# EFFECTS OF LEAF HARVESTING INTENSITY AND FREQUENCY ON GROWTH, NODULATION AND YIELD OF THREE COWPEA (*Vigna unguiculata* L.) VARIETIES IN BOR AND AWERIAL COUNTY, SOUTH SUDAN

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## DECLARATION

This thesis is my original work and has not been presented for an award of a degree in this or any other university.

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This thesis has been submitted with our approval as university supervisors.

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## DEDICATION

To my husband, brother, and sisters, and to my mother Rachael Athiec. I have experienced your love in reassuring and providing me with the courage to accomplish my dreams.

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**ABSTRACT**

Cowpea (*Vigna unguiculata* L. Walp) is an important crop in South Sudan, however, its low production has been attributed to poor agronomic and leaf harvesting practices which cause a reduction in grain yield and quality because of interference of the source-sink relationship. The objectives of this study were to determine: (i) the effect of leaf harvesting intensity on growth, nodulation, and yield of selected cowpea varieties; and (ii) the effect of leaf harvesting interval on growth, nodulation, and yield of selected cowpea varieties. A randomized complete block design (RCBD) experiment in a 4×3×3 factorial arrangement (comprising intensity, frequency, and variety factors, respectively) was conducted in Bor and Awerial sites in South Sudan. The harvesting intensity treatments comprised control (no leaf harvesting), 20%, 40%, and 60% leaf harvesting, frequency treatments comprised 2, 3, and 4 weeks harvesting intervals while the cowpea varieties comprised improved variety M66 and landraces Lubia and Areng. Effects due to environment, variety, interval, and intensity were significant ($p \leq 0.001$) for days to flowering, maturity, number of nodules per plant, pod weight, grain yield, and shoot dry weight. An increase in leaf harvesting intensity (40 and 60% intensities) delayed flowering and maturity, and decreased shoot dry weight, 100-seed weight, grain yield, pod weight, and number of seeds per pod. Harvesting cowpea leaves at 20% intensity in both sites and 40% intensity at Bor resulted in increases in the number of leaves per plant and number of branches per plant compared to all the other treatments. Piece-meal harvesting delayed flowering and maturity, increased dry matter accumulation and reduce the number of nodules per plant. It also increased the number of leaves per plant, number of branches per plant, pod weight and number of pods per plant. Cowpea variety Areng and M66 had higher shoot dry weight, grain weight, grain yield, and the number of nodules, pods, and seeds per plant than variety Lubia. Among the three varieties evaluated for defoliation, variety Areng took a much longer time to flower compared to the other two varieties. A decrease in the dry matter at the flowering stage was

less pronounced on variety Areng. Variety M66 accumulated the least dry matter at different intensities and was less suitable for foliage harvesting after flowering. Cowpeas grown at Awerial produced a higher grain weight (0.93-1.04 t/ha) than those in Bor (0.78-0.94 t/ha). Both harvest interval and intensity had a significant effect on growth parameters, yield, and yield components of cowpea varieties. The sensitivity of the varieties to change in the Environment influences the production potential of cowpea varieties. Cowpea variety Areng and M66 are suitable for yield and foliage production with minimal environmental influence.

## TABLE OF CONTENTS

## LIST OF TABLES

## LIST OF FIGURES

# CHAPTER ONE: INTRODUCTION

## 1.1 Background information

Cowpea (*Vigna unguiculata* L. Walp) is a leguminous crop widely cultivated in Africa and other parts of the world. It is mostly considered a very useful proteinous vegetable in many parts of the world and particularly in Sub-Saharan Africa (Adeoye *et al*., 2011). Cowpea grains are cooked with ingredients such as tomatoes (*Lycopersicon esculentum* L.), onions (*Allium cepa* L.*)* and meat to make a soup that is consumed with the main carbohydrate meals. Herniter *et al*. (2020) and Carvalho *et al.* (2017) reported that cowpea grain contains over 20% protein and several essential nutrients such as zinc, iron, and calcium. The essential nutrients are present in 90-360,7-8 and 2-2.4 mg/Kg of Calcium, Zinc, and Iron, respectively (Gondwe *et al*., 2019). Apart from human consumption, cowpea especially the haulm is a nutritious valuable animal feed which is commercially sold as a source of income to farmers (Singh *et al*., 2014). Compared to the cowpea grains, the haulms have a high market value of over 50% more than the market value for cowpea grain (Singh *et al*., 2003).

Being a legume, cowpea fixes nitrogen into the soil hence contributes to nitrogen nutrition of other crops such as sorghum (*Sorghum bicolour* L.), pearl millet *(Pennisetum americanum* L.) and maize (*Zea mays* L.*)*, when intercropped or grown in rotation (Mndzebele *et al*., 2020). This is especially the case in the areas where farmers do not use fertilizer, or the cost of fertilizer is prohibitive. Cowpea is an essential soil cover crop in the field/tree crops systems grown on poor land. This legume is tolerant to water stress and heat stress in different types of soils (Carvalho *et al*., 2019). Cowpea, as neglected and underutilized species, is grown by farmers during the rainy season in South Sudan. Cowpea yields are very low in Africa, particularly in South Sudan (SSLZ, 2013). Many farmers in South Sudan obtain very low yields from cowpea because of unimproved cultivars, poor agronomic practices, poor extension services and poor techniques of leaf harvesting (Ahmed *et al*., 2012). In addition, there are no well-defined agronomic practices for managing the crop for optimizing leaf and grain yield in the varieties being produced.

