day cereal crop that flowers earlier when the day lengths are short (Clerget *et al.*, 2007) and long photoperiod delays floral initiation (Uzoma *et al.*, 2010). According to Taylor (2006), pearl millet is very significant towards the achievement and maintenance of food security in Africa. Similar report was made by FAO (2008) that small grains are the best resort to avoiding chronic food shortages in the rural communities within the Sub-Saharan region due to their high levels of adaptability to conditions within the African terrain.

Pearl millet is more tolerant to drought (Nouri *et al.*, 2003) and low soil fertility than sorghum. New pearl milet varieties may reduce the possibility of zero yields (Alumira and Rusike, 2005). They can therefore make an important contribution to household food security in years of drought. Pearl millet crop is mostly grown as a rain fed monsoon crop during the rainy season and also, to a limited extent, as an irrigated summer season crop. It is often grown in rotation with sorghum, groundnut, cotton, foxtail millet, finger millet, and rice (Alumira and Rusike, 2005). Pearl millet can be followed by horse gram in the same year if it is sown in early May. The following rotations may be pearl millet-cotton-sorghum or pearl millet-sorghum-cotton in areas where sorghum and cotton are cultivated. In northern Ghana which is characterized by hot, dry conditions and infertile soils with low water holding capacity, pearl millet has the ability to produce grain yield where other crops generally fail completely, making it a preferred crop to start with immediately the rains set in (CGIAR, 1996). The pearl millet's aforementioned features make it meet most of its producers ' nutrient needs, which are considered poor and deprived peasant farmers.

2.3 Climate change and conservation of pearl millet

The main constraints for farmers living in semi-arid and arid tropicis are yield instability, the risk of crop failure and food insecurity. These constraints result from unreliable and erratic cropping season rainfall (Kasei, 2001). Boyer (1982) found genetic factors associated in plant response to drought stress, which is very important and vital for breeding plants. According to him, draught is a major limiting factor for agriculture and usually leads to crop yields being reduced.

As a result of global warming and greenhouse gas emissions, the world has experienced rising climatic conditions (Akromah, 2012). Efficient observation of species and genes does not support these situations, but rather serves to erosion of fastened genes and extinction of species. A significant north-south gradient characterizes the West African rainfall. This is a very profound gradient with broad differences of 15 to 30 percent over a brief interval owing mainly to the Inter Tropical Convergence Zone movement (Andre, 2008). The drier climate, accompanied by adverse effects on plant genetic resources, mostly cereals such as pearl millet, is the result of Western Africa's Southward advance of the Sahara desert (Akromah, 2012). The food basket is adversely affected by climate change in the sub-region of West Africa. The average yields pearl millet in situations like this and sorghum becomes relatively unstable over the years.

Ghana is equally experiencing the impact of climate change and this has called for the need to rethink agricultural strategies used. Kasei (2001) reported that the Sudan savanna zone of Ghana, although experiencing high annual rainfall figures of between 900-1120 mm, is seriously affected by annual water loss through evapotranspiration with a high occurrence of site-specific drought spells and soils that possess poor water holding capacity. Smallholder cereal crops exist extensively in sahelian West Africa where the average cultivation of cereal grain is 80 percent with an average growing period of 100-150 days in order to withstand these poor growing situations as well as the food deficit (Andre, 2008). Mangat (1992) reported that pearl millet performance was largely influenced by interactions between the environment and genetype. Therefore, variations in the Sudan and Sahel sub-region's micro-climates are expected to have a significant impact on major yield components of the cereal crop as well as its distribution in the growing regions of Ghana and West Africa as a whole.

2.4 Biotic constraints for pearl millet production

Major biotic constraints to pearl millet production include pests, diseases (*Heliochelius albipunctuella*), low yielding potential of local varieties, grain eating birds and parasitic weeds (*Striga hermonthica*) (Soler *et al*., 2008; Spencer and Sivakumar, 1987). According the Syngenta Foundation for Sustainable Agriculture (2005), Downy mildew, *Striga*, smut, erygot and rust are the deterrents to pearl millet production, with the first two being by far the most important. Mignounna *et al.* (2013) reported that *Striga hermonthica* (i.e., witchweed) threatens the livelihood of 300 million people and causes annual yield losses estimated at $7 billion. More than 17 countries in West, Central and Southern Africa are highly infested and complete crop losses are common in these areas (Lagoke *et al.*, 1991). In Mali, Konate (1986) reported that *Striga* threatens the major food crops (millet, sorghum, maize and cowpea) with field infestation, varying from 1 to 80% and yield losses varying between 25 to 100%. *Striga hermonthica* is a hemi-parasitic weed of millet and sorghum. The weed is an obligate parasite, implying that it will only germinate if triggered by the presence of host roots (or other sources that produce the chemical stimulants that stimulate germination) and it only completes its cycle and produce seed if attached to a host.

2.5 The genus and life cycle of *Striga hermonthica*

The most important parasitic seed plant in Africa belongs to the *Striga* genus of the Scrophulariaceae family. Members of this genus are obligatory annual hemiparasites; a host is required to finish their life cycle (Musselman, 1987). Although 30 or more *Striga* species have been mentioned, only five (5) are presently of economic importance in Africa (Ramaiah *et al.*, 1983). Their economic utility order in Africa is as follows; *S. hermonthica* Benth, (Del.) Kuntze, *S. asiatica* (L.) Kuntze, *S. gesneriodes* (Willd.), *S. aspera* (Willd.) Benth and *S. forbesii* Benth. All apart from *S. gesneriodes* are obligate parasites of cereal grains such as maize, sorghum, pearl millet and rice. Cowpea and other wild legumes are host for *S. gesneriodes*. Regardless of the host parasite combination, the life cycles and symptoms of *Striga* parasitism are basically the same although there are some few differences. Below is a generalized life cycle of *Striga* (as shown in Fig. 1.).

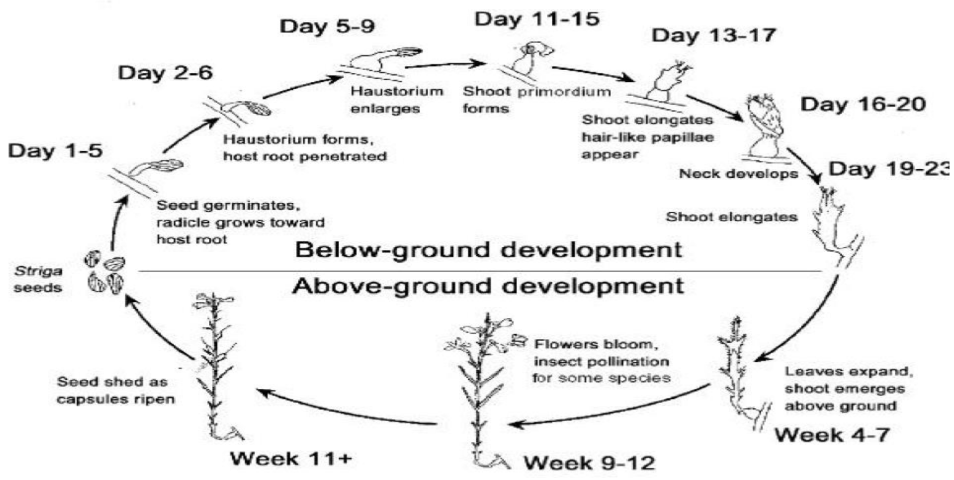

Figure 1: A generalised life cycle of witch weed, *Striga spp.*

Source: *Striga* Research methods (Berner, 1997)

Striga hermonthica is an obligate parasite and hence modulates its growth habit to correspond with its host life cycle (Ejeta and Gressel, 2007). Germination of the weed follows in response to chemicals exuded by the host crops. For parasitic attachment, whether initiation of germination or haustorial needs to occur very close to the host roots. *Striag hermonthica* seeds undergo through a period of dormancy and cannot sprout in the season in which they are produced. This is because of the after ripening requirement, which limits newly mature *Striga hermonthica* seed from germinating too late in the season, when hosts capable of helping a parasite weed to maturity are (Ejeta and Gressel, 2007). *Striga hermonthica* produces between 50,000 and 200,000 seeds per fully mature plants which stays dormant in the soil up to 20 yearst (AATF, 2006). These seeds are small and therefore have limited energy reserves. These conditions will make a sprouted *Striga hermonthica* to live in a free-livng state for only a short day because it must solely depend upon its tiny seed reserves. The weed will therefore need to attach to the host for survival.

There has been the problem with *S. hermonthica* in the field of farmers within Lake Victoria Basin and Western Kenya since 1936 (Ndwiga *et al.*, 2013). Ninety five percent (95%) of the continents *S. hermonthica*-infested fields are in fifteen countries of Eastern, Southern and West Africa (Ndwiga *et al.*, 2013). Farmers and various organizations using both traditional and conventional single stop gap *Striga* management efforts have tried to eradicate *Striga*, but the weed still pose a challenge. *S. hermonthica* life cycle showing host parasite interaction (Fig. 2).

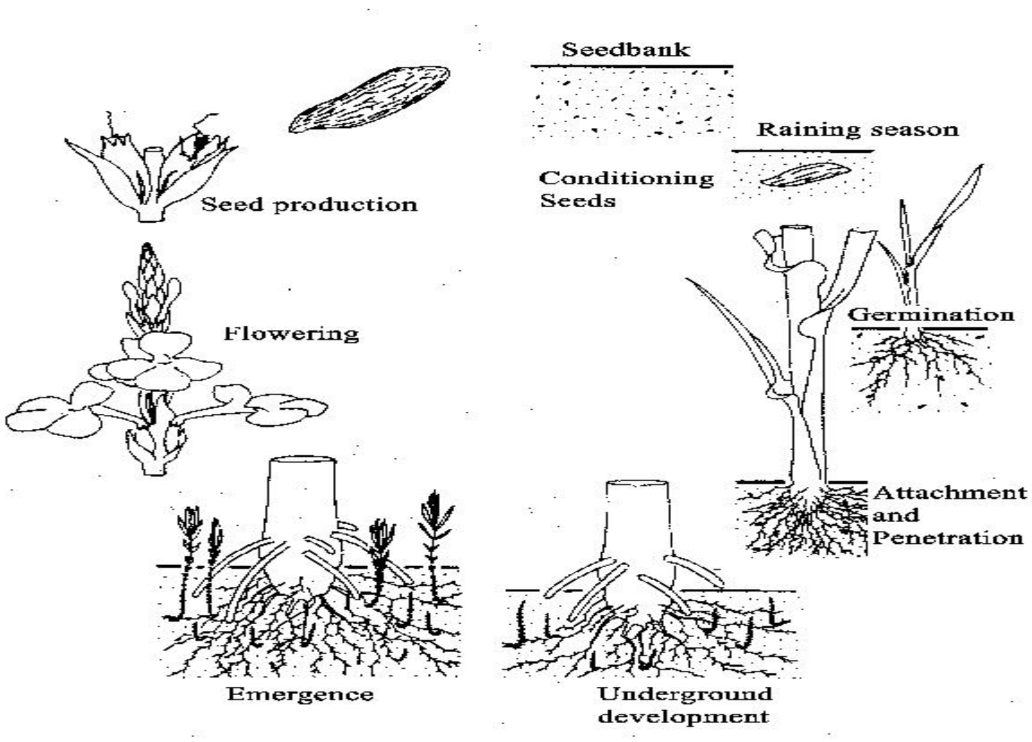

Figure 2: *Striga* in Pearl millet

Source: *Striga* Research Methods (Berner, 1997)

2.6 Origin, distribution and host range of *Striga*

"Witchweed" is a trivial name for *Striga hermonthica* because it attaches itself to the roots of the host and thus deprives the host plant of water and nutrients. *S.*

hermonthica belongs to the family of Orobanchaceae (Matusova *et al.*, 2005). More than 50 nations have recorded economically significant *Striga* species, particularly East and West Africa and Asia (Aly, 2007). In northern Africa and entends from Ethiopia and Sudan to Namibia, *Striga hermonthica* are very common (Gethi and Smith, 2004).

In Africa, Nigeria, Sudan, Mali, Burkina Faso and Ethiopia are heavily affected countries by *S. hermonthica* (AATF, 2011). Apart from cereals, its attacks varied of the wild grasses due to its wider host ranged. Maize (*Zea mays* L.), sorghum (*Sorghum bicolor* L.), pearl millets (*Pennisetum glaucum* L.), sugarcane (*Saccharum officinarum* L.) and rice (*Oryza sativa* L.) are the parasite-connected local crops in the African savanna (Babiker, 2007). Nubian hills of Sudan and Semien mountains of Ethiopia are known to be where *Striga hermonthica* and *Striga asiatica* originated (Ejeta and Gressel, 2007).

Over the years, *Striga* has spread through man's operations to other areas of sub-Saharan Africa. Nine (9) *Striga* speceis, including *Striga hermonthica*, *Striga asiatica* and *Striga gesneriodes,* have been discovered. *Striga hermonthica* is the most dangerous and commond especially in densely populated regions (MacOpiyo *et al.*, 2010) where it is located.

2.7 *Striga* economic importance

Infestation of *Striga* leads the agricultural economy of Africa to lose 30% to 50% on its productive soil (Amudavi *et al.*, 2007; Hearne, 2009). A study undertaken in 30 communities in Bono State, Northern Nigeria, showed that farmers ranked *Striga* infestation as the top priority challenge combined with low soil fertility for crop cultivation (Dugji *et al.,* 2006). Other investigations (Weber *et al.,* 1995) indicated *S. hermonthica* as a severe issue in Nigeria's Guinea savanna and yield losses ranged from 10% to 100%. A study of 83 farmers showed that *S. hermonthica* infested 73 percent of farms (woomer and savala, 2009) in Western Kenya.

In Kenya, average yield losses due to *Striga* are 1.15, 1.10 and 0.99 tonnes ha^{-1} for corn, sorghum and pearl millet, respectively (MacOpiyo *et al.,* 2010). However, in some fields with elevated *Striga* densities, the harm can reach up to 2.8 tonnes per hectare in corn and sorghum (Andersson and Halvarsson, 2011). This is an evidence of about 39.6 kg per capita maize loss, about 20 percent of the annual food requirement of a typical person. This is a clear indication of the consequences of *Striga* infections making smallholder fears helpless and often confused. It needs innovative and focused action to help them recover their soil's health in order to overcome this agricultural scourge.

2.8 *Striga hermonthica* control Methods

2.8.1 Methods of mechanical and cultural control

Several cultural methods, such as hand weeding, plant rotation, intercropping and fertilizer use, have been suggested for *Striga hermonthica* control (Ransom, 2000; Oswald and Ransom, 2001; Udom *et al.,* 2007; Jamil *et al.,* 2011) to decrease *S. hermonthica* seed production. Many of the traditional control strategies are still in vogue, including crop rotation, intercropping, trap and catch cropping, hand pulling, and fertilization according to Babiker (2007). Some of these techniques enhance soil fertility, stimulate host growth, but also adversely affect germination, attachment and subsequent development of *S. hermonthica* juvenile weeds (Fasill and Vrkleiji 2007). This approach, however, has only limited success for smallholder farmers, largely due to socio-economic and financial challenges.

2.8.1.1 Crop rotation practice on *Striga hermonthica* management

It is a low cost technology and solves the problem of poor soil fertility and infestation by *S. hermonthica*. Crop rotation together with non-host has proven to disrupt production of *S. hermonthica* that leads to a reduction of the weeds. Cereal-legume rotation has been discovered to decrease *S. hermonthia* infestation by 35% after a year and by 76% two years after rotational legumes (Kureh *et al.*, 2006). In reducing *S. hermonthica* infestation, soybean was more effective and also produced higher grain yield of maize than in cowpea in Guinea savanna zone of Nigeria (Kureh *et al.*, 2006). With dwindling farm sizes, crop rotation is becoming less feasible because of the increasing demand for land to produce the cereals and where rotations are made, it hardly surpasses the three years required for rotation to be effective in controlling *S. hermonthica* (Parker and Riches, 1993). This method offers advantages to small holder farmers in terms of crop diversity and risk avoidance, but this has led to low maize reserves and widespread incidences of pests and diseases. This is because smallholder farmers depend on cereals as their primary source of food and rotation during certain instances when the legumes are cultivated would not allow them to grow the cereals. This would lead to a reduction in cereal grain reserves from the previous season.

The potential for adoption of the technique rely on whether the break plant is a high value crop that fits into the cropping system. It also relies on whether the seeds for the break crop are widely available. If neighbors do not adopt the system, its effectiveness becomes limited. For pests and diseases, mono-cropping during one season would lead to the advance of a particular pest or disease, and if there is an epidemic, the probability of total crop failure is high. A common practice with most small holder farmers in Kenya, however, is intercropping maize with legumes so that the farmers can have yields from both. Crop rotation is therefore not a feasible venture when used alone.

2.8.1.2 Intercropping practice on *Striga hermonthica* management

Intercropping is the agricultural practice of producing two or more plants simultaneously in the same space with the aim of matching crop demand efficiently with the available growth resources and labor (Lithourgids *et al.*, 2011). The traditional advantage of intercropping is the production of higher yield on a piece of land by ensuring more efficient use of the available growth resources using a mixture of crops of varied rooting ability, canopy structure, height and nutrient requirements based on the complementary utilization of growth resources by the component crops (Lithourgids *et al.*, 2011). Oshwald *et al.* (2002) assessed *S. hermonthica* control ability of varied legume: cowpeas, soybeans, Bambara and groundnuts in Western Kenya. This was done in varied planting patterns with maize. The results led to a conclusion that though *S. hermonthica* numbers were decreased by the intercrops, if *S. hermonthica* was not uprooted before seed dispersal in a planting season, the season to season reduction in *S. hermonthica* numbers was significant.