Cowpea is in high demand in urban and rural areas in South Sudan and African Markets. It provides farmers with a good return on investments and requires less labour and external inputs than other crops Cowpea is a good source of protein, fatty acid, essential amino acid minerals and vitamins (Gonçalves *et al*., 2016; Da silva *et al*., 2018). Young tender leaves, immature pods and grains are used for home consumption as vegetable and grains in South Sudan and in most parts of Africa for institutions like schools and hospitals, low-income consumers in rural and urban areas, they are an affordable source of high-quality nutrition hence it improves food insecurity and malnutrition in the country. Cowpea dry seeds have a high percentage of protein (20-30 %) that is characterized as a complete protein compared to other vegetables (Dakora & Belane, 2019). Cowpea is an excellent source of carbohydrates, protein, vitamins, and minerals in the diet of many populations, especially in developing countries (Da Silva *et al*., 2018).

Cowpea plays an important role in soil fertility improvement through nitrogen fixation where farmers have limited resources and poor access to agricultural inputs. Cowpea improves soil fertility and the structure of competitive crops like maize and other cereal crops (Gondwe *et al*., 2019; Carvalho *et al*., 2017) therefore it is good for intercropping with other crops such as cereals crops. It is also used as a cover crop to minimize soil erosion due to heavy rainfall. Cowpea does not need a high rate of nitrogen fertilizer; its root has nodules in which soil bacteria called rhizobia facilitate the fixation of nitrogen from the air.

In South Sudan, mainly people responsible for vegetable cultivation are women. They engage in competitive markets as a way of empowerment. Cultivation of cowpea as a vegetable improves the livelihoods of vulnerable households. Women, for example, women can meet the costs of food, school fees, clothes, medication, and purchase of livestock through vegetable production.

Cowpea is grown in many areas under the rainfed condition as well as using irrigation or residual moisture along the river Nile or flood plains during the dry season in South Sudan. Cowpea is tolerant of drought and well adapted to sandy and poor soils. It grows well in the areas with temperatures of between 27 $^{o}$C and 30 $^{o}$C during the growing season and rainfall ranging from 600 and 1100 mm/year. The crop is planted on flat beds with three seeds/hill or broadcast with other cereal crops such as sorghum in a mixed planting. Planting is usually manual since mechanical planters are not available in South Sudan. Manual weed control is the most common method used by farmers and delays in weeding cause a drastic reduction in yield.

Cowpea production faces many challenges in South Sudan therefore the grain yield is about 0.4 tones/ha due to poor agronomic practices, insect pests, diseases, and the use of unimproved varieties. There is a high use of cowpea as a vegetable compared to grain in South Sudan. Cowpea is grown for its leaves and grain for human consumption as well as for animal feed. It is used as a cover crop to minimize soil erosion that is often caused by heavy rainfall. In South Sudan, young cowpea leaves are harvested and used as fresh vegetables or preserved by boiling the fresh tender leaves, dried and stored for sale or consumed during the dry season when the vegetables are scarce. The selling of fresh vegetables such as cowpea, jute mallow (*Corchorus olitorius*), Amaranthus (*Amaranthus* spp) and kale (*Brassica oleracea*) has empowered women who are practicing small-scale farming for vegetable production in South Sudan.

### 1.2 Statement of the Problem

Cowpea is extensively grown in tropical regions of Africa with West and Central Africa being the leading with about 8 and 2.4 million hectares, respectively (FAO/WFP, 2012). In South

Sudan, (Ngalamu *et al*., 2015) reported an approximate cowpea yield of about 0.4 tonnes/ha in fields grown by the farmers compared to a potential grain yield of 0.8 tonnes/ha obtained from a research station at the University of Kordofan, Central Sudan. Cowpea production in South Sudan faces several challenges that impede its expansion. These include an insufficient amount of information regarding cowpea production by local farmers. As a result of that, production is limited to the subsistence level. Cowpea is mainly grown for its leaves and grain consumption as well as animal feed in a mixed livestock-crop system. Repeated harvesting of leaves may cause a reduction in grain yield and quality because of interference of the source-sink relationship (Ibrahim *et al*., 2010). Young, fresh, and tender leaves are often randomly harvested 4-6 six weeks after planting and used as fresh or dried vegetables, stored to be consumed during the dry season. It is also used for commercial purposes when there are not enough vegetables in the area. Though many crops such as *Amaranthus spp,* Okra (*Abelmoschus esculentus*), Jute mallow (*Corchorus spp*) and purselane (*Portulaca oleracea*) are appreciated as leafy vegetable cowpea has high potential in solving the problem of food insecurity and subsequent livelihood in South Sudan ( Ngalamu *et al*., 2015).

**1.3 Justification**

Appropriate cowpea leaf harvesting practices have been identified to help enhance cowpea productivity (Matikiti et al., 2012). However, such practices have not been evaluated on different varieties under South Sudan conditions. The current study will therefore focus on evaluating the effects of leaf harvesting intensity and frequency on growth and yield components of cowpea varieties. Therefore, cowpea being dual purpose (for both leaf and grain) has a high potential in alleviating the problem of food and malnutrition among the rural communities in South Sudan. Furthermore, the cow grains and haulm are a good source of income for farmers. They also provide a nutritious source of animal feed to livestock industries which in the long run improves livestock production. Cowpea plant is drought tolerant and grows well in diverse environments with distinct soil and photoperiod. Apart from being a source of food to both urban and rural communities, cowpea is gaining industrial importance as a food formulation, and which is used in the reduction of lifestyle diseases such as increased cholesterol levels and coronary heart diseases. These benefits have realized the high exportation of cowpea to Europe from Africa in which over 95% of world production comes from Africa. West Africa particularly Niger and Nigeria account for over 70% of the exports. Therefore, eastern African countries including South Sudan must increase cowpea production due to the ready market in Europe and the long run earning the country foreign exchange. This will be achieved through good harvesting practices to enhance the high production of both leaves and grains.