Some cultivars of cowpea, soyabean and groundnut have however proven to have managed *S. hermonthica* to some extent through a combination of mechanisms. The strategies range from induction of suicidal germination of *S. hermonthica* seeds, nitrogen fixation and smothering effect (Sunda, 2014). In Ethiopia, Reda *et al.* (2005) found no significant variation between 10 varied legunes intercrop sorghum in the control of *S. hermonthica*. The *S. hermonthica* control was not different when the legume intercrops were compared to each other. Intercropping different legumes together with maize and sorghum, green leaf and crotalaria indicated some promise as a suitable component of an integrated *S. hermonthica* management strategy for smallholder farmers, but this would require to be combined with other cultural practices such as hand weeding and uprooting of the emerged *S. hermonthica* to avoid replacement of *S. hermonthica* seed bank (Khan *et al.*, 2007).

In conventional intercrops, competition for light by crops significantly contributes to lower yields (Mukhwama *et al.*, 2002). Intercropping disrupts pest cycle and improves opportunities for symbiotic nitrogen fixation (Woomer *et al.*, 2004). Maize intercrop with beans with two rows of maize and two rows of beans has led to increased yield in maize significantly by 51.2 and 61.4 percent respectively over farmers own practice and intercropping with one row of beans only (Ariga and Berner, 2001). Legumes intercropped with sorghum have proved to reduce *S. hermonthica* infestation in Nigeria, although sorghum yields were not significantly improved (Gworgwor, 2002). The use of *S. hermonthica* tolerant pearl intercrop with cowpea can thus lead to an increase in both cereals and legumes yields while reducing *S. hermonthica* infestation.

2.8.1.3 Hand pulling

Hand pulling is done through the normal weeding process that involves uprooting the *S. hermonthica* by hand. Hand pulling of *S. hermonthica* has been shown to reduce its infestation, but only if done before seed set, (Parker and Riches, 1993). The method is however time consuming and labour intensive (Khan *et al.,* 2003). Due to high costs of labour in continuously hand pulling of *S. hermonthica*, it appropriate that hand pulling should not start until 2-3 weeks after *S. hermonthica* starts to flower to remedy seedling (Parker and Riches, 1993). It is also only effective in reducing the weed infestation during preceding seasons since most of the harmed by *S. hermonthica* exists before the weed germinates from the ground. *S. hermonthica* also continues to mature in the field after maize has been harvested (Woomer and Savala, 2008), which is a time when hand weeding is not done. This therefore leads to further flowering and shedding of seeds which increases the *S. hermonthica* seed soil bank.

2.8.1.4 Fertilizer application on *Striga hermonthica* management

S. hermonthica is more favor in less fertile soil, a system that would improve soil fertility to increase yield as well as reduce *S. hermonthica* infestation will be also of double advantage. *S. hermonthica* infestation decreased with increasing soil organic matter and organic matter content seemed to be the main important factor which preserved the fertility of the soil (Vogt and Honisch, 1991). The use of crop residues and organic manure has been an effective preventive strategy against *S. hermonthica.* Soil micro-organisms thrive well in a medium high in organic matter, organic or inorganic soil enhancements may increase soil suppressiveness to *S. hermonthica*, and also enhance soil conditions to maximize yield of subsequent cereal.

According to Hess and Ejeta (1987) the application of N using urea recorded a reduction of 55-82% in *Striga hermonthica* numbers and weight. Mumera and Below (1993) also indicated that N fertilisers changes the assimilation partitioning in favor of the ear and maximized maize yield and decraesd *S. hermonthica* number by 64%. There was significantly reduction in Striga hermonthica infestation of 120 kg N ha^{-1} in the early variety of maize and 60 and 120 kg N ha^{-1} in late varieties. During conditioning, the nitrogenous compound fertilizer with urea considerably suppressed the germination of *S. hermonthica* when appied (Dzomeku and Murdock, 2007). The sprouting of *S. hermonthica* seed is associated with the production of germination stimulants by host crops. The secretion mainly relies upon the nutrient status of the soil (Jamil *et al.,* 2011). It has been demonstrated that lack of N and P, host crops produce high quantities of germination stimulants intothe rhizosphere, while adequate provision of N and P decrease this production (Lopez-Raez *et al.*, 2008; Jamil *et al.*, 2011). Research studies indicated that the effect of N was much less than the effect of P on strigolactones secretion. As diammonium phosphate (DAP) fertilizer contains 18% N and 46% P_2O_5, high availability of P in diammonium phosphate (DAP) might lead to low production of strigolactones. However, direct suppressing effect of N on *S. hermonthica* cannot be ignored (Simier *et al.,* 2006).

2.8.1.5 Trap and catch crops

Trap crops result in suicidal germination of the parasitic weed, which reduces the seed soil bank. According to Carsky *et al.* (2000) and Schulz *et al.* (2003) varieties of some legumes such as cowpea, soybean and groundnut have the aability to cause suicidal germinatin of *S. hermonthica* and subsequently improve soil fertility. The use of trap plants such as soybean also causes suicidal germination of *S. hermonthica* seedlings that do not eventually attack soybean; the *S. hermonthica* is ploughed off before flowers start, thus decreasing the amount of *S. hermonthica* seeds in the soil (Umba *et al.*, 1999).

In International Institute of Tropical Agriculture (IITA), 40 genetypes of soybeans were screened for their ability to stimulate *S. hermonthica* seeds germination using the cut roots soybean plants. The results indicated significant difference among the soybean genotypes in their ability to induce seed germination. Hess and Dodo (2003) also found that the use of leguminous trap crops that include varieties of groundnut (*Arachis hypogaea*), soybean (Glycine max), cowpea (*Vigna unguiculata*), and sesame (*Sesamum indicum*) stimulate the suicidal germination of *Striga* is another technology to control *Striga.* De Groote et al. (2010) found that soybean triggers suicidal germination of *Striga* and reduces the *Striga* seed bank in the soil when intercropped with maize.

2.8.2 Biological control

Biological control refers to the intensional ues of microbial organisms to supresse, decrease, or removes a pest poplation (Boyetchko, 1999). Biological methods of control comprise herbivorous insects, micro-organisms and smother plants (Sauerborn and Kroschel, 1996). These control agents can be used to manage several pests, including *Striga* weed.

2.8.3 Chemical control

Herbicides, fumigants (e.g. methyl bromide) and germination stimulants (e.g. ethylene) are chemicals that have been reported as a means of controlling *Striga* (Egley *et al.*, 1990). The herbicides ' control capacity is due to their relatively long rhizosphere persistence. Multi-location testing also indicated that this herbicide provided excellent early season control of both *Striga hermonthica* and *Striga asiatica* and was able to maximize yiled 3 to 4 folds in heavily infested areas (Kanampiu *et al.*, 2003). Simple herbicides can efficiently killed *Striga* emerged plants. However, much harm is done by the whole parasitic young plants before *Striga* emergence, so such herbicide treatments do not necessarily decrease yield losses. Accordingly, the major control strategy is to reduce the *Striga* seed bank in the soil by inducing the seeds to germinate without host crops (Hesammi, 2013).

2.9 Cropping systems in Ghana

Common cropping systems include monocropping, crop rotation, relay cropping, mixed cropping and inter-cropping. Among these cropping systems, the one that receives much attention as far as research is concerned is intercropping (Abdul-Rahaman, 2010). Row configurations in an intercrop system change the amount of light transmission to lower plant layers and affect the species' competition for water, light and nutrients.

2.10 Factors that influence intercropping systems of cereal-legumes

According to Brintha and Seran (2009), several elements of the effective intercropping scheme need to be taken into consideration before and during the production phase. For example, the capacity of the intercropping scheme for cereal-legume to supply nitrogen relies on plant density, plant species, nutrients and light interception (Francis, 1989). The choice of compactible crops, however, is based on crop habit, soil, light and water and fertilizer use (Brintha ansd Seran, 2009).

2.10.1 Maturity of the crops

The largest complementaryeffects and biggest yield advantages exist when the component plants have varied growing periods so make their ultimate demands on resources at different period (Ofori and Stern, 1987). Hence, crops which mature at different periods thus separating their times of maximum demand tonutrients and moisture aerial space and light could be suitable intercropped (1977). For example, Reddy and Reddi (2007) showed that, in maize/greengram intercropping system, maximum light demand for maize was around 60 days after planting, while greengrm was ready to harvest.

2.10.2 Compactible crops

Selection of the right crop combination is very crucial in intercropping systems because of the fact that crop competition could be reduced not only by spatial configuration, but also combining those plants best able to exploit soil nutrients (Fisher, 1977). Cereal-legume intercropping may be valuable as component plants use different nitrogen sources (Benites *et al.*, 1993), which is scarce in most soils in South Saharan Africa's small-scale farms (Mugwe *et al.*, 2011). The cereal may be more competitive than the N mineral legume in the soil, but if efficient rhizobium lines are present in the soil, the legume may symbiotically fix nitrogen. However, some combinations have adverse effects on the parts of the plant under the intercropping scheme. For example, when intercropped with maize, Mucuna (*Mucuna utilis*) was discovered to reduce maize yields, while cowpea and greengram had much less impact on maize and were tolerant of corn shade (Agboola and Fayemi, 1971). Intercrop maize-bean is commonly found in eastern Africa, while maize is intercropped with cowpeas, groundnuts and Bambara nuts in southern Africa (Odendo *et al.*, 2011).

2.10.3 Time of planting

Several studies have shown the effects of planting time on intercrop component performance. For example, Mongi *et al.* (1976) showed better yield from cowpea planting and maize at the same time. Barbosae *et al.* (2008) indicated that intercropping maize with cowpea provides intermediate results; especially when done early, showing that cowpea controls weeds to some point. Addo-Quaye *et al.* (2011) found that maize planted simultaneously with soybean or bean soybean had significantly higher leaf area index values, growth rate of plant crops and net assimilation rate compared to later

2.11 Benefits of intercropping systems

Most researchers maintain that intercropping is particularly important for smallholder farmers in the tropics ' low-input / high-risk environment (Willey *et al.*, 1983; Fujita and Ofosu-badu, 1996). Intercropping cereal-legume is widespread among smallholder farmers due to their potential to cope with soil erosion and poor soil fertility levels. Flexibility, profit, risk reduction against total crop failure, soil fertility enhancement and soil conservation, weed control and nutrient balance are the main reasons why smallholder farmers practice intercrop (Shetty *et al.*, 1995). Other advantages of intercropping include profit maximization and less fixed land costs as a result of a second crop in the same field, according to Thobatsi (2009). Furthermore, intercropping can provide higher yields than sole crop yields, higher yield stability, efficient use of soil nutrients, effective weed control, guaranteed against total crop failure, improved cultivar quality and cereals as a single crop also require a larger area of land to provide the same yield as cereals in an intercropping system (Viljoen and Allemann 1996).

2.11.1 Water use efficiency

Water availability is one of the key variables in estimating productivity in intercropping processes for cereals and legumes. Improving the effectiveness of water use in these systems results in maximizing the use of other resources (Hook and Gascho, 1988), and the preservation of water has been recognized because of the early elevated index of leaf areas (Ogindo and Walker, 2005). The most important in terms of production and water effectiveness was the ongoing pearl millet/forage legume intercrp (Garba and Renard, 1991). Hulugalle and Lal (1986) discovered that in maize-cowpea intercrop water use effectiveness was greater than in sole crops, unless soil water was restricted. Under water-limiting situations, however, water-use efficiency in the intercrop compared to sole cereal may lead to greater retumed growth and lower yields (Ofori and Stern, 1987).

2.11.2 Nutrient use efficiency

Maximized absorption of nutrients in intercropping structures can happen both spatially and temporally. Spatial nutrient uptake can be maximized by raising root mass, whereas temporal nutrient uptake advantages result when the intercropping system plans have the greatest nutrient requirements at distinct times (Anders *et al.*, 1996). Moreover, if the species have different rooting and uptake patterns, such as intercrop cereal-legume, it may result in more efficient use of available nutrients and higher uptake of nitrogen in intercrop compared to single crops (Fujita and Ofosu-

Badu, 1996). On the other side, when cultivating a single species, all roots tend to compete with each other as they are all comparable in orientation and under the ground (Brintha and Seran, 2009). Several researches beyond the South Saharan Africa region have shown the relative effectiveness of intercrops to monocrops. For instance, Vsterager, Neilsen and Hogh-Jensen (2008) indicated that intercropping maize-cowpea is beneficial on soils that lack nitrogen. Dahmardeh, Ghabari, Syahsan and ramrod (2010) discovered that intercrop corn and cowpea maximize the amount of nitrogen, nutrients and potassium in comparison with tosole corn plants. The beneficial effects of intercropping on cereal grains, however, can also accelerate the depletion of soil nutrients, particularly for phosphorus, due to increased use of soil nutrients and greater removal by harvested crops (Mucheru-Muna *et al.*, 2010). According to Chalka and Nepalia (2006), intercropped corn with soybean has resulted in considerably reduced depletion of nitrogen, phosphorus and potassium and higher absorption of N. Recent efforts to replace soil fertility in Africa have been made to introduce legume as an intercrop and/or in rotation to reduce the use of internal inputs (Sanginga and Woomer, 2009).

2.11.3 Radiation use efficiency

The total system light interception is estimated by crop geometry and foliage design (Trenbath, 1983). Intercropping between elevated and low canopy plants is intended to enhance light interception and thus boost the output of smaller plants needs that they be sown once between adequately broader taller rows (Brintha and Seran, 2009). Total quality of light interception and effectiveness are the two main variables that influence yield in relation to incident radiation in the intercropping scheme (Keating and

Carberry 1993). For instance, in corn and bean intercropping, Tsubo and Walker (2003) discovered that intercepted radiation was higher than monocrops. According to Tsubo and Walker (2003), intercropped maize bean has radiation efficiency 77 percent higher than sole cropped beans. Intercropping maize and soybean has improved radiation use over the sole crops (Keating and Carberry, 1993). Other research outside the region of South Saharan Africa showed similar results (Reddy *et al.*, 1980).

2.11.4 Weed control

In general, traditional intercropping systems were believed to be better than monocrops in controlling weeds, pests and diseases, but it should be noted that intercropping is an almost infinitely variable and often complicated system in which adverse effects can also occur. Weed growth depends on the competition effect of the whole crop community, which relies heavily on the competitive abilities of the component crops and their respective plant population in intercropping (Willey *et al.*, 1983). For instance, Khan *et al.* (2002) noted that cereals and cowpea intercrop considerably decreased *Striga* infestation. This was due to the cowpea soil cover creating unfavorable circumstances for the germination of *Striga* (Mbwaga *et al.*, 2001). Intercrop of maize and beans reduced dry weed weight by 50-66% when established at a plant density of 222,000 plants per hectare for beans equivalent to 33% of the maize density of 37,000 plants per hectare (Mashingaidze, 2004). Similar results were reported by other studies using intercropping systems as an integrated weed management strategy (Caporali *et al.*, 1998)

2.12.5 Pests and diseases

In the case of pests and diseases, the significant impact is that one crop may create a barrier to the spread of the pest or disease of the other plant (Willey *et al.,* 1983). Brown (1935) quoted by Brintha and Seran (2009) stated that the infestation of bud worms in sole maize crops was greater than that of soybean intercropped maize. Sekamatte *et al*. (2003) discovered soybean and groundnut to be more helpful than common beans in suppressing termite.

2.11.6 Erosion control

Soil erosion is controlled by preventing rain drops from hitting sposed or bare soil where they tend to seal surface pores, restricting water from entering soil and maximizing surface run-off through intercropping systems (Brintha and Seran, 2009). Cowpea acts as a cover crop in the maize and cowpea intercropping system and minimizes the effect of soil erosion as compared to the maize-bean system (Kariaga, 2004). Reddy and Reddi (2007) reported that in the intercrops of taller cereal crops with short legume crops, taller crops act as wind barriers for short plants. Similar studies showed that run-off in the intercropping system of sorghum and cowpea decreased by 20-30 percent compared to sorghum monocrops and by 45-55 percent compared to sole cowpea crops (Zougmore *et al.,* 2000).

2.12 Land equivalent ratio or land productivity

Land equivalent ratio (LER) is described as the complete land area required for single-cropping returns to intercropping yields (Mead and Willey, 1980). It is an indication of the efficiency of intercropping compared to sole cropping with the significance of unity to be the critical for using environmental resources. When LER is greater than 1 (one), the intercropping favors species development and yield, but where the LER is less than 1 (one) the intercropping has a negative effect on crop development and yield (Willey, 1979; Willey *et al.,* 1980).

Asynchronous resource requirements ensure that the late maturing plant can recover from potential harm created by the early maturing plant element and the accessible resources. For example, radiation capture over time until the end of the growing season is used carefully (Keating and Carberry, 1993). On the other hand, when the component crops have the same growth habits and durations, their maximum growth factor requirements usually occur at the same time. The land use efficiency measured by relative yields increased with increasing maize population. Planting cassava and maize in the same row, in interrow and in alternate row arrangements had no significant effect on maize nor on cassava root yields, the earliness of maize maturity notwithstanding. Due to a compensatory relationship in the yields of cassava and maize interroppings, the choice of an appropriate maize variety and maize intercropping system will rely on the relative importance to a farmer of the two crops (Ezumah *et al.,* 1999). Muoneke *et al.* (2007) indicated that the intercropping system's productivity showed a yield advantage of 2-63 percent as shown by a land equivalent ratio of 1.02-1.63, an indication of maximum land resource utilization by cultivating the crops together. Dahmardeh *et al.* (2009) recorded a land equivalent ratio of 2.26 for cowpea intercropped maize. Such elevated productivity acquired through intercropping can only be achieved if the morphological characteristics of the two crops are highly complementary and diverse ecological niches are used, resulting in more effective use of resources (Willey, 1979). Study conducted by Ezeibekwa (2009) indicated that groundnut and poultry maure introduced into cassava and maize intercropping system, led in maximsed crop productivity proved by high land equivalent ratios. Some studies reported gains in productivity involving legumes.

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Experimental site

During the 2018 rain fed cropping season, field experiment was conducted at Natugnia-Sirigu in the Kassena-Nankana East District of the Upper East Region of Ghana. The experimental site is situated on latitude 10^0 45' N and Longitude 01^0 06' W. The vegetation of the site is grassland regrowth with short trees and shrubs. Dawadawa (*Parkia biglobosa*), Baobab (*Adansonia digitata*), Shea (*Vitellaria paradoxa*) and Mango (*Mangifera indica*) are common trees found. The climate is warm, Semi-arid with average total annual monomodal rainfall of 950 mm. This short rainy season is followed by a pronounced dry season between October and April. The climate is characterized by dry and wet seasons, which are influenced mainly by two air masses, the North-East Trade winds and the South-Westerly’s (Tropical Maritime). The harmattan air mass (North-East Trade Winds) is usually dry and dusty as it originates from the Sahara Desert. During such periods, rainfall is virtually absent due to low relative humidity, which rarely exceeds 20 percent and low vapour pressure less than 1000 Pascal. Day temperatures are high recording 42° Celsius (especially between February and March) and night temperatures could be as low as 18° Celsius. The soil in the study area has been described as savannah ochrosols with Sandy loam according to IUSS World Reference Base (2006).

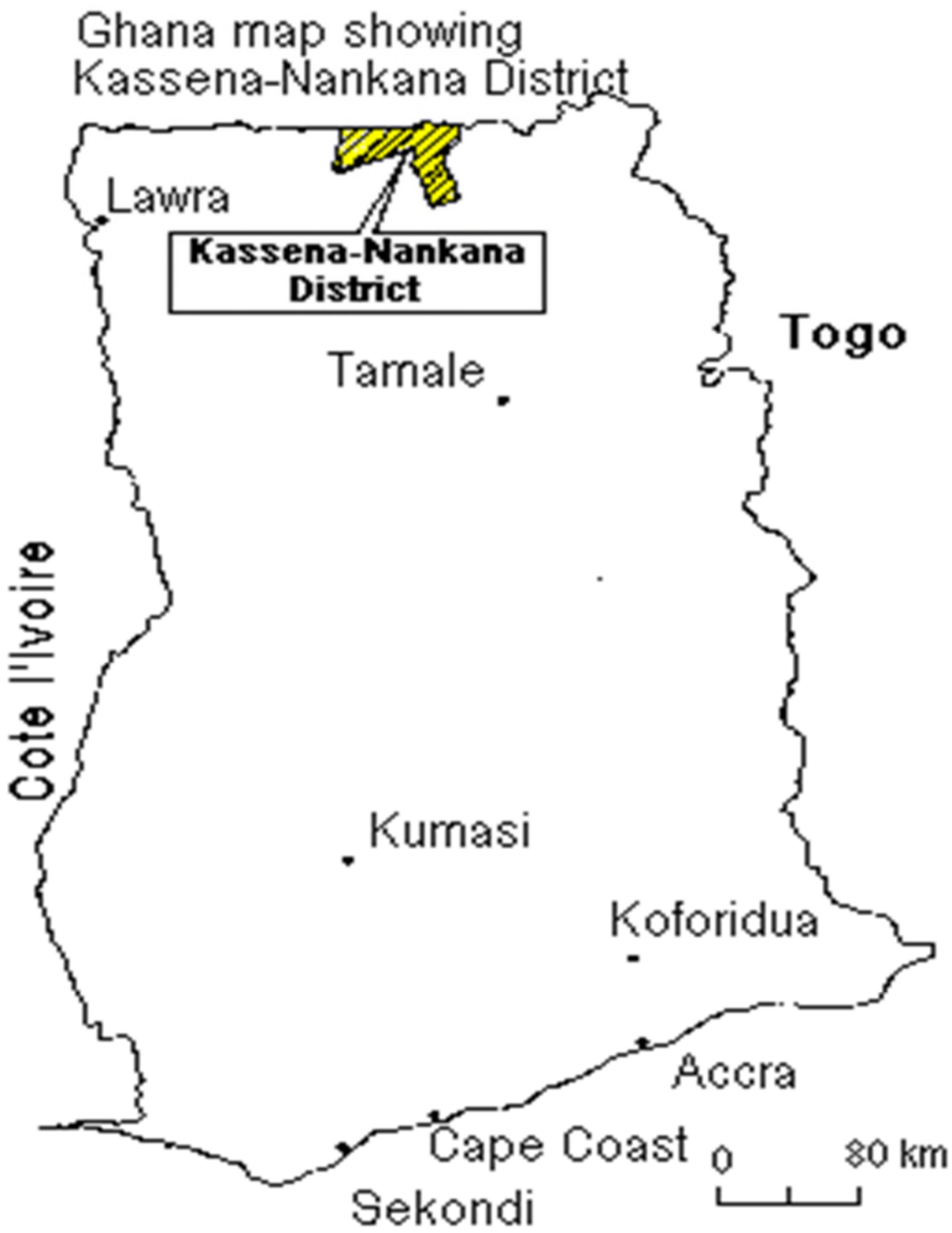

Figure 3: Map of Ghana showing Kassana/Nankana East District

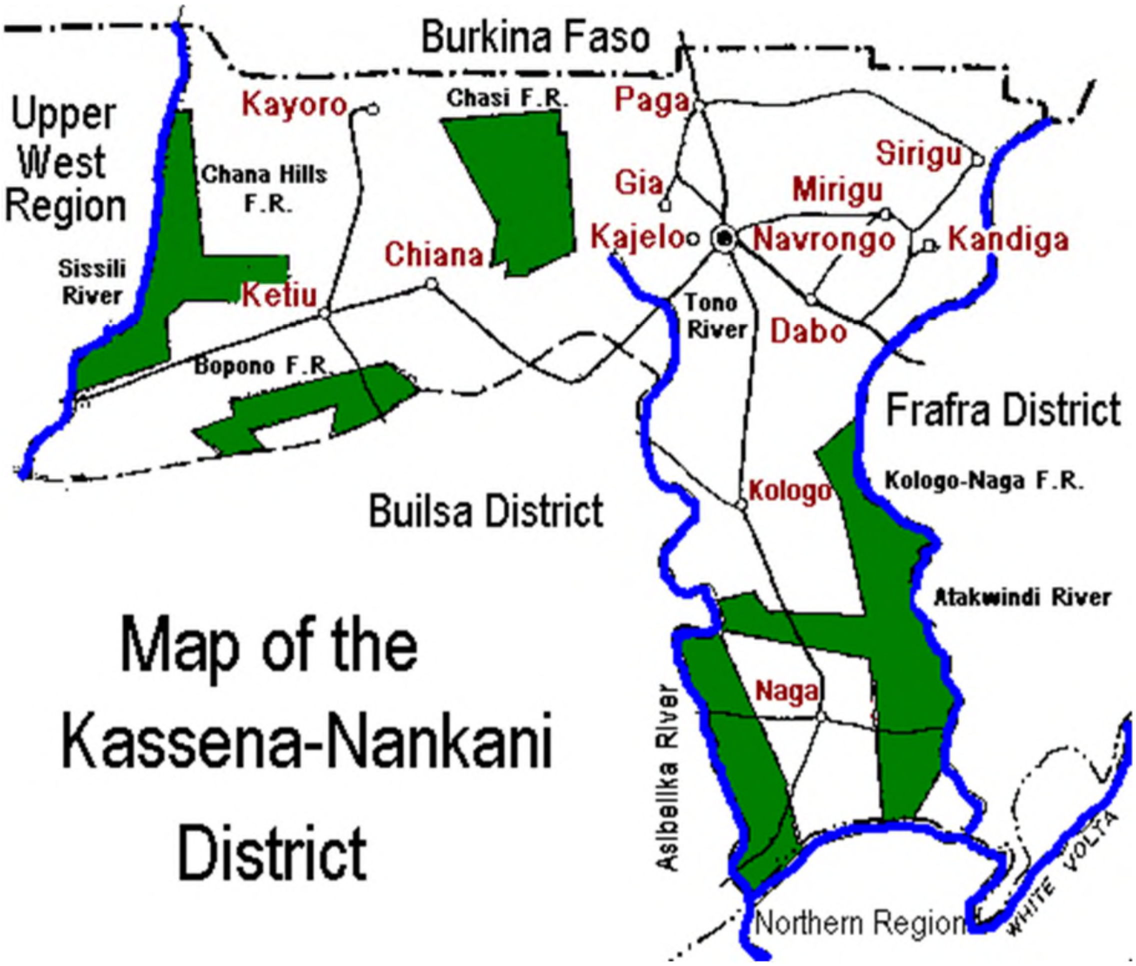

Figure 4: Map of Kassena/Nankana East District

3.2 Experimental design and treatments

The experimental design was a 4 × 3 factorial laid out in a Randomized Complete Block Design (RCBD) with three (3) replications. A Factorial treatment combination consisting of four (4) pearl millet varieties (Akad-kom, Kaanati, Naad-Kohblug and Waapp Naara) and three (3) intercropping patterns (Sole millet, Millet-cowpea (1:1) and millet-cowpea (2:1)) were used as treatments (Table 1). Apart from these treatments, additional plot was created under each replication for sole cowpea to enable calculation of land equivalent ratio (LER). There were thirteen (13) plots in each replication with each plot measuring 5 x 5 m (25 m^2) with total plot size of 1,386 m^2. An alley of 1.5 m between blocks and 1.0 m between plots was used for easy movement of materials and agronomic operations. Each plot consisted of 8 ridges and 5 m long (25 m^2). The millet varieties were released by CSIR-SARI and obtained from SARI, Manga-Bawku. The local photoperiod sensitive medium maturing spreading cowpea type ("Padituya") from farmers was used.

3.3 Pearl millet varieties and cropping patterns

3.3.1 Factor 1: Pearl millet varieties

Four pearl millet varieties were tested:

Akad-kom

Kaanati

Naad kohblug

Waapp naara

3.3.1 Factor 2: Cropping patterns

The cropping patterns were

One row of pearl millet to one row of cowpea

Two rows of pearl millet to one row of cowpea

Non-intercropped plots, Sole pearl millet and Sole cowpea were made to serve as sole crop

Table 1: Treatment combination

Code	Treatments
T1	Sole Akad-kom
T2	1 row Akad-kom : 1 row cowpea
T3	2 rows Akad-kom : 1 row cowpea
T4	Sole Kaanati
T5	1 row Kaanati : 1 row cowpea
T6	2 rows Kaanati : 1 row cowpea
T7	Sole Naad kohblug
T8	1 row Naad kohblug : 1 row cowpea
T9	2 rows Naad kohblug : 1 row cowpea
T10	Sole Waapp naara
T11	1 row Waapp naara : 1 row cowpea
T12	2 rows Waapp naara : 1 row cowpea
T13	Sole cowpea

VARIETIES OF PEARL MILLET

Plate 1. Akad-kom

Plate 2. Kaanati

Plate 3. Naad kohblug

Plate 4. Waapp naara

CROPPING PATTERNS

Plate 5. Sole pearl millet

Plate 6. Sole cowpea

Plate 7. One row of pearl millet to one row of cowpea

Plate 8. Two rows of pearl millet to one row of cowpea

3.4 Preparation of land and seed planting

The vegetation was cleared, bullocks were used to plough and ridges made across the slope followed by pegging to layout the experimental plots. Germination test of seed was done to ascertain their viability. Each of the millet varieties was planted at a planting distance of 0.75 m × 0.3 m (0.225 m^2) and row length of 5 m (approximately 7 stands per row). A maximum of five seeds were planted per hole and seedlings thinned to two plants per hole two weeks after emergence. Cowpea was planted at three seeds per hole and thinned to two seedlings at a spacing of 0.75 m×0.2 m (0.15 m^2) and row length of 5 m (approximately 7 stands per row). Cowpea variety was also sown in three separate sole plots for determination of Land Equivalent Ratio (LER). In sole and intercrop, both millet and cowpea were sown at a depth of 3 cm on the same day. Empty hills were refilled first week after planting.

3.5 Management of plants in the field

Weeding was conducted at two (2) and five (5) weeks after planting (WAP) (Joshua and Gworgwor, 2000) using hoe, followed by careful hand pulling of other weeds except *Striga*.

Plate 9: Weed control at 2 WAP **Plate 10: Weed control at 5 WAP**

3.6 Data colletion

On Soil, *Striga* count, millet, and cowpea data were gathered as described below:

3.6.1. Soil sampling and analyses

Soil samplings were done prior to planting and immediately after harvest. An auger was used to take five representative soil samples on the experimental field at a depth of 0-10 and 10-20 cm from each replication. The soil samples were taken in a zigzag way across each replication (Smith and Atkinson, 1975). Samples were then bulked together and prepared for analysis for initial soil status at the start of the experiment. The second sampling followed similar procedure as in first sampling above, but across treatments jus tafter harvesting to assess which and how much nutrient was left as residue in the soil. The soil samples were air-dried crushed and passed through a 2 mm sieve. Gravel, stones, non-decomposed plant parts were all discarded. Samples were then stored in polythene bags for chemical and physical analysis. The samples were sent to Council for Scientific and Industrial Research, Savanna Agricultural Research Institute (CSIR-SARI) soil laboratory for analyses of the soil physico-chemical properties.

3.6.1.1 Soil pH

The initial pH was determined using a glass electrode (H19017 Microprocessor) pH meter in a 1:2.5 soil to distilled water ratio. A 10 g air-dried soil was weighed into a 100 ml beaker. To this, 50 ml distilled water was added and stirred vigorously for 20 minutes. The soil–water suspension was allowed to stand for 30 minutes. After calibrating the pH meter with buffer solution of pH 4.0 and 7.0, the pH was read by immersing the electrode into the upper part of the suspension (Motsara and Roy 2008).

3.6.1.2 Soil organic carbon

The modified Walkley and Black procedure as described by Nelson and Sommers (1982) was used to determine organic carbon. The procedure used involves a wet combustion of the organic matter with a mixture of potassium dichromate and sulphuric acid after which the excess dichromate was titrated against ferrous sulphate. One gram soil was weighed into a conical flask. A reference sample and a blank were included in separate conical flasks. Ten millilitres of 0.166 M (1.0 N) potassium dichromate solution was added to the soil and the blank flask. To this, 20 ml of concentrated sulphuric acid was carefully added from a measuring cylinder; contents were then swirled and allowed to stand for 30 minutes on an asbestos mat. Distilled water (250 ml) and 10 ml concentrated orthophosphoric acid were added and the mixture allowed to cool. One milliliter of diphenylamine indicator was added and titrated with 1.0 *M* ferrous sulphate solution. Calculation:

$$OC(\%) = \frac{M \times 0.39 \times mcf\ (V1 - V2)}{g} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 1$$

Where:

M = molarity of the ferrous sulphate solution

V_1 = volume of ferrous sulphate solution required for blank titration, mL

V_2 = volume of ferrous sulphate solution required for sample titration, mL

g = weight of air dry sample in grams

mcf = moisture correction factor (100 + % moisture) / 100

3.6.1.3 Soil total nitrogen

Initial total nitrogen was obtained using the Kjeldahl method; involving digestion and distillation as described by Bremner and Mulvancy (1982). Ten grams of soil sample was weighed into a Kjeldahl digestion flask and 10 ml distilled water added to it. After 30 minutes, 5 ml concentrated sulphuric acid and selenium mixture were added, mixed carefully and digested for 3 hours until a colourless solution was observed. The digest was diluted with 50 ml distilled water and allowed to cool. The digest was made to 100 ml with distilled water and mixed well. A 10 ml aliquot of the digest was transferred to the reaction chamber and 20 ml of 40% NaOH solution was added followed by distillation. The distillate was collected over 4% boric acid. Using bromocresol green as an indicator, the distillate was titrated with 0.02 NHCl solutions. A blank distillation and titration was also carried out to take care of N traces in the reagents as well as the water used. Calculation:

Weight of N in the soil = $\frac{14 \times (A-B) \times N}{1000}$ … 2

Where:

A = volume of standard HCl used in the sample titration

B = volume of standard HCl used in the blank titration

N = Normality of standard HCl

3.6.1.4 Available phosphorous

The readily acid–soluble forms of phosphorus were extracted with Bray No. 1 solution as outlined by Olsen and Sommers (1982). Phosphorus in the sample was determined on a spectrophotometer (210 VGP Buck scientific) by the blue ammonium molybdate with ascorbic acid as a reducing agent. A 5 g soil was weighed into 100 ml extraction bottle and 35 ml of Bray 1 solution (0.03 *M* NH_4F and 0.025 *M* HCl) was added. The bottle was placed on a reciprocal shaker and shaken for 10 minutes and filtered through a Whatman No. 42 filter paper. An aliquot of 5 ml of the filterate was pipetted into 25 ml flask and 10 ml colouring reagent (ammonium paramolybdate) was added followed by a pinch of ascorbic acid. After mixing well, the mixture was allowed to stand for 15 minutes to develop a blue colour. The colour was measured using a spectrophotometer at 660 nm wavelength. A standard series of 0, 1.2, 2.4, 3.6, 4.8, and 6.0 mg P/L were prepared by pipetting respectively 0, 10, 20, 30, 40 and 50 ml of 12.0 mg P/L in 100 ml volumetric flask and made to volume with distilled water. The initial available phosphorus was then extrapolated from the standard curve which gave 6.91 mg/kg.