### 1.4 Objectives

The main objective of the study was to improve cowpea productivity among the rural community in South Sudan through improved leaf harvesting practices. The specific objectives were:

i. To determine the effect of leaf harvesting intensity on growth, nodulation, and yield of selected cowpea varieties

ii. To evaluate the effect of leaf harvesting interval on growth, nodulation, and yield of selected cowpea varieties

### 1.5 Hypotheses

i. Increase in leaf harvesting intensity reduces the growth, nodulation, and yield of cowpea.

ii. Reducing the leaf harvesting interval reduces growth, nodulation, and yield of cowpea.

# CHAPTER TWO: LITERATURE REVIEW

## 2.1 Ecology and botany of cowpea

Cowpea (*Vigna unguiculata* L.) is an indigenous crop of Africa; Nigeria is considered the centre of diversity of cowpea crop and India is considered its second centre of diversity after Nigeria (Coley, 1991). Southern Africa and East Africa are also considered to be the centres of cowpea diversity with the existence of different species (Kay, 1979). *Vigna unguiculata species* in Africa are thought to have hybridized with cultivated cowpea and this contributed to the genetic variability that led to cowpea domestication although *unguiculata*, *melanophthalmus* and *sesquipelis* are less diverse than primitive cultivar groups (*Textilis* and *biflora*) (Ba *et al*., 2004).

Cowpea is an annual leguminous plant which is related to the common bean in many forms excluding the foliage that is characterized by dark-green colour and shinnies. Cowpea is erect, semi-erect, climbing, and prostrate type of growth depending on genotype. It develops trifoliate leaves attached to the petiole and seeds are commonly kidney-shaped and develop in the pods. Seed coats are characterized by smooth coats which include black, cream, white, green, red, buff, and brown (Singh, 1997) and cowpea has many spreading varieties (Davis *et al*., 1991). The emergence of cowpea is related to common bean, for example, the cotyledon seedling can be injured because the buds do not regenerate below the cotyledon's node (Timko *et al*., 2007).

Cowpea is a self-pollinated plant but a back-crossing rate of 5% has been observed. Cowpea cultivars are categorized into five groups depending on their morphological characteristics. *Biflora* also known as catjang has small erect with short pods found in Asia (Sebetha *et al*., 2009), *textilis* type of cowpea with long peduncles carried three to four pods found in Africa and it is used for fibres (Bresami, 1985) and *sesquipedialis* is green podded is used as snap and commonly grown in Asia (Timko *et al*., 2007).

## 2.2 Production system of cowpea

Cowpea is widely cultivated all over the world and is found in most markets in Africa in form of leafy vegetables and grain (Blade *et al*., 1997). In Africa, intercropping is used as part of the cropping system to enhance crop productivity on farmers' small farms. Though monocropping is effective, farmers grow cowpea in different cropping patterns such as mixed cropping and intercropping (Singh *et al*., 2003). In intercropping systems, cowpea not only enhances productivity in mixed farm systems but is also used as an alternative crop in case of failure of the main crops such as cereals during drought or dry spells.

Farmers in Nigeria have adopted improved varieties of cowpea that yield high under well-developed agronomic practices (Singh and Ajeigbe, 2001). In cowpea, productivity is usually based on foliage and seed therefore production is mainly for leaf, seed, and fodder purposes (Bubenheim *et al*., 1990). Sole cropping and intercropping are the main two cowpea producing patterns with the latter involving cereals (Nielsen *et al*., 1994). In cowpea production, leaf harvesting is always done during the vegetative stage followed by seed harvesting at the end of the season (Chaturvedi *et al*., 1980).

In Africa and other cowpea-growing continents, cowpea is mostly affected by pests and diseases of different categories (Aremu et al., 2007). To reduce the incidence of pests and diseases requires selection of resistant varieties which are adapted to the target agroecological zones and cropping patterns. The selection of the varieties should also be based on the time to maturity, yielding potential, drought tolerance and sensitivity to day length (Dugje et al., 2009).

Cowpea is adapted to a high temperature range of 20°C-35°C. It grows under a wide range of moisture conditions except flooded conditions. Cowpea is tolerant to drought and can produce high yields under minimal rainfall (Ngalamu *et al*., 2015). Cowpea is a resistant crop, but it usually hosts many insect pests that attack other vegetables in the field. These insect pests include whiteflies (*Bemisia tabaci*), leaf miners, leafhoppers (*Empoasca* sp.), thrips (*Megalurothrips sjostedti*), mites (*Tetranychus* spp.) and aphids (*Aphis craccivora*). However, new leafhopper- resistant varieties have been developed by the International Institute of Tropical Agriculture (IITA). These include VITA-1, VITA-3 Tvu59 and Tvu123 (Oyewale 2013).

**2.3 Utilization and importance of cowpea**

Cowpea has many uses in the world and Africa, particularly in the greater r Sudan. Cowpea grain is considered fit for human consumption in Africa and the leaves serve as a major source of protein throughout the world (Bittenbender *et al*., 1990). Nutritive values in grain and leaves qualify the cowpea to be one of the most important food crops in Sub-Saharan Africa. This legume serves as a cheap source of protein in developed and developing countries as a supplement to meat (Madodé *et al*., 2011). The leaf and pods are normally harvested and consumed together with cereal products such as maize, rice, sorghum, and wheat when they are still fresh to provide complementary proteins. Leaves, fresh pods and dried seeds are used in form of different types of foodstuffs. According to Davis (1991), cowpea seed constitutes 24% protein, 1.9% fat, and 63.3% carbohydrate, and among other legumes, cowpea has the highest concentrations of phosphorus (P), potassium (K) and magnesium (Mg) (Iqbal *et al*., 2006).