Calculation:

P (mg/kg) = $\frac{(a-b)\times 35\times 15\times mcf}{g}$…………………………………………………………3

Where:

a = mg P/L in the sample extract

b = mg P/L in the blank

g = sample weight in grams

mcf = moisture correction factor

35 = volume of extraction solution

15 = final volume of the sample solution

3.6.1.5 Extraction of exchangeable cations

Potassium in the soil was determined in 1.0 M ammonium acetate (NH_4OAc) extract. A 10 g sample was transferred into a leaching tube and leached with a 250 ml of buffered 1.0 M ammonium acetate (NH_4OAc) solution at pH 7. Hydrogen plus aluminium were determined in 1.0 *M* KCl extract as described by Page *et al.* (1982).

3.6.1.6 Determination of exchangeable potassium

Potassium in the percolate was determined using flame photometry as described by Helmke and Sparks (1996). Standard series of potassium was prepared by diluting 1000 mg/l potassium solution to 100 mg/l. Portions of 0, 5, 10, 15 and 20 ml of the 100 mg/l standard solutions were put into 200 ml volumetric flasks. One hundred millilitres of 1.0 *M*NH_4OAc solution was added to the flask and made to 200 ml with distilled water. The standard series obtained were 0, 2.5, 5.0, 7.5, 10.0 mg/l for potassium. Potassium was measured directly in the percolate by flame photometry at wavelength of 766.5nm.

Calculation: Exchangeable K (cmol (+) /kg soil) = $\frac{(A-B)\times 250 \times mcf}{(10 \times 39.1 \times g)}$ …. 4

Where:

A = mg/L K in the diluted sample

B = mg/L K in the blank sample

g = air dried sample weight of soil in grams

mcf = moisture correction factor

3.6.1.7 Determination of calcium and magnesium exchangeable

Twenty five milliliter portion of the extract was removed into a conical flask and the volume made to 50 ml with distilled water. Potassium ferro-cyanide (1 ml) at 2%, hydroxylamine hydrochloride (1 ml), potassium cyanide (1 ml) at 2% (from a burrette), ethanolamine buffer (10 ml) and 0.2 ml Eriochrome Black T solution were added. The mixture was titrated with 0.01 Methylene diamine tetraacetic acid (EDTA) to a pure turquoise blue colour. A 20 ml 0.01 MEDTA in the presence of 25 ml of 1.0 M ammonium acetate solution was added to provide a standard blue colour for titration and the titre value recorded. The titre value of calcium was subtracted from this value to get the titre value for magnesium.

Calculation: Ca +Mg (cmol (+) /kg soil) = $\frac{0.01 \times (V1-V2 \times 1000}{0.1 \times W}$ … … … … … … … … … … …5

Where:

V_1 = mL of 0.01 *M* EDTA used in the sample titration

V_2 = mL of 0.01 *M* EDTA used in the blank titration

W = weight in grams of air dry soil extraction

0.01 = concentration of EDTA used, $Moldm^{-3}$

3.6.2 *Striga hermonthica* seed bank determination before planting and after harvest

Before planting and after harvest, a composite soil sample was obtained from each of the blocks by randomly sampling soil from each plot and mixed thoroughly. One (1) kg soil sample was obtained from the composite sample and taken to SARI in Nyankpala for *Striga* seed count determination. Average *Striga* counts were determined for each of the plots through potassium carbonate separation method as outlined by Berner *et al.,* (1997).

3.6.3 *Striga* count and Biomass

This was done by counting the total number of *Striga* in each of the plots. The counting was done in weeks 8, 10, 12, and 14 after planting millet. At each *Striga* count, the plants of the parasite were uprooted and sent to the University for Development Studies (UDS) Laboratory in Tamale and fresh weight were taken. The parasitic plantswere then packed in envelopes and oven dried at 80°C for 48 hours and weighed for biomass determination using electronic scale.

3.6.4 Millet traits measurements

3.6.4.1 Plant height

The plant heights were evaluated using a tape measure and the mean calculated for each plot from the floor to the stem tip from the randomly marked ten (10) crops in each plot. Data was taken at 3, 5, 7 and 9 weeks after planting (WAP).

Plate 11. Measuring plant height

3.6.4.2 Number of leaves

Number of leaves was drawn for each plot on the same date plant height were taken and the mean value was calculated.

3.6.4.3 Pearl millet leaf area (LA)

Leaf area of millet was determined at 3, 5, 7 and 9 WAP. LA was taken by measuring the length and width of three (3) leaves from the lower part of the plant, in the middle and at the top on each of the ten (10) tagged plants in each plot.

Each leaf area was estimated using the formula proposed by Krishnamurthy *et al* (1974): Leaf area = k (l x w)..7

Where,

l= leaf length

w=leaf width

k= factor (in cereals= 0.75).

3.6.4.3.1 Pearl millet leaf area index (LAI)

Pearl millet leaf area index was calculated at 3, 5, 7 and 9 WAP. Leaf area index (LAI) expresses the ratio of leaf surface (One side only) to the ground area occupied by the plant or a crop stand worked out as per specifications of Gardner *et al*. (1985). Leaf area index was calculated by dividing the total area of leaves by total land area it occupied.

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3.6.4.4. Tiller count

At the base of the plant, the number of tiller emanating from ten (10) tagged plants at 3 and 5 WAP was carefully counted.

Plate 12. Pearl millet tiller count

3.6.4.5 Reproductive tiller number

Tillers that were bearing or producing panicles were also counted and sampled averages were computed from the results at 7 WAP.

3.6.4.6 Days to 50% heading of pearl millet

Records were taken on the individual plants that flowered every day until half of the total plant population flowered in each of the plot. The number of days it took for half of the total plant population to flower was was recorded as days to 50% heading.

3.6.4.7 Length, diameter and weight of panicle

Average length of the panicle head was estimated using tape measure from the harvested panicles. The head circumference was first estimated using tape measure, which was then used to calculate the panicle's average diameter using the formula below; ($D = C/\pi$); where D = diameter C = circumference and $\pi = 3.143$. After harvest, initial new head weights were taken. The heads were evenly dried and then weighed on an electronic balance and the average head weight was calculated.

3.6.4.8 Number of days to maturity

It was determined and recorded as the amount of days it took for the panicle to reach maturity.

3.6.4.9 Biomass/Stover weight

Pearl millet stalks were cut near the soil surface and their total fresh weight taken. A subsample was thereafter taken from the total stalks in each plot, weighed and recorded. The subsample was thereafter dried and weighed. The weights for both were used to calculate the pearl millet biomass.

3.6.4.10 1000 seed weight and Total grain yield

Thousand seeds were chosen from each therapy using electronic weighing equilibrium and weighed. The weights of the seeds were determined in grammes (g). Grain yield

(GY) was estimated using a measurement scale to weigh the grain yield per plot after drying the panicles in the sun to about 10 percent moisture content, threshing, winnowing, and cleaning. Using the formula (10000 x yield per plot)/(plot size x 1000), the grain yield per plot was converted to kg/ha

3.6.5 Cowpea traits

Height of plant, number of branches of leaves per plant, number of nodules at 42 DAS, number of pods per plant, weight of pods at harvest, dry weight of pods, number of seeds per pod, weight of 100 grains, yield of grains, and yield / plot of Haulm.

3.6.5.1 Plant height

Five plants were randomly selected from each plot and tagged. Their heights were measured at 7 WAP and at flowering stage using a graduated meter rule from the soil level to the last terminal leaf of the plant. The mean height of the five plants was recorded to represent each treatment.

3.6.5.2 Number of leaves

On the five marked crops, the amount of the cowpea leaf was counted at 7 WAP and the mean value was calculated.

3.6.5.3 Nodule count

At 42 DAP; the roots of five randomly selected plants were carefully dug using a shovel. The soil was carefully removed and all nodules picked into a white envelope and sealed. The nodules attached to root hairs were gently washed under running water in a fine sieve to remove all remaining nodules and soil particles. The nodules were then finally counted and their mean recorded. Plant stand lost was compensated during the statistical analyses. *Striga* count and leaf count data were transformed using the square root ($\sqrt{n} + 0.5$) transformation.

3.6.5.4 Effective nodules and nodule dry weight

To determine the efficient ones, the nodules were taken to the laboratory and sliced open with a blade. Those with reddish and pinkish colour were considered effective while those with green, grey or dark colour were considered ineffective (Gwata *et al.*, 2003). After drying the oven at 65°C for 48 hours, nodule dry weight was determined using an electronic scale.

3.6.5.5 Biomass yield

Five (5) plants were randomly chosen and cut to the ground level for shoot dry matter determination at 50% flowering. Plant materials were then put in large brown envelopes and oven dried at 60°C for 72 hours. The dried plant materials were then weighed and biomass dry weight determined.

3.6.5.6 Number of pods and seeds per plant

Number of pods from the five randomly tagged plants was counted and the mean calculated for each plot. Seeds from 100 randomly sampled pods from each plot were counted and mean calculated for each. The number of seeds per pod is calculated as follows: Number of seeds per plot = $\frac{\textit{Total number of seeds counted}}{\textit{Number of pods counted}} \dots \dots \dots \dots \dots \dots \dots \dots \dots \mathbf{8}$

3.6.5.7 Weight of hundred seeds and grain yield

One hundred seeds from each plot were selected and weighed using on an electronic scale and the weights were recorded in grammes. Grain yield was determined from the net plot within two middle rows of each plot. Plants within the net plot (the central rows) were harvested, threshed and dried in an oven for 96 hours at 65°C and weighed. The grain yield was extrapolated from the dry weight of the grain as suggested by Okogun *et al.* (2005).

3.6.6 Land equivalent ratio

To study competition effects between crops and to evaluate intercrop performance, the competition function; Land Equivalent Ratio (LER) was calculated. The LER is an accurate assessment of the biological efficiency of the intercropping situation. For treatments to be analyzed as an additive series, the land equivalent ratio (LER) was calculated as described by (Alhassan and Egbe, 2014):

$LER = LER_{im} + LER_{sm}$ ……………………………………………..……………9

$PLER = \frac{Yim}{Ysm}$ ……………………………………………………….…………………10

$PLER = \frac{Yic}{Ysc}$ ……………………………………………………….…………….……11

Where the subscript letters, m and c stand for pearl millet and cowpea, respectively; Y_{im} and Y_{sm} are yields of pearl millet intercrop and sole crop while Y_{ic} and Y_{sc} represent yields of cowpea intercrop and sole crop. LER value above one indicates an advantage of intercropping over sole cropping while LER value below one shows that there is no advantage by intercropping.

3.7 Analysis of data

Using GENSTAT statistical software version 12, data collected was subjected to Variance Analysis (ANOVA). Significant differences between treatments were determined at a probability level of 5 percent using the Least Significance Difference

(LSD). All count data (i.e., *Striga* count) were transformed logarithmically (Kihara *et al., 2011*) before being subjected to ANOVA to reduce variation in the results.

CHAPTER FOUR

4.0 RESULTS

4.1 Rainfall in 2018

Rainfall for the 2018 crop season began in May with an average rainfall of 169 mm in the Kassena-Nankana East District of the Upper East Region of Ghana. Before decreasing in October, the precipitation improved and peaked to 261 mm, giving sufficient relative humidity to promote early pearl millet growth and development (Fig. 5).

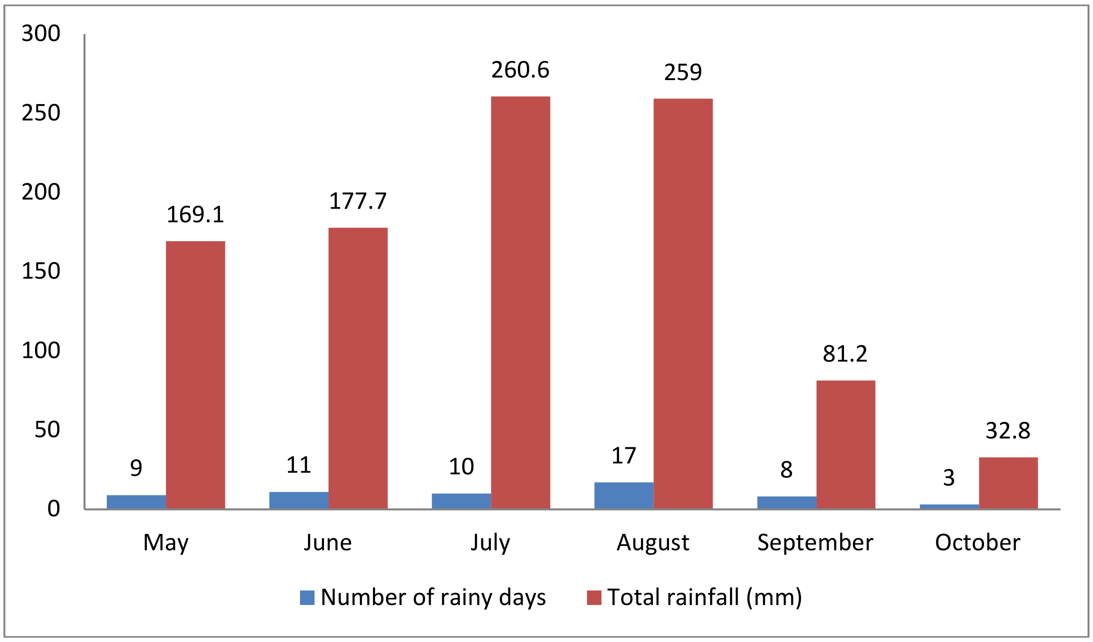

Figure 5: Rainfall during the 2018 cropping season at Natugnia-Sirigu

Source: (Navrongo meteorological station, 2018)

4.2 Initial and postharvest soil analysis for soil physico-chemical properties

Variety and intercropping did not affect the physico-chemical properties of soil. However, baseline soil analysis gave lower percentages of soil nutrient such as nitrogen, phosphorous, calcium and magnesium in both top and sub soils (Table 2) compared to postharvest soil analysis (Table 3). Organic carbon percent, nitrogen percent, calcium (Cmol+/kg) and magnesium (Cmol+/kg) were not substantially affected by the pearl millet variety and cropping pattern (*P>0.05*).

Table 2: Initial soil sample analysis

Depth (cm)	pH	O.C (%)	N (%)	P (mg/kg)	K (mg/kg)	Ca	Mg	CEC
						Cmol+/kg		
0-10	5.84	1.17	0.11	6.64	67	2.72	0.82	5.26
10-20	5.57	0.85	0.07	5.58	59	1.80	0.56	3.87

Table 3: Soil sample analysis after harvest

Treatment	pH	O.C (%)	N (%)	P (mg/kg)	K (mg/kg)	Ca	Mg	CEC
						Cmol+/kg		
T1	5.42	1.70	0.32	5.82	78	2.73	0.79	5.66
T2	5.80	1.85	0.22	6.87	73	2.69	0.80	5.53
T3	6.02	1.71	0.35	6.79	69	3.11	0.94	5.81
T4	5.83	1.69	0.31	6.73	70	3.19	0.89	5.73
T5	5.75	1.83	0.27	6.85	71	2.73	0.91	5.34
T6	5.93	1.62	0.22	6.90	78	2.68	0.85	5.79
T7	5.87	1.74	0.20	6.84	76	3.10	0.93	5.63
T8	6.17	1.88	0.36	6.91	74	3.02	0.87	5.84
T9	5.40	1.75	0.33	6.80	69	2.81	0.79	5.77
T10	5.72	1.59	0.23	6.80	72	2.88	0.89	5.80
T11	5.85	1.73	0.27	6.91	77	2.30	0.86	5.59
T12	5.82	1.68	0.27	6.79	69	2.77	0.85	5.38
T13	5.54	1.90	0.38	6.93	80	3.15	0.83	5.22

4.3 Initial and postharvest *Striga* seed bank determination

Initial *S. hermonthica* soil seed bank varied with plots and postharvest *S. hermonthica* soil seed bank was significantly affected (*P<0.05*) by pearl millet variety and cropping pattern (Figure 6). The initial *S.hermonthica* soil seed bank ranged from 353 to 374 seeds per 100 g soil sample. The postharvest *S. hermonthica* soil seed bank revealed that Akad-kom intercropped with cowpea (1:1) and Naad kohblug intercropped with cowpea (1:1) recorded the least value of 134 seeds per 100 g soil while maximum of 192 seeds per 100 g soil for sole Waapp naara (Figure 5).