In South Sudan and Sudan, grains from cowpea are cooked with a cereal such as maize or sorghum and eaten as "*Ballila*" (better known as *Githeri* in Kenya), while the dual-purpose cowpea is also used as fodder (Alzouma, 1989). The practice of feeding cowpea vegetative parts to livestock is popular in mixed farming and increases its economic significance (Singh and Ajeigbe, 2002). Apart from its nutritive value, cowpea is also used as soil cover and green manure to prevent soil erosion and improve soil fertility (Blade *et al*., 1997). Most smallholder farmers preserve cowpea by drying leaves for the dry spell. The dried seeds have a valuable aroma taste and cook easily compared to other peas such as garden pea.

Most farmers harvest cowpea for vegetables by uprooting whole young plants, defoliating the plant intermittently to allow pods to set seeds and harvesting. The cowpea also has a suppressing ability in weeds management. Being tolerant to drought and tropical crops, it is a good food and forage variety in typical tropical climate agriculture (Kabede & Bekeko, 2020).

### 2.4 Factors influencing production of cowpea

High temperatures reduce the growth period of cowpea, consequently, the number of flowers and pods are affected by ripple effects that result in low yield (Ndiso *et al*., 2016). Several factors and varietal effects influence leaf nutrient position and leaf anatomy (Thornley, 2002), High radiation decreases soluble nutrients in the leaf extracts of legumes (Vu *et al*., 2006). A decrease in protein in leaves influences the photosynthetic rate, nutrients mobilization and remobilization in plants. Being short day plant and depending on genotype, cowpea exhibit photoperiod sensitivity to flowering, and maturity of seeds.

Photoperiod-induced delays bud appearance in hot conditions but does not affect the floral development in most cowpea genotypes (Ehlers and Hall, 1996). Variety and cropping systems such as intercropping affect the total yield of cowpea plants compared to sole planting which produces high yields of cowpea (Sebetha *et al*., 2010). Cowpea grown as a sole crop contains more protein than when they are intercropped (Muhammad *et al*., 2006). A farming system such as planting of crops without any spatial arrangement better-known as broadcasting is a poor technique that reduces the yield and quality of cowpea crops (Singh and Ajeigbe, 2001; 2002).

The genetic constitution of cowpea and method analysis of nutrient contents in cowpea influence detectable nutrients (Afiukwa *et al*., 2013). Hot temperature affects the maturity of cowpea, for example, photosensitive varieties matured earlier than photo insensitive one. In this case, the plant is affected by short days and late long days duration (Ishiyaku *et al*., 2005). Increases in the number of flowers per plant depend on the increase of peduncles per plant which result in positive effects on grain yield (Mangggoel *et al*., 2012). Cowpea's vegetative stage has been improved to allow canopy growth which is important for yield increase and the vegetative growth is affected by photoperiod under hot environments (Ishiyaku and Singh, 2003). Cowpea is also affected by plant density whereby high plant density decreases the number of leaves, branches peduncles, flowers per plant and total dry matter yield (Malami and Sama'ila, 2012).

Consumption of foods based on cowpea varieties would be a very important step towards alleviating poverty and malnutrition (Bilal *et al*., 2017; Omomowo & Babalola, 2021) and other varieties as drought-tolerant cowpea usually has lower water potential (Ψ) in leaves, pods and seeds than non-drought tolerant plants (Carvalho *et al*., 2019). Weeding and spatial arrangement of cowpea improves grain yield and other growth parameters while yield decrease normally occurs when good agronomic practices such as weeding, pest management and planting time are not followed (Adigun *et al*., 2014; Ajani *et al*., 2017) Harvest index (HI) also reduces due to high total dry matter of the shoot and low grain yield per plant under high plant population density conditions (Ahmed *et al*., 2012).

### 2.5 Effect of harvesting intensity on growth, nodulation, and yield of cowpea

Harvesting intensity reduces leaf size which reduces assimilate translocation to sinks therefore biomass is reduced. Sinks such as nodules are key to biological nitrogen fixation which is important in seed protein content and grain yield production (Lin *et al*., 2018). Reduced harvest intensity leads to an increase in 100 seed weight and a decline in amount of leaf harvested (Zhang *et al*., 2015).

An increase in harvesting intensity results in reduced leaf area which reduces assimilation to nodules, therefore, the plant only depends on the nitrogen accumulated for its growth and production. This results in low yield and dry matter. Research conducted by (Lin *et al*., 2018) on quantitative trait loci on biparental mapping population of cowpea genotypes at F8 generation found that chromosomes 1 and 8 shared a QTL for cowpea leaf width and 100-grain weight. This shows the dependability of the two traits on their respective performance by which negative influence on a leaf would lead to a reduction in the 100-grain weight of cowpea (Digrado *et al*., 2022).

The ability of a plant to regrow after a certain degree of defoliation is significant. Therefore, less intense defoliation allows regeneration of photosynthetic tissues which facilitate the growth of plants through the storage of photo-assimilates. Increased photo assimilates storage is achieved since there is a high rate of net photosynthesis, photosynthetic quenching, light interception, sugar accumulation, sucrose synthase activities and fructose supply from the leaves and stems (Zhang *et al*., 2020). Therefore, selecting optimum harvesting intensity would benefit grain yield production in cowpea, however, the multi-environmental trial is necessary to determine the influence of the environment on the genetic expression of the genes controlling 100-seed weight and leaf growth (Carvalho *et al*., 2017).