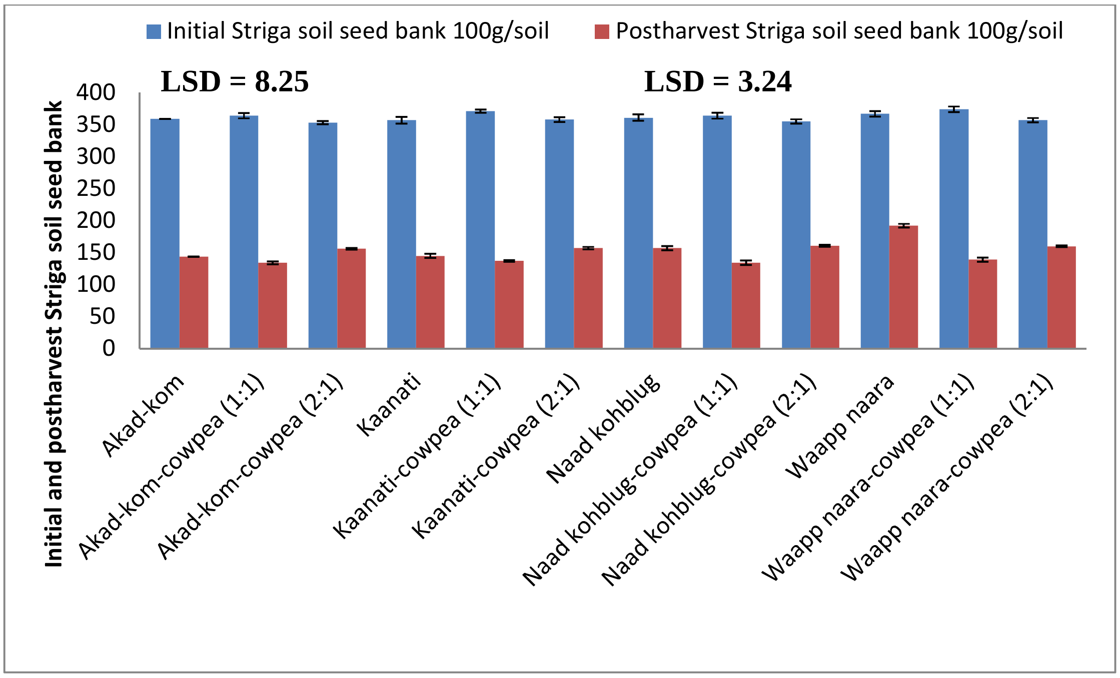

Figure 6: Effect of treatments on *S. hermonthica* soil seed bank. Bars represent SEM

4.4 Percentage reduction in soil *Striga* seed bank

Percentage reductions in *Striga* soil seed bank were significantly affected by interaction between pearl millet variety and cropping pattern. Percentage *Striga* soil seed bank reduction ranged from 31 to 46 percent (Figure 7). The greatest percentage reduction in *Striga* soil seed bank observed in Naadd kohblug intercropped with cowpea (1:1), Kaanati inetercropped with cowpea (1:1) and Akad-kom inetercropped with cowpea (1:1) (46%), whilst the lowest was recorded for sole Waapp naara (31%).

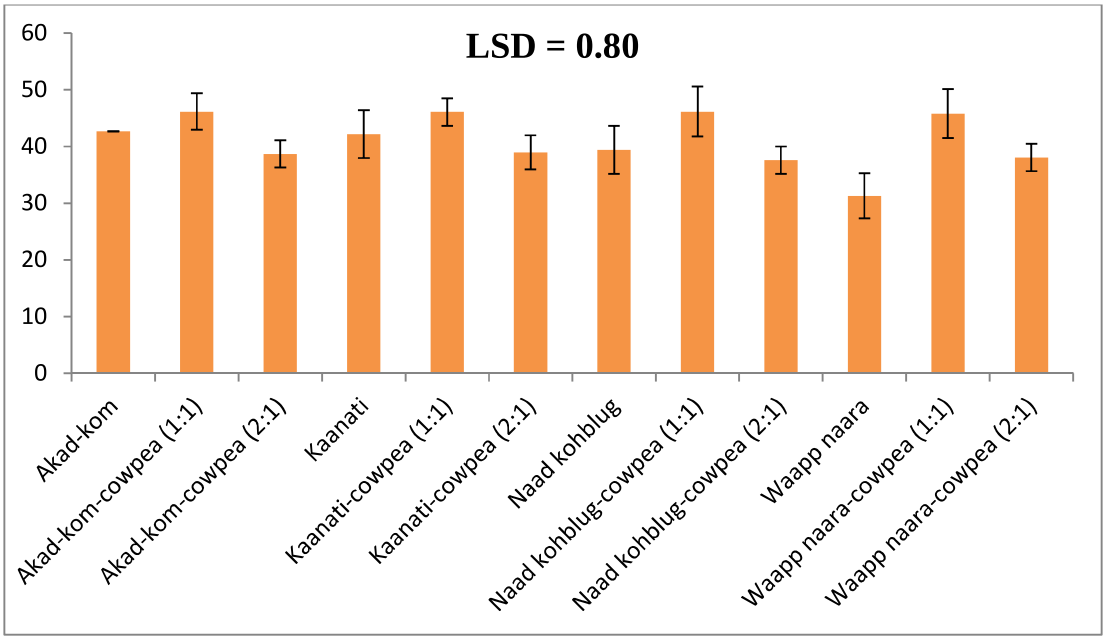

Figure 7: Percentage reduction in soil *Striga* seed bank. Bars represent SEM

4.5 Pearl millet growth data

4.5.1 Plant height

The interaction between pearl millet variety and cropping pattern showed no significant difference in pearl millet plant height at 3, 5 and 7 WAP (*P>0.05*). However, as shown in Table 4, the main effect (millet variety) had an important effect on plant height at 3, 5, 7, and 9 WAP. Naad kohblug produced the tallest plant height in all sampling periods followed by Kaanati while the Akad-kom and Waapp naara were statistically similar. Intercropping influenced plant height with MC (2:1) cropping pattern giving the greatest plant height of 99.70, 146.30 and 161.30 cm at5, 7 and 9 weeks after planting respectively.

Table 4: Effect of milliet-cowpea intercrop on millet plant height

Treatment	Plant height (cm) in weeks after planting (WAP)			
	3	5	7	9
Variety				
Akad-kom	22.40	94.70	134.30	154.40
Kaanati	27.40	100.40	144.80	164.30
Naad kohblug	28.50	103.30	148.10	170.70
Waapp naara	24.30	80.50	124.40	140.50
LSD (5%)	**2.69**	**7.90**	**11.03**	**6.67**
Cropping pattern				
Sole crop	26.48	87.20	141.00	159.30
MC (1:1)	24.38	87.20	126.40	151.80
MC (2:1)	26.10	99.70	146.30	161.30
LSD (5%)	**2.33**	**7.90**	**9.55**	**5.78**
CV (%)	10.70	6.85	8.20	4.30
V * CP interaction	NS	NS	NS	11.56

NS = No significant difference

4.5.2 Leaf area index (LAI)

Result on the effect of pearl millet variety and crop pattern on the Leaf Area Index (LAI) showed that the parameter was not significantly affected by the interaction between millet variety and crop pattern ($P>0.05$). However, pearl millet variety significantly ($P<0.05$) influenced leaf area index, such that Naad kohblug and Akad-kom exhibited significant superiority over the remaining varieties for LAI (Table 5). Waapp naara registered the least LAI at 5, 7 and 9 WAP.

The results revealed high significant differences between the cropping patterns for leaf area index during the investigation period (Table 5). The MC (1:1) cropping pattern exhibited superiority over the remaining cropping patterns for LAI. The MC (2:1) cropping pattern registered the least LAI at 3, 5, and 9 WA

Table 5: Effect of millet-cowpea intercrop on leaf area index

Treatment	Leaf area index in weeks after planting (WAP)			
	3	5	7	9
Variety				
Akad-kom	0.84	3.33	5.04	3.88
Kaanati	0.73	3.69	5.33	3.41
Naad kohblug	0.94	5.29	7.53	5.51
Waapp Naara	0.79	3.10	4.79	2.58
LSD (5%)	**0.05**	**0.33**	**0.33**	**0.29**
Cropping pattern				
Sole crop	0.63	3.57	5.16	3.28
MC (1:1)	0.77	4.63	6.17	4.12
MC (2:1)	0.52	2.95	4.79	3.55
LSD (5%)	**0.14**	**0.96**	**0.96**	**0.84**
CV (%)	18.00	6.80	8.90	7.20
V * CP	NS	NS	NS	NS

NS = No significant difference

4.5.3 Pearl millet tiller count

At 3 and 9 WAP, the interaction between pearl millet varieties and cropping patterns did significantly (*P<0.05*) affect tiller counts. However, at 5 and 7 WAP, the interaction was insignificant. At 7 and 9 WAP, Waapp naara gave the highest tiller count per plant of 4.04 and 4.11 respectively, compared to Akad-kom, Kaanati and Naad-kohblug treatment means.

With regards to cropping pattern, sole crop recorded the highest tiller counts of 2.93, 4.95, 3.95 and 4.03 per plant at 3, 5, 7 and 9 WAP respectively as shown in Table 6.

Table 6: Effect of pearl millet-cowpea intercrop on tiller counts

Treatment	Tiller counts in weeks after planting (WAP)			
	3	5	7	9
Variety				
Akad-kom	2.81	4.90	3.51	3.57
Kaanati	2.70	4.33	3.17	3.12
Naad kohblug	2.63	4.52	3.61	3.68
Waapp Naara	2.48	4.34	4.04	4.11
LSD (5%)	**0.35**	**0.60**	**0.42**	**0.31**
Cropping pattern				
Sole crop	2.93	4.95	3.95	4.03
MC (1:1)	2.43	4.35	3.38	3.38
MC (2:1)	2.62	4.27	3.42	3.46
LSD (5%)	**0.30**	**0.52**	**0.36**	**0.27**
CV (%)	13.50	13.60	12.00	8.70
V * CP	0.61	NS	NS	0.54

NS = No significant difference

4.5.4 Pearl millet productive tiller count

The interaction between pearl millet varieties and cropping patterns did not significantly (*P>0.05*) affect pearl millet productive tiller counts at 7 and 9 WAP. However, the main effect of pearl millet variety significantly affected number of productive tiller counts at 7 WAP. Akad-kom recorded the greatest number of productive tiller counts (1.49 per plant) than Kaanati, Naad kohblug and Waapp naara treatments at 7 WAP. There was no significant difference between Akad-kom, Kaanati and Naadd kohblug.

Table 7: Effect of pearl millet-cowpea intercrop on productive tiller counts

Treatment	Productive tiller counts in weeks after planting (WAP)	
	7	9
Variety		
Akad-kom	1.49	1.68
Kaanati	1.33	1.36
Naad kohblug	1.51	1.68
Waapp naara	0.74	1.70
LSD (5%)	**0.35**	**0.31**
Cropping pattern		
Sole crop	1.22	1.73
MC (1:1)	1.22	1.68
MC (2:1)	1.09	1.40
LSD (5%)	**0.30**	**0.27**
CV (%)	30.50	19.90
V * CP	NS	NS

NS = No significant difference

4.5.5 Days to 50% heading for pearl millet

Pearl millet varieties and cropping pattern showed significant (*P<0.05*) difference on days to 50% heading of pearl millet. Days to 50% heading recorded on the different treatments varied from 41 to 48 days. Sole Waapp naara recorded the greatest number of days to 50% heading (48 days) followed by Naad kohblug-cowpea (2:1) (45 days). There was lower value for days to 50% heading at sole Kaanati treatment mean (41 days) (Figure 7). All other treatment effects were statistically similar.

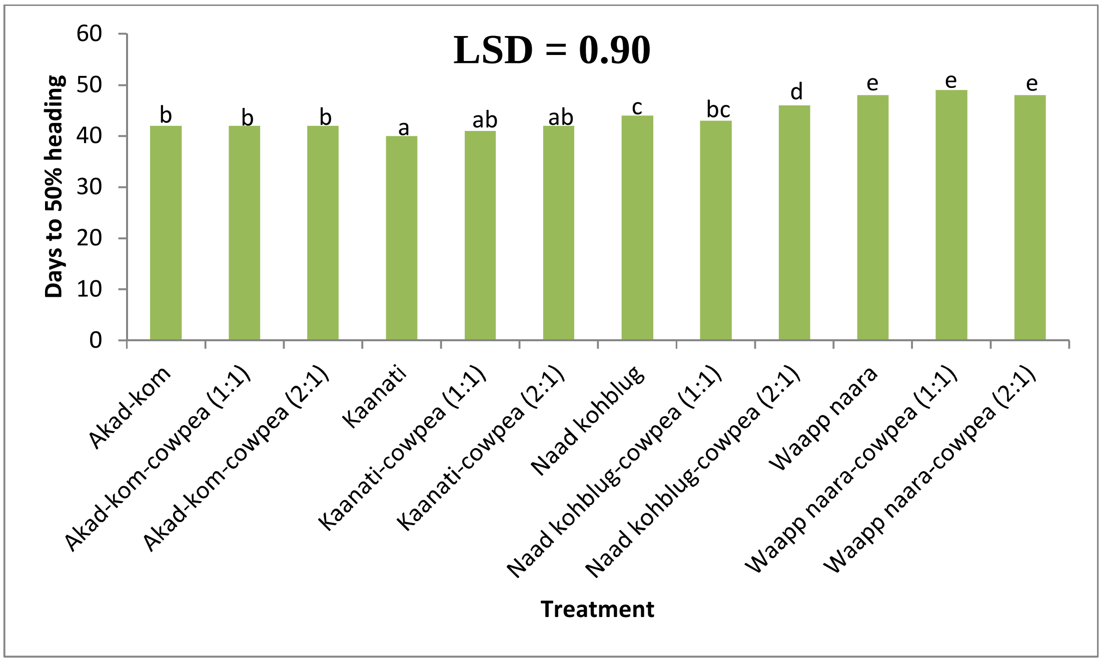

Figure 8: Days to 50% heading of pearl millet as affected by treatments

4.6 *Striga* data

4.6.1 *Striga* count

Interaction between pearl millet varieties and intercropping significantly influenced (*P<0.05*) *Striga* count at 8, 10 and 12 WAP (Table 8). Waapp naara had significantly greater *Striga* emergence of 4.40, 4.85 and 7.47 per plot at 8, 10 and 12 WAP respectively compared to other treatment. Kaanati had very low *Striga* counts (2.25 emergence plot^{-1}) at 8 WAP. At week 10 and 12, Naad kohblug gave the least emergence of 1.74 and 1.79 respectively per pot. Averagely, Sole crop recorded the highest (4.00 and 6.73) *Striga* seedling emergence at 10 and 12 WAP respectively with MC (1:1) treatment recording the lowest (1.72, 1.71 and 2.63) at 8, 10 and 12 WAP respectively.

Among the sole, Waapp naara recording the highest (2.40, 3.13 and 4.56 kg/ha) and Naad kohblug gave the lowest (1.65, 1.30 and 1.26 kg/ha) at 8, 10 and 12 WAP, respectively (Table 8).

At week 14, pearl millet varieties and cropping patterns did not show a significant difference in terms of *Striga* numbers.

Table 8: Effects of pearl millet variety and cropping pattern on *Striga* count

Treatment	*Striga* count (√x + 0.5) in weeks after planting (WAP)				
	8	10	12	14	Cumulative
Variety					
Akad-kom	2.27	2.57	4.00	1.75	1.67
Kaanati	2.25	3.06	4.52	1.15	1.69
Naad kohblug	2.68	1.74	1.79	1.07	1.46
Waapp Naara	4.40	4.85	7.47	2.59	3.57
LSD (5%)	**1.48**	**1.66**	**1.96**	**1.57**	**0.48**
Cropping pattern					
Sole crop	3.49	4.00	6.73	1.87	2.66
MC (1:1)	1.72	1.72	2.63	1.86	1.42
MC (2:1)	3.50	3.45	3.97	1.69	2.21
LSD (5%)	**1.28**	**1.44**	**1.69**	**1.35**	**0.41**
CV (%)	52.10	55.60	45.10	88.60	23.20
V * CP	2.56	2.87	3.39	NS	0.83

NS = No significant difference

4.6.2 *Striga* biomass production

At 7 WAP, *Striga* biomass was not affected by the interaction between pearl millet varieties and crop patterns (*P>0.05*). *Striga* biomass was considerably affected by the primary impact of pearl millet variety (*P<0.05*). Waapp naara produced the highest (2.40 g/ha) *Striga* biomass at 8 WAP while Naad kohblug produced the lowest (1.65 g/ha) *Striga* biomass as shown in (Table 9). With regards to cropping patterns, MC (2:1) gave the highest (2.00 g/ha) *Striga* biomass followed by sole crop (1.99 g/ha) and MC (1:1) being 1.19 g/ha at 8 WAP. The interaction of pearl millet varieties and cropping patterns for *Striga* biomass at 10 and 12 WAP was significantly different (*P<0.05*). The lowest *Striga* biomass of 1.30 and 1.26 g/ha were recorded in Naad kohblug at 10 and 12 WAP respectively and the highest *Striga* biomass of 3.13 and 4.56 g/ha were recorded for Waapp naara at 10 and 12 WAP respectively. Neither the pearl millet variety nor the cropping pattern resulted in significant (*P>0.05*) influence on *Striga* biomass production at 14 WAP.

Table 9: *Striga* biomass (g/ha) production at 8, 10, 12 and 14 WAP

Treatment	*Striga* biomass in weeks after planting (WAP)			
	8	10	12	14
Variety				
Akad-kom	1.46	1.71	2.39	1.18
Kaanati	1.40	2.02	2.61	0.91
Naad kohblug	1.65	1.30	1.26	1.30
Waapp naara	2.40	3.13	4.56	1.80
LSD (5%)	**0.70**	**0.95**	**1.12**	**0.84**
Cropping pattern				
Sole crop	1.99	2.65	4.06	1.32
MC (1:1)	1.19	1.22	1.76	1 27
MC (2:1)	2.00	2.25	2.28	1.32
LSD (5%)	**0.60**	**0.82**	**0.97**	**0.73**
CV (%)	41.40	47.60	42.30	66.20
V * CP	NS	1.64	1.94	NS

NS = No significant difference

4.7 Pearl millet yield data

4.7.1 Pearl millet panicle length, girth and weight of panicle

The interaction between pearl millet varieties and cropping patterns did not significantly (*P>0.05*) affect the panicle length, girth and weight of pearl millet. However, the main effect of pearl millet variety did significantly (*P<0.05*) affect panicle length and girth of pearl millet. Naad kohblug treatment effect produced the highest (31.07 cm) panicle length while Akad-kom treatment effect produced the lowest (12.38 cm). Akad-kom treatment effect recorded the highest panicle girth (11.12 cm) while Kaanati treatment effect produced the lowest panicle girth (7.11cm) as shown in Table 10.