### 2.6 Effect of harvesting interval on growth, nodulation, and yield

An increase in harvesting interval decreases the competence of cowpea to suppress the weed population. Photosynthesis activities are negatively affected by the increase in leaf harvesting interval, consequently, the grain yield reduces with an increase in leaf harvesting frequency

(Saidi *et al*., 2007). Leaves harvesting at five weeks intervals can also affect the total yield however it does not affect the concentration of protein in seeds (Nielsen *et al*., 1994). The Number of nodules is reduced in plants when the leaves are harvested more frequently. Reduction in leaf harvesting frequencies results in a high rate of photosynthetic processes on leaf surface area which result in a low rate of leaf development, grain, and nodule formation (Saidi *et al*., 2007).

High leaf harvesting frequency delays the time to flowering which allows for appropriate development of shoots leading to high production of growth components (Oyiga *et al*., 2010). Harvesting leaves weekly with low-intensity results in increased leaf yield (Matikiti *et al*., 2012). Leaf harvesting time and regularity influence cowpea performance were harvesting weekly increases leaf yield but decreases seed weight. Harvesting cowpea leaves at one-week interval result in high leaf and grain yields when no leaf harvesting is done during the vegetative growing stage (Saidi *et al*., 2010). The leaf harvest technique is the main objective of achieving high vegetable production in cowpea production (Matikiti *et al*., 2012).

# CHAPTER THREE: MATERIALS AND METHODS

## 3.1 Experimental site

Evaluation of cowpea varieties for intensity and interval of harvesting was conducted in South Sudan (Figure 3.1). The experiment was conducted in the Bor and Awerial sites of South Sudan. Bor site is located at an altitude of 407 m above sea level. In this area, the average temperature ranges from 27°C to 38°C. Bor receives a unimodal pattern of an average rainfall of about 891 mm per annum. The rainy season occurs from May to November and the dry season is experienced from December to April of every year. The area is characterized by vertisol soil type which is relatively more fertile than the soil type such as the eastern semi-arid pastoral zone. The main crops grown in the area are sorghum (Sorghum bicolor), cowpea (Vigna unguiculata), groundnut (Arachis hypogaea L.), sesame (Sesamum indicum) and vegetables such as pumpkins (Cucurbita), eggplant (*Solanum melongena*), kale (*Brassica* spp), Jute Mallow (*Corchorus olitorius*), okra (*Abelmoschus esculentus*), *Amaranthus* spp, cucumber (*Cucumis sativus*) and purslane (*Portulaca oleraceae*) (South Sudan Livelihood zones, 2013).

Awerial site is located at an altitude of 450 m above sea level. Awerial experiences an average rainfall of about 900 mm per annum, in a single season from March to November. The maximum temperature reaches 40°C in March while the lowest temperature can reach 26°C in July. The area has vertisol and ferrosol soil types. The most important food crops grown are sorghum (*Sorghum bicolor*), Sesame (Sesamum indicum), pearl millet (*Pennisetum glaucum*), cowpea (*Vigna unguiculata*), green gram (*Vigna radiata*), groundnut (*Arachis hypogaea* L.), maize (*Zea mays*) and vegetables such as okra (*Abelmoschus esculentus*), Jute mallow (*Corchorus olitorius*), cucumber (*Cucumis sativus*) and pumpkins (*Cucurbita*) (South Sudan Livelihood zones, 2013).

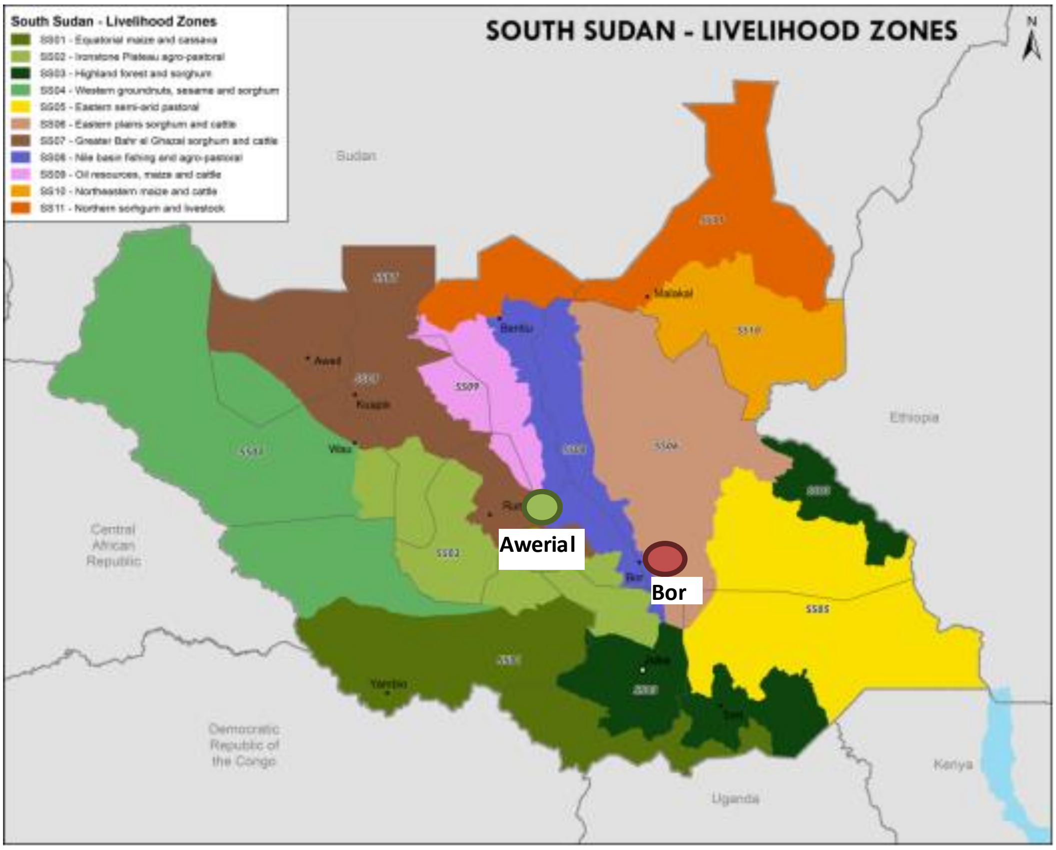


**Figure 3.1: A map of South Sudan showing the locations of Awerial and Bor experimental sites**

### 3.2 Varieties

Three cowpea varieties Kunde M66, *Lubia* and *Areng* were used in this study. Lubia and Areng cowpea varieties were selected because they are the most preferred varieties by farmers in South Sudan. Variety kunde (M66) was selected as an improved variety in Kenya.

### 3.3 Experimental procedure

The field was ploughed and harrowed twice to a moderately fine till using a handheld hoe. Seeds were inoculated with *Bradyrhizobium* spp inoculum obtain from an improved agrovet in Nairobi Kenya. In a 4-row plot measuring 2 m × 2 m, three seeds were planted per hill at a spacing of 30 cm × 20 cm and then later thinned to one plant per hill a week after emergence.

The seed rate used was 25kg $ha^{-1}$ for all the varieties selected (Kunde M66, Lubia and Areng). The experiment was conducted in a randomized complete block design (RCBD) in a 3×4×3 factorial arrangement, replicated three times. The factors studied were cowpea variety, intensity, and frequency. Cowpea varieties Kunde M66, Lubia and Areng were used in this study. Leaf harvesting intensity comprised control (no leaf harvesting), 20%, 40% and 60% while the harvesting intervals comprised 2, 3- and 4-weeks intervals of leaf harvesting. The growth of broad leaf and grass weeds was restricted and minimized by carrying out hand weeding three times during the growth period of the crop. Infestation of both chewing and sucking insect pests was minimized by applying single doses of broad-spectrum insecticide at the rate of 50 g $L^{-1}$ alpha-cypermethrin 50 (BESTOX® 100EC).

### 3.4 Data collection

A random sample of five plants was obtained from the central two rows of each plot and tagged. The first sampling commenced 4 weeks after sowing (WAS), and this coincided with the start of leaf harvesting. Data were collected from the tagged plants. Plants height were measured from the base to the tip of the longest leaf of five randomly selected plants (using a ruler) at 10 weeks after sowing from each plot and the mean height presented for analysis. To show the progression of development of several branches, the number was determined from each plant as the crop grew. The number of leaves per plant was determined from the sample plants from each plot at maturity stage. Dates of anthesis were determined from each plot by counting flowered plants from each plot. Plants were considered to have flowered when half of the plant population per plot reached the flowering stage (Shimelis *et al*., 2010).

Determination of the number of nodules was done by random sampling of three plants from the middle rows of each plot. The plants were carefully uprooted and gently shaken, washed gently in running water to remove the soil before the number of nodules per plant was counted at maturity stage (Matikiti *et al*., 2012). The number of pods per plant was determined from 5 plants in each plot at harvesting time. To determine the 100-seed weight, one hundred seeds per plot were randomly selected and counted after harvest and then weighed using a sensitive weighing balance in grams (g). Pod weight was determined by counting and weighing the total number of pods selected from the five plants sampled and tagged in each plot at harvest time. Total dry matter was determined by uprooting whole plants (together with the pods) at maturity, and sun dried to a constant weight. Grain yield was taken after harvest from the middle part of the row from each end. The area from which the plants were harvested for grain yield determination was 2 $m^2$ for each treatment. At physiological maturity, dry pods were harvested from each experimental plot excluding the outer rows and the outer guard plants in each row and shelled, the grains were sun-dried and weighed.

**3.5 Data analysis**

The data were analyzed following a two-step procedure where data were first analyzed for individual sites (Bor and Awerial) to get the mean performance of the varieties for traits determined followed by a combined analysis of variance over the sites using SAS software (SAS NC., 2001). Means were separated using the least significant difference (LSD) whenever the main effects were significant at $p \leq 0.05$. Regression analysis was carried out to determine the relationship between harvesting intensity and selected cowpea plant attributes.

## CHAPTER FOUR: RESULTS

### 4.1 Rainfall data distribution during the growing season

Rainfall data was determined using the rain gauges station at CRS (Catholic Relief Service) in Bor and WFP (World Food Program) in Awerial. In both locations, rainfall amount was low in the first three months of January, February, March, and April (Figure 4.1). However, the month of May recorded 229.2 mm of rainfall in Bor which was the highest rainfall amount recorded across all the months. Bor (229.2 mm) had a higher rainfall amount than Awerial (167 mm) in May. Similarly, in all the months' the rainfall amount in Bor was higher than in Awerial. This suggests that Bor might favor the growth and physiology of cowpea.