Table 10: Effect of millet-cowpea intercrop on the pearl millet yield attributes

Treatment	Panicle length (cm)	Panicle girth (cm)	Panicle weight (g)
Variety			
Akad-kom	12.38	11.12	35.43
Kaanati	27.44	7.11	37.87
Naad kohblug	31.07	9.08	38.64
Waapp naara	22.91	8.08	38.49
LSD (5%)	**0.83**	**0.16**	**2.86**
Cropping pattern			
Sole crop	23.55	8.82	38.19
MC (1:1)	23.44	8.87	36.75
MC (2:1)	23.36	8.86	37.88
LSD (5%)	**0.71**	**0.14**	**2.48**
CV (%)	3.60	1.80	7.80
V * CP	NS	NS	NS

NS = No significant difference

4.7.2 Pearl millet 1000 grain weight, yield of grain and stover yield

The result showed that the interaction between pearl millet varieties and crop patterns did not affect 1000 grain weight significantly (*P>0.05*). However, 1000 grain weight was considerably affected by the primary impact of pearl millet variety (*P<0.05*). The weight of thousand grains in Naad kohblug (12.19 g/ha) was greater than that of other treatment means. Waapp naara treatment effect recorded the lowest 1000 grain weight of 8.29 g/ha.

The interaction between pearl millet varieties and cropping patterns did not significantly (*P>0.05*) affect grain yield. However, the main effect of pearl millet variety was significantly (*P<0.05*) different with regard to grain yield such that Akad-kom gave the highest (1892.00 kg/ha) while Waapp naara gave the lowest (1778.00 kg/ha).

The MC (1:1) cropping pattern produced the greatest millet grain yield (1890.00 kg/ha) and this was statistically higher than that of other cropping pattern.

Stover yield significantly differed (*P<0.05*) among the pearl millet varieties with Naad kohblug producing the highest Stover yield (3300 kg/ha) than the other treatments. Kaanati gave the lowest Stover yield (2000 kg/ha). The interaction between pearl millet varieties and cropping patterns did not significantly (*P>0.05*) affect the stover yield.

Table 11: Effect of millet-cowpea intercrop on grain and stover yield

Treatment	1000 grain weight (g)	Grain yield (kg/ha)	Stover yield (kg/ha)
Variety			
Akad-kom	11.44	1892.00	2600.00
Kaanati	11.27	1822.00	2000.00
Naad kohblug	12.19	1889.00	3300.00
Waapp naara	8.29	1778.00	2333.00
LSD (5%)	**0.18**	**65.70**	**239.00**
Cropping pattern			
Sole crop	10.73	1833.00	2258.00
MC (1:1)	10.85	1891.00	2658.00
MC (2:1)	10.83	1792.00	2758.00
LSD (5%)	**0.15**	**56.90**	**207.00**
CV (%)	1.70	3.70	9.60
V * CP	NS	NS	NS

NS = No significant difference

4.8 Cowpea Data

4.8.1 Height of the cowpea plant, number of branches and number of leaves

Table 12 presents the outcomes of cowpea plant height, number of branches and number of leaves. The interaction between pearl millet variety and crop pattern did affect cowpea plant height and number of leaves per plant considerably ($P<0.05$). However, the interaction effect of the pearl millet variety and the crop pattern did not substantially ($P>0.05$) affect the amount of branches per plant at 7 WAP. Kaanati generated the largest (4.81) amount of cowpea branches while Naad kohblug gave the smallest (3.99) amount of cowpea branches that was considerably lower than the Akad-kom and Waapp naara treatment means.

Table 12: Effect of millet-cowpea intercrop on cowpea growth parameters

Treatment	Plant height (cm)	Number of branches plant^{-1}	Number of leaves plant^{-1}
Variety			
Akad-kom	117.11	4.70	108.44
Kaanati	112.18	4.81	115.47
Naad kohblug	109.54	3.99	104.23
Waapp naara	119.76	4.45	110.44
LSD (5%)	**9.31**	**0.48**	**8.16**
Cropping pattern			
Sole crop	-	-	-
MC (1:1)	113.07	4.70	105.57
MC (2:1)	115.02	4.33	109.94
LSD (5%)	**8.50**	**0.33**	**7.45**
CV (%)	5.40	7.20	5.10
V * CP	10.75	NS	9.42
Cowpea	109.23	4.77	92.66

NS = No significance difference

4.8.2 Cowpea number of nodules, dry weight and efficient percentage of nodules

The interaction between pearl millet variety and cropping pattern had a significant effect ($P<0.05$) on the amount of nodules per plant and dry weight of the nodule. Akad-kom generated the lowest number of nodules per plant when cowpea was intercropped and considerably lower ($P<0.05$) than other pearl millet varieties intercropped with cowpea. However, there was no important distinction ($P>0.05$) between the treatment means of Waapp naara, Kaanati and Naad kohblug. The cropping pattern had no important impact on the number of nodules ($P>0.05$).

The highest dry weight nodule was obtained when Naad kohblug, which was significantly higher ($P<0.05$) than that of other treatments, was intercropped with cowpea. The effect of the Akad-kom treatments was also significantly lower than that of the Waapp naara and Kaanati treatment means as shown in Table 13.

MC (1:1) had the highest nodule dry weight (2.82 g/plant), while MC (2:1) had the lowest dry weight nodule of 2.64 g/plant. Intercropping has not affected the percentage of effective nodule significantly ($P>0.05$).

Table 13: Effect of pearl millet-cowpea intercrop on nodules dry weight

Treatment	Number of nodules Plant^{-1}	nodule dry weight (g)	Effective nodule percentage (%)
Variety			
Akad-kom	34.096	2.18	91.20
Kaanati	44.89	2.88	89.80
Naad kohblug	40.69	3.02	87.80
Waapp naara	45.05	2.93	86.60
LSD (5%)	**5.66**	**0.56**	**9.08**
Cropping pattern			
Sole crop	-	-	-
MC (1:1)	42.20	2.82	89.10
MC (2:1)	39.70	2.64	88.70
LSD (5%)	**5.16**	**0.51**	**8.29**
CV (%)	9.20	13.60	6.80
V * CP	6.53	0.64	NS
Cowpea	37.35	2.53	89.60

NS = No significance difference

4.8.3 Number of pods per plant and seed number per pod

The interaction between pearl millet variety and crop pattern has not affected the number of pods per plant and the number of seeds per pod of cowpea significantly ($P>0.05$). However, the main effect of the varieties of pearl millet ($P<0.05$) affected the number of pods per plant significantly. Kaanati gave the highest number of pods per plant and this differed considerably ($P<0.05$) from that of combinations of Naad kohblug and Akad-kom treatment only. In terms of the number of pods per plant, Waapp naara ranked second to Kaanati and this was statistically higher ($P<0.05$) than the rest of the treatments. There was no significant difference ($P>0.05$) between Naad kohblug and Akad-kom's effects.

Table 14: Effect of millet-cowpea intercrops on pod plant^{-1} and seed pod^{-1}

Treatment	Number of pod plant^{-1}	Number of seeds pod^{-1}
Variety		
Akad-kom	10.28	11.35
Kaanati	11.17	10.86
Naad kohblug	10.40	10.82
Waapp naara	10.78	10.52
LSD (5%)	**1.19**	**1.11**
Cropping pattern		
Sole crop	-	-
MC (1:1)	10.83	11.09
MC (2:1)	10.81	10.81
LSD (5%)	**1.09**	**1.01**
CV (%)	7.40	6.80
V * CP	NS	NS
Cowpea	12.13	11.57

NS = No significance difference

4.8.4 Cowpea 100 seed weight, grain and haulm yield

The impacts on cowpea 100 seed weight, grain and haulm yield of pearl millet variety and cropping pattern are described in Table 15. Cowpea 100 seed weight was not considerably affected by intercropping ($P>0.05$).

The interaction between pearl millet variety and crop pattern affected cowpea grain and haulm yield significantly ($P<0.05$). Naad kohblug delivered the highest yield of grain and this differed significantly ($P<0.05$) from that of Waapp naara and Akad-kom treatment means. In terms of grain yield, Kaanati ranked second to Naad koblug, statistically higher ($P<0.05$) than Waapp naara and Akad-kom combinations.

In terms of cropping patterns, MC (1:1) obtained the highest grain yield and this differed significantly ($P<0.05$) from the rest of the cropping pattern. The MC (2:1) recorded the lowest 296.10 kg/ha grain yield. Kaanati produced the highest yield of 518.30 kg/ha and this differed significantly from the mean of 480.00, 471.70 and 436.70 kg/ha of Waappp naara, Akad-kom and Naad kohblug respectively.

MC (1:1) yielded the highest haulm yield, significantly ($P<0.05$) higher than the treatment effect of MC (2:1).

Table 15: Effect of millet-cowpea intercrop on seed weight, grain and haulm yield

Treatment	100 seed weight (g)	Grain yield (kg/ha)	Haulm yield (kg/ha)
Variety			
Akad-kom	14.18	266.70	471.70
Kaanati	14.35	323.30	518.30
Naad kohblug	14.48	370.00	436.70
Waapp naara	13.95	263.30	480.00
LSD (5%)	**0.94**	**59.01**	**55.35**
Cropping pattern			
Sole crop	-	-	-
MC (1:1)	14.44	386.10	542.00
MC (2:1)	14.13	296.10	432.00
LSD (5%)	**0.86**	**63.00**	**50.53**
CV (%)	4.40	13.50	7.60
V * CP	NS	79.69	63.91
Cowpea	14.60	623.30	570.00

NS = No significance difference

4.9 Land equivalent ratio

Land equivalent ratio was significantly (*P<0.05*) affected by intercropping (Table 16). The highest land equivalent ratio value of 1.44 was recorded on Naad kohblug variety and the lowest land equivalent ratio value of 1.24 was recorded on Waapp naara variety. All other treatment means were statistically similar. The MC (1:1) gave the highest (1.41) land equivalent ratio and this was significantly (*P<0.05*) greater than the MC (2:1) cropping pattern (1.25).

Table 16: Effect of intercropping on land equivalent ratio

Treatment	PLERc	PLERm	LER
Variety			
Akad-kom	0.43	0.88	1.31
Kaanati	0.52	0.78	1.30
Naad kohblug	0.59	0.85	1.44
Waapp naara	0.42	0.82	1.24
LSD (5%)	**0.09**	**0.15**	**0.13**
Cropping pattern			
MC (1:1)	0.57	0.84	1.41
MC (2:1)	0.42	0.83	1.25
LSD (5%)	**0.07**	**0.11**	**0.09**
CV (%)	15.7	15.2	7.90
V * CP	NS	0.22	0.18

NS = No significance difference, PLERc = Partial land equivalent ratio cowpea, PLERm = Patial land equivalent ratio of pearl millet

4.10 Relationships between pearl millet agronomic parameters and *Striga* counts

Pearl millet grain yield negatively correlated with *Striga* count (r = -0.42) (Table 17). However, grain yield positively correlated with number of tiller count per plant, panicle girth and panicle weight per plant (r = 0.13 to 0.40). *Striga* biomass negatively correlated with panicle length, stover yield, grain yield (Table 17).

Table 17:Relationship between pearl millet agronomic parameters and *Striga* count

Parameter	1	2	3	4	5	6	7	8	9
1. Cumulative *Striga* count	-								
2. *Striga* biomass (kg/ha)	0.95***	-							
3. Tiller count	0.40**	0.39**	-						
4. Productive tiller count	-0.01	0.05	0.25*	-					
5. Panicle length (cm)	-0.04	-0.07	-0.17	-0.23*	-				
6. Panicle girth (cm)	0.05	0.05	0.29*	0.23*	-0.91***	-			
7. Panicle weight (g)	0.13	0.09	0.05	-0.02	0.36**	-0.31*	-		
8. Stover yield (kg/ha)	-0.19	-0.24*	-0.04	-0.02	0.36**	-0.03	0.17	-	
9. Grain Yield (kg/ha)	-0.42**	-0.39**	-0.06	-0.04	0.04	0.07	-0.28*	0.24*	.48**

* = significant (P< 0.05), ** = significant (P< 0.01), *** = significant (P< 0.001). Values without asterisk(s) have no significant linear correlation

CHAPTER FIVE

5.0 DISCUSSION OF RESULTS

5.1 Soil physico-chemical analysis before planting and after harvest.

Results of baseline soil analysis showed that 0-10 cm depth was more fertile with high levels of Nitrogen (0.11%), organic carbon (1.17%) and available phosphorus (6.64 mg/kg), compared to 10-20 cm depth which had low levels of the same nutrients. The soil pH was within the range for productive soils. Results of soil textural analysis indicated that the site's textural class was sandy loam.

Postharvest soil analysis showed similar influence of treatments on soil fertility. Effects of millet-cowpea intercrop on essential nutrients were very much similar in postharvest soil analysis. Pieterse and Verkleiji, (2001) on contrary indicated that soybean crops enhance soil fertility. In sole cowpea and cowpea-cotton treatments, Rusinamhodzi (2006) also discovered that mineral N had risen. In the 0-25 cm soil layer under pea sole crop, Hauggaard-Nielsen *et al.* (2001b) noted greater soil mineral N at postharvest relative to other crop-independent treatments. Muoneke *et al.* (2007) stated that effectiveness of a cropping system not only reduced the *Striga* seed soil bank but also increased the nitrogen supply to the host crop. Gbehounou and Adongo (2002) pointed out that intercropping with cowpea leads to higher yield. In general, due to nitrogen fixation during the growing season, some legumes provide free supply of 15-20 units of nitrogen per month (Charles – Marie, 1992).

5.2 Initial and postharvest *Striga* seed bank determination

Initial *S. hermonthica* soil seed bank varied with plots and postharvest *S. hermonthica* soil seed bank was significantly affected by pearl millet variety and cropping pattern (Figure 6). The initial *Striga* seed bank count was high compared to postharvest. The high seed bank load before planting might be due to the level of *S. hermonthica* plants that flowered and produced seeds previously (Amout, 2019). This is in line with Ejeta and Gressel, (2007) who reported that *Striga* seed bank is determined by the level of *Striga* plants that flower and produce seeds, coupled with lack of suicidal germination. The high seed bank load may also be favoured by mono cropping because mono cropping of cereal hosts with little or no specific measures against *Striga* would lead to immense amounts of seeds accumulating in the seed bank.

Striga seeds are disseminated through various mechanisms which include: runoff water from *Striga* infested fields which carries them in creeks and rivers and thereafter deposits them on farm plots; seeds eaten by animals and pass through the digestive tracts undamaged, and are later spread through animal droppings; seeds sticking on shoes and clothes, muddy soil and farm tools; and contaminants of planting seeds (Woomer and Savala, 2008). These activities would lead to an increase in *Striga* seed bank in areas where the seeds have been deposited irrespective of the soil fertility status in the areas.

5.3 Pearl millet-cowpea intercrop reduced percent *Striga* seed bank

Striga seed bank is determined by the level of *Striga* plants that flower and produced seeds, coupled with lack of suicidal germination (Ejeta and Gressel (2007). A single *Striga* plant can produce 10,000–200,000 minute seeds under optimal conditions

(Hearne, 2009). The best sustainable *Striga* control should be the depletion of the vast, long lived *Striga* seed bank.

The influence of pearl millet-cowpea intercrop on *Striga* seed bank reduction was significant. Results from the present study showed that millet variety and cropping pattern reduced percentage *Striga* seed bank between 31.4 to 42.7% and 37.6 to 46.2%, respectively. Dugje and Ngala (2012) reported that the level of *Striga hermonthica* infestation of sole millet was significantly higher than millet intercropped with cowpea. De Groote *et al.,* (2010) reported suicidal germination of Striga and reduced Striga seed bank in maize soybean intercrop. Dawud *et al.* (2017) also reported depletion of the parasite seed bank with trap crop and thus reduce damage inflicted to cereal crops. Depletion of the *Striga* seed bank by trap crop (cowpea) may be as a result of suicidal germination (Murdoch & Kunjo 2003).

Interaction between Kaanati and Akad-kom varieties and the MC (1:1) cropping pattern reduced percentage *Striga* seed bank by 42% - 46%. The decreased number of *Striga* seed bank may be attributed to the suicidal germination caused by the germination stimulant produced by the cowpea (Padituya) roots. This agrees with De Groote *et al.,* (2010) and Amout (2019) who observed that the use of trap crop such as soybean triggers suicidal germination of *Striga* and therefore reduces the *Striga* seed bank in the soil when intercropped with maize. Findings by Schulz, *et al*. (2003) and Franke *et al*. (2005) indicated that intercropping *Striga* tolerant maize and selected soybean varieties led to 46% reduced *Striga* seed bank.

The results of this study also supported Kureh *et al.* (2000) observation that there is variability among non-host crops and within crop cultivars in their ability to stimulate *Striga* seed germination. The high seed bank in sole cropping is as a result of accumulation in the *Striga* seed bank. As reported by Mbwaga *et al.* (2001) the effectiveness of cereal-legume intercropping to influence *Striga* germination depends on the effectiveness of produced stimulants, root development, fertility improvement, shading effect and its compatibility to *Striga* species as the management option is *Striga* specific. As reported by Khan *et al.* (2002) the effectiveness of cereal-legume intercropping to influence *Striga* germination depends on the effectiveness of produced stimulants, root development, fertility improvement, shading effect and its compatibility to *Striga* species as the management option is *Striga* specific.

Result from the present study indicated that these *Striga* tolerant pearl millet varieties when planted can help reduce *Striga* soil seed bank in *Striga* endemic areas in the near future, as more will germinate but its growth and development is not supported. The reduced *Striga* seed bank in the soil in both cropping systems during 2018 cropping season at Natugnia-Sirigu in the field means a reduced potential for overall flower and capsule production and, consequently, a reduced capacity of increasing the *Striga* soil seed bank in the soil. Hence, an effective management approach to reduce and eventually deplete the *Striga* seed bank.

5.4 Pearl millet–cowpea intercrop reduced *Striga* numbers

The results showed that there was a very important distinction in the 8, 10 and 12 WAP incidence of *Striga*. The elevated *Striga* figures in the Waapp naara variety (4.40, 4.85 and 7.47) may be due to their susceptibility to the parasitic witch weed at

8, 10 and 12 WAP respectively. The high *Striga* seed bank might lead to more *Striga* emergence. *Striga* thrives well in areas with poor soil fertility. Carboso *et al.* (2010) reported that one of the witch weed most contributing factors for development is low soil fertility and cropping systems in Sub-Saharan Africa with no external inputs. Waapp naara recorded greater *Striga* emergence because it might be more susceptible compared to other varieties (Fasil and Wondimu, 2001). *Striga* attack incidence and severity depends on *Striga* susceptibility of the host (Esilaba 2008). Rodenburg *et al.* (2006) reported fewer resistant crops to *Striga* compared to non-resistant crops. The cowpea may have acted as trap plants, stimulating suicidal *Striga* germination or microclimate under the canopy of the plant. This is in agreement with Midega *et al.* (2010), who reported decreased Striga hermonthica in finger millet (*Eleusine coracana*) with desmodium green leaf (*Desmodium intortum*) compared to monocrops.

Low emergence of *Striga* varieties in Kaanati, Akad-kom, Naad kohblug intercropped with cowpea in the MC (1:1) cropping pattern could be attributed to reduced *Striga* germination or reduced attachment of germinated *Striga* to host plant roots as a result of interactive effect between variety and intercropping. The cowpea might have acted as a trap crop, stimulating suicidal *Striga* germination or microclimate under the crop canopy being altered and interfering with the germination and development of *Striga*, and Kaanati, Akad-kom, and Naad kohblug also exhibiting high resistance. The roots of several legumes are known to induce suicidal germination of *Striga* seeds, and this feature has been incorporated into the cereal-legume intercropping suppression strategies of *Striga* (Einallal, 2013).

The efficacy of cereal-legume intercropping to influence *Striga* germination depends on the efficacy of the stimulant/inhibitors produced, root development, fertility improvement, shading effect and its compatibility with *Striga* species as Striga's response to management options is specific (Mbwaga *et al.*, 2001). Since *Striga* is a obligate parasite, interactions between *Striga* and its host serves as a key role in the survival of the parasitic weed, if this interaction has been interrupted, it could be an advantageous approach to the integrated management of this parasite. Differences in the production of *Striga* stimulants are known to occur between crop cultivars (Hess *et al.*, 1992), and this may be the cause of reduced *Striga* emergence in Kaanati, Akad-kom, Naad kohblug varieties, and crop pattern MC (1:1) in this study. Aliyu and Emechebe (2006) revealed that cowpea and soybean release exudates that cause *Striga* germination but were not parasitized as trap plants. This was in agreement with the findings of Kureh *et al.* (2006) who indicated that intercropping maize with cowpea reduced emerged *Striga* density. This reduction may also be due to shading effects from the cowpea canopyIt could also be the result of significantly higher plant stand per unit area and dense cover might have more suppressing and shading effect, thereby reduced soil temperature and hence reduced seed germination and emergence of *S. hermonthica* (Parker and Riches, 1993; Berner *et al.*, 1996; Kureh *et al.*, 2006). Shading especially with more than 60% light interception can reduce *S. hermonthica* infestation but not underground attachment of the parasite to maize (Oswald, 2005). Chivinge *et al.* (2001) reported that cowpea cultivars reduced Striga emergence by 40%.

Striga emergence was more prominent in Waapp naara and MC (2:1) respectively in all sampling periods (Table 8). This could be due to the stimulation of exudates from the root of trap crop and ability to cause suicidal germination. Badu-Apraku *et al.*, (2007) stated that host plant resistance is the plant's ability to prevent attachment of the parasite or to kill the attached parasite resulting in reduced emergence. However, the inconsistency in *Striga* emergence in the season could be due to the fact that only a small number of *Striga* emerged, as was seen in the final *Striga* counts at week 14 (Table 8). It was interesting to note that, the higher *Striga* emergence did not show any negative effect on the crops which might be due to pearl millet resistance/tolerance level of the *Striga*. According to Ejeta and Butler (1993), crops such as cowpea and soybean lured *Striga* seed germination but did not support its subsequent growth and development.

5.5 Pearl millet-cowpea intercrop reduced *Striga* biomass production

From table 9, the analysis indicated significant differences on *Striga* dry weight among all the treatments at 8, 10 and 12 WAP. Higher *Striga* biomass was recorded in sole and MC (2:1) cropping patterns. The greater biomass might be due to initial *Striga* seed bank variations at the site and the more the seed bank the more seeds will germinate with suitable hosts, therefore, translating to greater *Striga* biomass. The greater biomass might also be due to high crop density with high host leading to high number of *Striga* seed germination and later greater biomass. According to Gurney *et al.*, (1999) and Amout (2019), the level of *Striga* biomass on a host influences host productivity, but added that the relationship is non-linear; that is a point is reached where host grain production is independent of parasite biomass. The greater *Striga* biomass in Waapp naara variety, sole and MC (2:1) cropping patterns could also be due to variation in soil fertility status of the site as *Striga* thrives well in poor fertile soils. Hence, plots disadvantage with good soil fertility (sole) will have more *Striga* germinating resulting in greater *Striga* biomass compared to the intercrop. The reduction in *Striga* biomass in Naad kohblug variety and MC (1:1) cropping pattern may be attributed to Improved N fixation as a result of cropping pattern which impeded *Striga* growth and development.

Generally, the results indicated reduction of Striga biomass in Naad kohblug variety and MC (1:1) cropping pattern which might be due to the shading effects. This observation is in line with Kureh *et al.*, (2006) and Amout (2019) who reported that reduction maybe due to shading effects from the maize-soybean intercropped plots.

5.6 Effect of intercropping on plant height of pearl millet

The present study (Table 4) showed that the height of pearl millet was significantly influenced by the cultivar type and intercrop competition. The differences in plant height as demonstrated by the four pearl millet varieties at 3, 5, 7 and 9 WAP might be as a result of the environmental conditions that favoured the performance of some treatments. As Amout (2019) shows, it is important to select the best adapted resistant cultivar for each location as resistance is often regional and performance depends on environmental conditions as well. It could also be the genetic make-up of the varieties that lead to their differences in height. Naad kohblug treatment effect was superior to all other treatment means in terms of plant height at all sampling periods. This might be due to its ability to mobilize resources for accelerated growth. Any advantage in biomass production would have resulted in the correct orientation of the leaves for maximum light interception as reported by Alhassan (2000).

The results suggested that there is indeed the existence of genetic differences among the pearl millet varieties the genetic materials belong to different pool. Raouf *et al.* (2009) reported similar results with significant differences in plant height among pearl millet varieties. In accordance with the result, Gozubenli *et al.* (2001) reported a significant variation in the variety for maize cultivar plant height. Presence of *Striga* in the experimental plots did not reduce the height of pearl millet. Although, *Striga* reduces cell elongation and photosynthetic activities contributing to shorter pearl millet internodes and stunted growth. However, these symptoms were not observed in the current experiment. Plots that were intercropped had similar plant height.

5.7 Effect of intercropping on leaf area index (LAI) of pearl millet

In the current research (Table 5), LAI showed a growing trend with the increase in plant development up to 7 WAP. The result was a decrease in all treatments that could be ascribed to the drying and senescence of leaves and the transport of photo assimilates from the source (leaves) to the other components of the plant, especially in economic sinks (grains). The reduction may also be as a result of less partitioning of dry matter into leaf production in favour of the principal physiological activities this stage, this demanded dry matter accumulation and storage. Alhassan (2000) and Kombiok (2004) reported similar observation, and this might have been as a result of senescence.

Naad kohblug variety and MC (1:1) cropping pattern comparatively recorded greater LAI during most of the crop life span which is a beneficial trait for improved yield Kumar *et al.* (2010). The higher LAI in Naad kohblug variety and MC (1:1) cropping pattern indicate a greater interception of incoming solar compared to monocrops, and this may also be the reason for increased total stover yield/ha in intercropping systems relative to their monocultural counterparts. These findings disagreed with Filho's (2000) outcomes, which found no important differences in LAI between cowpea-cropped sole maize and maize. The Chau and Deshmukh (1993) indicated that a LAI of about 4.6 to 6.0 at flowering was adequate to yield 6 tons/ha of grain.

5.8 Effect of intercropping on days to 50% heading of pearl millet

Differences recorded among treatments on days to 50 percent heading might be due to different pearl millet varieties used, with different genetic make-up, or due to environmental conditions within treatments, and/ or inter-specific competition within intercropped pearl millet varieties and cropping patterns (Amout, 2019). The number of days to 50% for treatments ranged from 41 to 48 days. Timely accessibility and appropriate quantities of nutrients, particularly atmospheric N fixation, could have boosted the accumulation of dry matter and improved plant development has endorsed the crop's physiological functions to early flowering as indicated (Khan *et al.* 2008). Waapp naara recorded the greatest (48) on days to 50 percent heading among the pearl millet varieties and Kaanati variety recorded the least (40). The higher value recorded in this study might be due to differences in genotypes used and variation in the levels of *Striga* infestation.

5.9 Effect of intercropping on tiller and productive tiller counts

Tillers per plant have been recognized as the most significant character contributing output (Naeem *et al.,* 1994). Tiller number and grain size are the main elements of output (Kashif and Khalia (2004) and are strongly and favorably associated with grain yield (Akmal *et al.,* (1992). Tillers per plant were identified as most important yield contributing characters (Naeem *et al.,* 1994). Tiller number and grain size are the major yield components (Kashif and Khalia (2004) and it strongly and positively correlated with grain yield (Akmal *et al.,* (1992). The greater tiller number in Akad-kom and Naad kohblug in the present study showed (Table 6) that at week 3 and 5 week, respectively the Akad-kom and Naad kohblug varieties respectively, could be the contributing characters for high grain yield. Waapp naara indicated the significant minimum values at week 3 and 5. Pearl millt varietis that show high tiller numbers and low *Striga* counts might be indicative of genotypes that are less prone to *Striga* infestation. Between *Striga* count and productive tiller count there was a significant positive correlation (r = 0.34). Entry Akad-kom and Naad kohblug have high number of productive tiller count and relatively low *Striga* emergence. The low *Striga* emergenc by these genotypes might be due to their less susceptibility to *Striga* infestation.

5.10 Pearl millet-cowpea intercrop improved grain and biomass yield

In the current research (Table 11), the variety Naad koblug (12.19) was discovered to be associated with the highest grain weight of 1000 grains. The minimum grain weight was reported in the variety Waapp naara (8.29 g). Naad kohblug variety's elevated grain weight could have led to its elevated grain yield. The weight of 1000 grains had a direct impact on yield (Singh *et al.*, 2003).

The high grain yield displayed by Akad-kom and Naad kohblug treatments than the other varieties suggest that, there was less competition for nutrients for Akad-kom and Naad kohblug. Also, this may be due to the varietal difference between the varieties, the height of the plant, the number of productive tillers, the length of the panicle, the highest panicle size, the number of grains per panicle and other yield components. Kashif and Khalia (2004) recorded a beneficial immediate impact on grain yield from plant height, flag leaf region, spike length and amount of grains/spike. The greater grain yield also, might be that more photosynthetic products were directed to the production of vegetative parts which contributed to high grain yield.

Generally, the yield of pearl millet in the intercrops (millet-cowpea (1:1)) intercrop was similar to those in Akad-kom and Naad kohblug treatments. This confirmed to the fact that pearl millet components that positively correlated to grain yield were not affected by *Striga*, as *Striga* appeared in both cropping patterns and no symptom of the witch weed were observed. The pearl millet varieties were really tolerant to *Striga* which is in line with Adu *et al.,* (2014) that the newly developed pearl millet genotypes by CSIR-SARI are resistant/tolerant to *Striga* infestation and these genotypes include Akad-kom, Naad kohblug, Kaanati and Waapp naara. In intercrops, the cereal usually has a competitive advantage as they are tall and benefit from maximum photosynthetic active radiation reaching the foliage, so they may not experience declines in yield. The two crops (Pearl millet and cowpea) may have utilized nutrients from different soil depth, reducing competition for nutrients or non-existent (Amout, 2019).

Greater *Striga* biomass, cumulative *Striga* emergence and least reduction in *Striga* seed bank in sole crop and MC (2:1) responded with a 3 and 5% reduction in grain yield, respectively compared to MC (1:1). Yield reduction in MC (2:1), and sole crop may be a result of variation in the utilization of resources. Waapp naara variety had the least grain yield due to poor performance in yield components. Akad-kom and 1:1 recorded 6 and 5% greater grain yield compared to Waapp naara and 2:1 among millet varieties and cropping pattern, respectively. The MC (1:1) cropping pattern produced the highest grain yield as a result of its quite higher grain weight. The improved yield under intercrop maybe attributed to maximum resource use.

5.11 Relationship between pearl millet agronomic parameters and *Striga* counts

The effect of intercropping pearl millet varieties and cowpea on linear relationship among pearl millet agronomic parameters was significant. Correlation analysis findings disclosed a positive correlation between grain yield and 1000 grain weight (r = 0.48). Singh *et al.* (2003) recorded a strong direct impact of 1000-grain weight on the yield per plant of grain. This outcome is consistent with the finding of Pearl (2012) who reported in his research a significant correlation between grain yield and 1000 seed weight, plant height and days to mid anthesis. Kashif and Khalia (2004) also revealed positive ($P<0.05$) correlation and extremely substantial ($P<0.01$) correlation between grain yield and corn yield elements. Unnikrishnan *et al.* (2004) reported the highest direct positive effect of ear girth on grain yield followed by ear length, plant height, and weight of 1000 grain. Grain yield negatively correlated with *Striga* emergence (r = -0.42).

The observed correlation obtained with *Striga* parameters probably could be linked to the genetic features of pearl millet varieties. This result is in line with the findings of Amout (2019), who reported significant and negative correlation between maize grain yield and the emergence and damage rating of *Striga*. From the study, susceptible pearl millet variety created an enabling environment for *S. hermonthica* to compete favourably with the crop which depresses the crop growth and subsequent poor yield at harvest, but in contrast, *S. hermonthica* resistant/tolerant pearl millet varieties supported lower *Striga* incidence which lead to greater yield.

5.12 Pearl millet-cowpea intercrop enhanced land equivalent ratio

Results show that all intercropping systems had total LER values higher than 1 (Table 16) which means that intercropping was more efficient than single cropping. The fundamental concept of better use of resources in intercropping can explain higher productivity of intercropping over sole cropping (Jackson, 2009). Crop differ in the way they use environmental resources and complement each other and make better use of resources when they grow together than when they are grown separately (Li *et al.*, 2006). Partial LER values for pearl millet varieties and cowpea revealed that pearl millet varieties were more productive. Pearl millet was more productive in Akad-kom and Naad kohblug varieties with MC (1:1) cropping pattern. Overall, based on a relatively higher partial LER for pearl millet varieties over cowpea (Table 16), it may be suggested that pearl millet was the main crop influencing the final productivity of the systems studied. This is further demonstrated by the non-significant variations in the partial LER for cowpea, which imply that the efficacy of cowpea in the use of accessible resources in pearl millet and cowpea intercrop was not influenced by intercropping processes such as pearl millet varieties. Variety Naad kohblug and cropping pattern MC (1:1) gave a greater total Land Equivalent Ratio (LER) of 1.44 and 1.41 respectively. Abera *et al.* (2005) also observed that, in terms of food production per unit area, the LER values ranged from 1.15 to 1.42 suggesting higher productivity and land use effectiveness of intercropping corn (Zea mays)-climbing bean (*Phaseolus vulgaris*) relative to distinct planting.

CHAPTER SIX

6.0 CONCLUSION AND RECOMMENDATIONS

6.1 Conclusions

It can be concluded that, pearl millet varieties and cropping patterns used in this experiment managed *Striga* by reducing *Striga* emergence, seed bank, and *Striga* biomass resulting to improved grain yield and land equivalent ratios values greater than 1 (LER > 1). Waapp naara variety was more susceptible to *Striga*, with high *Striga* numbers and biomass compared to Kaanati, Akad-kom and Naad kohblug respectively. The pearl millet varieties studied in this research revealed that Akad-kom and Naad kohblug produced the greatest grain yields. Kaanati and Akad-kom were found to be the early maturing varieties which will favour climate smart production.

The MC (1:1) cropping pattern had the least *Striga* numbers and biomass resulting to greatest grain yield compared to MC (2:1). The Land equivalent ratios of Naad kohblug variety and MC (1:1) intercrop were profitable. Postharvest soil analysis showed that the cropping systems used in this trial did not have much influence on soil physico-chemical properties.