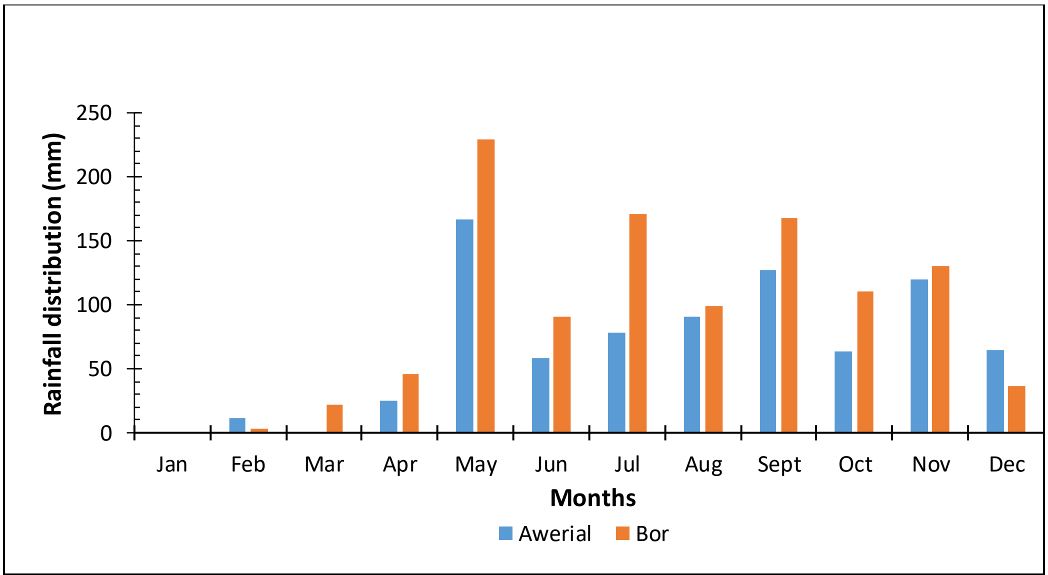


**Figure 4.1. Rainfall data during the 2017 growing season in Awerial and Bor experimental sites in South Sudan**

### 4.2 Combined analysis of variance

Effects due to environment, variety, interval, and intensity were significant ($p \leq 0.001$) for days to flowering, days to maturity, number of nodules at flowering, shoot dry weight at flowering, weight of pod, grain weight, leaf fresh weight and shoot dry weight at flowering stages, plant height, leaf number (Tables 4.1 and 4.2). Environment × intensity interaction was significant

($p \leq 0.001$) for days to maturity (Table 4.1). Environment × variety × interval interaction was significant ($p \leq 0.05$) for days to maturity.

Environment × intensity interaction was significant ($p \leq 0.001$) for shoot dry weight, fresh weight at vegetative stage and shoot fresh weight at flowering stage (Table 4.2). Effects due to interval × intensity were significant ($p \leq 0.001$) for shoot fresh weight at the flowering stage. Significant ($p \leq 0.01$) effects due to environment × variety were observed for shoot fresh weight at the vegetative stage (Table 4.2). Effects due to environment × intensity and environment × interval × intensity were significant ($p \leq 0.05$) for fresh shoot weight at flowering while environment × variety × interval interaction was significant ($p \leq 0.05$) for hoot dry weight at flowering. Effects due to interval × intensity and environment × interval × intensity interaction were significant ($p \leq 0.05$) for shoot dry weight at the flowering stage (Table 4.2).

Effects due to variety, interval and intensity were significant ($p \leq 0.001$) for 100 seed weight (Table 4.3). In this study, it was evident that the means of the three cowpea varieties evaluated for interval and intensity of defoliation varied for the weight of the seed (Table 4.3). A significant ($p \leq 0.01$) variety × interval interaction effects were observed for 100 seed weight, and environment × intensity interaction effects for the number of pods per plant exhibited varietal difference for 100 seed weight depending on the intensity of defoliation and establishment of pods under the influence of environment and intensity of defoliation (Table 4.3). Significant ($p \leq 0.01$) variety × intensity interaction was observed for the duration it takes cowpea to flower and 100 seed weight. Environment × variety × interval interaction was significant ($p \leq 0.05$) for grain weight while effects due to interval × intensity and environment × interval × intensity were significant ($p \leq 0.05$) for the weight of pod and shoot dry weight at the flowering stage. Effects due to environment × variety × interval × intensity were significant ($p \leq 0.05$) for grain weight (Table 4.3).

**Table 4.1. Mean squares for growth and phenological development of cowpea varieties evaluated at Awerial and Bor sites in South Sudan**

| Source of variation | Df | No. of DTF | No. of DTM | No. of nodules/ plant | Shoot dry weight (t/ha) |
|---|---|---|---|---|---|
| Environment (E) | 1 | 4908.89*** | 56689.69*** | 252.81*** | 63882.6*** |
| Replicate (R) | 2 | 2.86 | 76.83 | 120.12 | 323.27* |
| Variety (V) | 2 | 605.09*** | 3454.62*** | 2224.84*** | 5370.70*** |
| E ×V | 2 | 46.29*** | 294.51*** | 625.01*** | 7741.90*** |
| Interval (I) | 2 | 121.52*** | 181.41*** | 487.16*** | 3606.68*** |
| E × I | 2 | 2.04 | 5.01 | 60.53** | 18.70 |
| V × I | 4 | 1.65 | 1.91 | 9.81 | 46.87 |
| E × V × I | 4 | 0.38 | 3.04 | 5.57 | 257.83 |
| Intensity (INT) | 3 | 280.04*** | 726.01*** | 216.74*** | 5622.35*** |
| E × INT | 3 | 8.56* | 143.71*** | 35.82* | 108.00 |
| V × INT | 6 | 9.51** | 15.70 | 25.21* | 82.95 |
| E × V × INT | 6 | 3.45 | 33.27* | 11.84* | 277.05* |
| I × INT | 6 | 2.62 | 2.73 | 13.12 | 355.62* |
| E × I × INT | 6 | 0.95 | 1.28 | 11.10 | 292.05* |
| V × I × INT | 12 | 1.16 | 2.52 | 4.62 | 46.08 |
| E × V × I × INT | 12 | 2.31 | 1.50 | 0.84 | 109.85 |
| Error | 142 | 1.80 | 9.70 | 8.29 | 110.69 |
| CV% | | 2.76 | 3.11 | 5.07 | 5.40 |
| $R^2$ | | 0.97 | 0.94 | 0.91 | 0.90 |