6.2 Recommendations

- *Striga* tolerance pearl millet varieties (Akad-kom and Naad kohblug) are recommended in *Striga* infested field in the Sudan Savannah for reduced *Striga* seed bank and improved millet yield.
- Millet-cowpea (1:1) cropping pattern is recommended for improved soil fertility, reduced *Striga* seed bank and sustainable improved yield.
- For best land productivity or LER, smallholder farmers can plant Naad kohblug using MC (1:1) cropping pattern.
- Future cropping system research in the region should focus on evaluation of long term effects of different cropping systems on the soil chemical and physical properties and crop yields

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APPENDICES

Appendix 1: Analysis of variance for initial *Striga hermonthica* soil seed

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication	2	1424	713	0.34	
Variety	3	315400	78851	37.20	<.001
Cropping pattern	2	48600	24200	11.47	<.001
Variety × Cropping pattern	6	21133	10567	4.98	0.023
Residual	22	33911	2119		
Total	35	420468			

Appendix 2: Analysis of variance for postharvest *Striga hermonthica* soil

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication	2	115.84	57.37	1.23	
Variety	3	4690.78	1563.59	33.58	<.001
Cropping pattern	2	605.76	302.88	6.50	0.006
Variety × Cropping pattern	6	948.45	156.41	3.36	0.014
Residual	22	1014.47	46.56		
Total	35	7364.22			

Appendix 3: Analysis of variance for pearl millet plant height, 3 WAP

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication 2	51.958	25.979	3.43		
Variety	3	210.914	70.305	9.27	<.001
Cropping pattern	2	30.177	15.089	1.99	0.161
Variety × Cropping pattern	6	24.329	4.055	0.53	0.776
Residual	22	166.800	7.582		
Total	35	484.178			

Appendix 4: Analysis of variance for pearl millet plant height, 5 WAP

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication	2	178.55	89.27	1.37	
Variety	3	2772.71	924.24	14.14	<.001
Cropping pattern	2	1049.40	524.70	8.03	0.002
Variety × Cropping pattern	6	456.04	76.01	1.16	0.361
Residual	22	1438.07	65.37		
Total	35	5894.77			

Appendix 5: Analysis of variance for pearl millet plant height, 7 WAP

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication	2	305.1	152.6	1.20	
Variety	3	3123.1	1041.0	8.18	<.001
Cropping pattern	2	2555.4	1277.7	10.04	<.001
Variety × Cropping pattern	6	1376.2	229.4	1.80	0.145
Residual	22	2799.5	127.3		
Total	35	10159.3			

Appendix 6: Analysis of variance for pearl millet plant height, 9 WAP

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication	2	114.74	57.37	1.23	
Variety	3	4690.78	1563.59	33.58	<.001
Cropping pattern	2	605.76	302.88	6.50	0.006
Variety × Cropping pattern	6	938.45	156.41	3.36	0.017
Residual	22	1024.47	46.57		
Total	35	7374.21			

Appendix 7: Analysis of variance for pearl millet leaf area, 3 WAP

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication	2	1149.6	574.8	2.37	
Variety	3	6268.1	2089.4	8.60	<.001
Cropping pattern	2	2017.0	1008.5	4.15	0.030
Variety × Cropping pattern	6	570.6	95.1	0.39	0.876
Residual	22	5344.1	242.9		
Total	35	15349.5			

Appendix 8: Analysis of variance for pearl millet leaf area, 5 WAP

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication	2	539.9	269.9	0.71	
Variety	3	11692.9	3897.6	10.26	<.001
Cropping pattern	2	1060.7	530.4	1.40	0.269
Variety × Cropping pattern	6	1964.5	327.4	0.86	0.538
Residual	22	8360.7	380.0		
Total	35	23618			

Appendix 9: Analysis of variance for pearl millet leaf area, 7 WAP

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication	2	192.2	96.1	0.24	
Variety	3	11141.8	3713.9	9.19	<.001
Cropping pattern	2	5221.8	2610.9	6.46	0.006
Variety × Cropping pattern	6	4270.8	711.8	1.76	0.154
Residual	22	8891.8	404.2		
Total	35	29718.3			

Appendix 10: Analysis of variance for pearl millet leaf area, 9 WAP

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication	2	146.1	73.0	0.25	
Variety	3	11326.4	3775.5	12.88	<.001
Cropping pattern	2	6717.8	3358.9	11.46	<.001
Variety × Cropping pattern	6	4360.3	726.7	2.48	0.055
Residual	22	6449.9	293.2		
Total	35	29000			

Appendix 11: Analysis of variance for tiller count, 3 WAP

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication	2	0.3539	0.1769	1.38	
Variety	3	0.5244	0.1748	1.37	0.279
Cropping pattern	2	1.5272	0.7636	5.97	0.008
Variety × Cropping pattern	6	2.6906	0.4484	3.51	0.014
Residual	22	2.8128	0.1279		
Total	35	7.9089			

Appendix 12: Analysis of variance for tiller count, 5 WAP

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication	2	0.5017	0.2508	0.66	
Variety	3	1.8897	0.6299	1.66	0.205
Cropping pattern	2	3.2850	1.6425	4.32	0.026
Variety × Cropping pattern	6	2.0861	0.3477	0.91	0.503
Residual	22	8.3650	0.3802		
Total	35	16.1275			

Appendix 13: Analysis of variance for tiller count, 7 WAP

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication	2	0.4650	0.2325	1.26	
Variety	3	3.5300	1.1767	6.37	0.003
Cropping pattern	2	2.5417	1.2708	6.88	0.005
Variety × Cropping pattern	6	2.0917	0.3486	1.89	0.128
Residual	22	4.0617	0.1846		
Total	35	12.6900			

Appendix 14: Analysis of variance for tiller count, 9 WAP

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication	2	0.0939	0.0469	0.47	
Variety	3	4.4564	1.4855	14.81	<.001
Cropping pattern	2	3.0022	1.5011	14.97	<.001
Variety × Cropping pattern	6	2.3178	0.3863	3.85	0.009
Residual	22	2.2061	0.1003		
Total	35	12.0764			

Appendix 15: Analysis of variance for productive tiller count, 7 WAP

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication	2	0.7714	0.3857	2.98	
Variety	3	2.7851	0.9284	7.18	0.002
Cropping pattern	2	0.1301	0.0651	0.50	0.611
Variety × Cropping pattern	6	0.5228	0.0871	0.67	0.672
Residual	22	2.8439	0.1293		
Total	35	7.0534			

Appendix 16: Analysis of variance for productive tiller count, 9 WAP

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication	2	0.7072	0.3536	3.46	
Variety	3	0.7364	0.2455	2.40	0.095
Cropping pattern	2	0.7606	0.3803	3.72	0.040
Variety × Cropping pattern	6	0.8794	0.1466	1.44	0.246
Residual	22	2.2461	0.1021		
Total	35	5.3297			

Appendix 17: Analysis of variance for days to 50% heading

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication	2	0.3889	0.1944	0.68	
Variety	3	277.1944	92.3981	323.80	<.001
Cropping pattern	2	5.7222	2.8611	10.03	<.001
Variety × Cropping pattern	6	16.7222	2.7870	9.77	<.001
Residual	22	6.2778	0.2854		
Total	35	306.3056			

Appendix 18: Analysis of variance for *Striga* count, 8 WAP

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication	2	7.762	3.881	1.70	
Variety	3	27.990	9.330	4.08	0.019
Cropping pattern	2	25.275	12.638	5.52	0.011
Variety × Cropping pattern	6	63.923	10.654	4.66	0.003
Residual	22	50.322	2.287		
Total	35	175.272			

Appendix 19: Analysis of variance for *Striga* count, 10 WAP

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication	2	6.836	3.418	1.19	
Variety	3	46.522	15.507	5.39	0.006
Cropping pattern	2	34.544	17.272	6.00	0.008
Variety × Cropping pattern	6	237.744	39.624	13.76	<.001
Residual	22	63.351	2.880		
Total	35	388.996			

Appendix 20: Analysis of variance for *Striga* count, 12 WAP

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication	2	3.421	1.711	0.43	
Variety	3	147.868	49.289	12.30	<.001
Cropping pattern	2	105.299	52.650	13.13	<.001
Variety × Cropping pattern	6	389.094	64.849	16.18	<.001
Residual	22	88.187	4.008		
Total	35	733.869			

Appendix 21: Analysis of variance for *Striga* count, 14 WAP

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication	2	6.660	3.330	1.30	
Variety	3	9.497	3.166	1.24	0.320
Cropping pattern	2	0.243	0.122	0.05	0.954
Variety × Cropping pattern	6	7.885	1.314	0.51	0.791
Residual	22	56.233	2.556		
Total	35	80.519			

Appendix 22: Analysis of variance for *Striga* biomass, 8 WAP

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication	2	1.8810	0.9405	1.84	
Variety	3	5.7804	1.9268	3.76	0.026
Cropping pattern	2	5.1319	2.5659	5.01	0.016
Variety × Cropping pattern	6	12.9471	2.1579	4.21	0.006
Residual	22	11.2739	0.5124		
Total	35	37.0143			

Appendix 23: Analysis of variance for *Striga* biomass, 10 WAP

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication	2	2.2643	1.1321	1.20	
Variety	3	16.5594	5.5198	5.86	0.004
Cropping pattern	2	13.1324	6.5662	6.97	0.005
Variety × Cropping pattern	6	82.5141	13.7524	14.60	<.001
Residual	22	20.7195	0.9418		
Total	35	135.1897			

Appendix 24: Analysis of variance for *Striga* biomass, 12 WAP

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication	2	1.759	0.880	0.67	
Variety	3	50.932	16.977	12.96	<.001
Cropping pattern	2	34.880	17.440	13.31	<.001
Variety × Cropping pattern	6	143.439	23.907	18.25	<.001
Residual	22	28.822	1.310		
Total	35	259.833			

Appendix 25: Analysis of variance for *Striga* biomass, 14 WAP

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication	2	2.6675	1.3337	1.81	
Variety	3	3.7075	1.2358	1.68	0.201
Cropping pattern	2	0.0184	0.0092	0.01	0.988
Variety × Cropping pattern	6	2.4014	0.4002	0.54	0.770
Residual	22	16.2133	0.7370		
Total	35	25.0080			

Appendix 26: Analysis of variance for cumulative *Striga* count

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication	2	1.8370	0.9185	3.86	
Variety	3	26.3637	8.7879	36.88	<.001
Cropping pattern	2	9.2725	4.6362	19.46	<.001
Variety × Cropping pattern	6	27.5707	4.5951	19.29	<.001
Residual	22	5.2416	0.2383		
Total	35	70.2856			

Appendix 27: Analysis of variance for panicle length (cm)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication	2	0.0817	0.0408	0.06	
Variety	3	1771.6833	590.5611	821.69	<.001
Cropping pattern	2	0.2217	0.1108	0.15	0.858
Variety × Cropping pattern	6	2.2517	0.3753	0.52	0.785
Residual	22	15.8117	0.7187		
Total	35	1790.0500			

Appendix 28: Analysis of variance for panicle girth (cm)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication	2	0.06222	0.03111	1.21	
Variety	3	79.51417	26.50472	1033.06	<.001
Cropping pattern	2	0.01722	0.00861	0.34	0.718
Variety × Cropping pattern	6	0.25167	0.04194	1.63	0.185
Residual	22	0.56444	0.02566		
Total	35	80.40972			

Appendix 29: Analysis of variance for panicle weight (g)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication	2	11.060	5.530	0.62	
Variety	3	59.816	19.939	2.24	0.112
Cropping pattern	2	13.832	6.916	0.78	0.473
Variety × Cropping pattern	6	19.553	3.259	0.37	0.893
Residual	22	196.107	8.914		
Total	35	300.367			

Appendix 30: Analysis of variance for pearl millet 1000 grain weight (g)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication	2	0.05056	0.02528	0.78	
Variety	3	79.80972	26.60324	824.97	<.001
Cropping pattern	2	0.07389	0.03694	1.15	0.336
Variety × Cropping pattern	6	0.34611	0.05769	1.79	0.148
Residual	22	0.70944	0.03225		
Total	35	80.98972			

Appendix 31: Analysis of variance for pearl millet grain yield (kg/ha)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication	2	7222	3611	0.80	
Variety	3	65556	21852	4.83	0.010
Cropping pattern	2	60556	30278	6.70	0.005
Variety × Cropping pattern	6	12778	2130	0.47	0.822
Residual	22	99444	4520		
Total	35	245556			

Appendix 32: Analysis of variance for pearl millet Stover yield (kg/ha)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication	2	31667	15833	0.26	
Variety	3	8227500	2742500	45.88	<.001
Cropping pattern	2	1680000	840000	14.05	<.001
Variety × Cropping pattern	6	653333	108889	1.82	0.141
Residual	22	1315000	59773		
Total	35	11907500			

Appendix 33: Analysis of variance for cowpea plant height (cm), 7 WAP

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication	2	89.22	44.61	1.16	
Variety	4	464.53	116.13	3.01	0.050
Cropping pattern	2	22.62	11.31	0.29	0.750
Variety × Cropping pattern	2	330.48	165.24	4.28	0.032
Residual	16	617.37	38.59		
Total	26	1524.21			

Appendix 34: Analysis of variance for cowpea number of leaf branches per plant

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication	2	0.0263	0.0131	0.13	
Variety	4	2.6139	0.6535	6.25	0.003
Cropping pattern	2	0.8400	0.4200	4.02	0.039
Variety × Cropping pattern	2	0.5607	0.2804	2.68	0.099
Residual	16	1.6733	0.1046		
Total	26	5.7142			

Appendix 35: Analysis of variance for cowpea number of leaves per plant, 7 WAP

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication	2	41.49	20.74	0.70	
Variety	4	1161.45	290.36	9.80	<.001
Cropping pattern	2	114.54	57.27	1.93	0.177
Variety × Cropping pattern	2	689.70	344.85	11.64	<.001
Residual	16	474.07	29.63		
Total	26	2481.24			

Appendix 36: Analysis of variance for number of nodules per plant

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication	2	2.17	1.09	0.08	
Variety	4	448.17	112.04	7.87	0.001
Cropping pattern	2	37.45	18.73	1.32	0.296
Variety × Cropping pattern	2	325.25	162.62	11.42	<.001
Residual	16	227.78	14.24		
Total	26	1040.82			

Appendix 37: Analysis of variance for nodule dry weight (g)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication	2	0.0319	0.0159	0.12	
Variety	4	2.7913	0.6978	5.06	0.008
Cropping pattern	2	0.1838	0.0919	0.67	0.528
Variety × Cropping pattern	2	2.9413	1.4706	10.66	0.001
Residual	16	2.2081	0.1380		
Total	26	8.1563			

Appendix 38: Analysis of variance effective nodule percent

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication	2	83.75	41.88	1.14	
Variety	4	77.21	19.30	0.53	0.719
Cropping pattern	2	0.90	0.45	0.01	0.988
Variety × Cropping pattern	2	111.11	55.55	1.51	0.250
Residual	16	587.69	36.73		
Total	26	860.66			

Appendix 39: Analysis of variance for number of pods per plant of cowpea

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication	2	2.2067	1.1033	1.73	
Variety	4	8.6900	2.1725	3.41	0.034
Cropping pattern	2	0.0017	0.0008	0.00	0.999
Variety × Cropping pattern	2	3.3683	1.6842	2.65	0.102
Residual	16	10.1800	0.6363		
Total	26	24.4467			

Appendix 40: Analysis of variance for number of seeds per pod of cowpea

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication	2	5.2941	2.6470	4.84	
Variety	4	3.4691	0.8673	1.59	0.226
Cropping pattern	2	0.4538	0.2269	0.42	0.667
Variety × Cropping pattern	2	3.5046	1.7523	3.21	0.067
Residual	16	8.7459	0.5466		
Total	26	21.4674			

Appendix 41: Analysis of variance for 100 seed weight (g) of cowpea

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication	2	0.6541	0.3270	0.83	
Variety	4	1.3607	0.3402	0.86	0.509
Cropping pattern	2	0.6017	0.3008	0.76	0.484
Variety × Cropping pattern	2	2.5250	1.2625	3.19	0.068
Residual	16	6.3326	0.3958		
Total	26	11.4741			

Appendix 42: Analysis of variance for cowpea grain yield (kg/ha)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication	2	1422	711	0.34	
Variety	4	315400	78850	37.20	<.001
Cropping pattern	2	48600	24300	11.47	<.001
Variety × Cropping pattern	2	21133	10567	4.99	0.021
Residual	16	33911	2119		
Total	26	420467			

Appendix 43: Analysis of variance for cowpea haulm yield (kg/ha)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication	2	7319	3659	2.68	
Variety	4	43463	10866	7.97	<.001
Cropping pattern	2	72600	36300	26.62	<.001
Variety × Cropping pattern	2	13567	6783	4.98	0.021
Residual	16	21815	1363		
Total	26	158763			

Appendix 44: Analysis of variance for partial land equivalent ratio (PLERc)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication	2	0.004975	0.002488	0.42	
Variety	3	0.121979	0.040660	6.84	0.005
Cropping pattern	1	0.130538	0.130538	21.96	<.001
Variety × Cropping pattern	3	0.053746	0.017915	3.01	0.066
Residual	14	0.083225	0.005945		
Total	23	0.394462			

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Appendix 45: Analysis of variance for partial land equivalent ratio (PLERm)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication	2	0.00032	0.00016	0.01	
Variety	3	0.03427	0.01142	0.73	0.549
Cropping pattern	1	0.00015	0.00015	0.01	0.923
Variety × Cropping pattern	3	0.26437	0.08812	5.65	0.009
Residual	14	0.21819	0.01558		
Total	23	0.51729			

Appendix 46: Analysis of variance for land equivalent ratio (LER)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication	2	0.00306	0.00153	0.14	
Variety	3	0.09375	0.03125	2.88	0.074
Cropping pattern	1	0.11620	0.11620	10.70	0.006
Variety × Cropping pattern	3	0.43291	0.14430	13.28	<.001
Residual	14	0.15207	0.01086		
Total	23	0.79800			