*, **, *** indicate significance at $p\leq$ (0.05), $p\leq$ (0.01) and $p\leq$ (0.001) level of probability; CV=Coefficient of Variation; $R^2$ = coefficient of determination, df=degree of freedom; DTF- days to flowering; DTM- days to maturity; No=number

**Table 4.2. Mean squares for cowpea plant height, leaf number, branch number and shoot dry weight at Awerial and Bor sites in South Sudan**

| Source of variation | Df | Plant height (cm) | No. of leaves/plant | No. of branches/plant | Shoot Dry weight (t/ha) |
|---|---|---|---|---|---|
| Environment (Env) | 1 | 92051.56*** | 185962.2*** | 8767.20*** | 2.07*** |
| Replicate (Env) | 2 | 10.64 | 179.974 | 4.59 | 0.06 |
| Variety (V) | 2 | 58212.702*** | 20871.92*** | 705.65*** | 4.39*** |
| Env x V | 2 | 2150.524*** | 10612.6*** | 98.89*** | 0.03 |
| Interval (I) | 2 | 3159.002*** | 1560.548*** | 36.18*** | 0.14* |
| Env x I | 2 | 39.608 | 421.54* | 20.68** | 0.00 |
| V x I | 4 | 1454.868** | 1494.39* | 43.36* | 8.50 |
| Env x V x I | 4 | 7614.43*** | 8323.31*** | 185.90*** | 8.07 |
| Intensity (INT) | 3 | 11557.59*** | 7706.01*** | 267.67*** | 21.62*** |
| Env x INT | 3 | 470.268* | 1942.68*** | 91.60*** | 0.06 |
| Variety x INT | 6 | 2512.21*** | 2636.10*** | 24.24*** | 0.76*** |
| Env x V x INT | 6 | 108.766 | 188.46 | 6.50* | 0.01 |
| Interval x I | 6 | 1659.298*** | 2115.37*** | 74.05*** | 0.04 |
| Env x I x INT | 6 | 795.274*** | 127.31*** | 6.27* | 0.01 |
| V x I x INT | 12 | 987.896*** | 1247.15*** | 9.92*** | 0.04 |
| Env x V x I x INT | 12 | 611.184*** | 811.38*** | 5.91* | 0.00 |
| Error | 142 | 92.244 | 478.13 | 13.72 | 7.57 |
| CV (%) | | 6.37 | 6.76 | 6.80 | 17.58 |
| $R^2$ | | 0.99 | 0.93 | 0.93 | 0.97 |

*, **, *** indicate significance at $p \leq (0.05)$, $p \leq (0.01)$ and $p \leq (0.001)$ level of probability; CV=Coefficient of Variation; $R^2$ = coefficient of determination, df= degree of freedom, No.=number

**Table 4.3 Mean squares for yield and yield components of cowpea varieties evaluated at Awerial and Bor sites in South Sudan**

| Source of variation | Df | No. of pods/plant | Pod wt.(t/ha) | Grain wt.(t/ha) | No. of seeds/pod | 100 seed wt.(g) |
|---|---|---|---|---|---|---|
| Environment (E) | 1 | 2516.69*** | 23.32*** | 2.64*** | 3.74 | 0.00 |
| Replicate (R) | 2 | 159.58** | 0.02 | 0.07 | 31.48** | 0.81 |
| Variety (V) | 2 | 1456.42*** | 1.96*** | 6.16*** | 231.75** | 434.02*** |
| E ×V | 2 | 54.7 | 3.39*** | 0.04*** | 1.10 | 0.00 |
| Interval (I) | 2 | 474.44*** | 0.29*** | 0.15*** | 204.80*** | 25.41*** |
| E × I | 2 | 65.00 | 0.00 | 0.01 | 15.29 | 0.00 |
| V × I | 4 | 3.54 | 0.00 | 0.01 | 2.54 | 1.62** |
| E × V × I | 4 | 1.96 | 0.00 | 0.00 | 0.81 | 0.00 |
| Intensity (INT) | 3 | 1311.64*** | 0.42** | 0.36*** | 172.83*** | 20.67*** |
| E × INT | 3 | 269.17** | 0.00 | 0.01 | 17.31* | 0.00 |
| V × INT | 6 | 17.91 | 0.02 | 0.00 | 16.01* | 2.22** |
| E × V × INT | 6 | 2.70 | 0.01 | 0.02 | 7.31 | 0.00 |
| I × INT | 6 | 93.66* | 0.03 | 0.02 | 6.30 | 0.74 |
| E × I × INT | 6 | 25.50 | 0.03 | 0.04 | 3.50 | 0.00 |
| V × I × INT | 12 | 11.78 | 0.00 | 0.01 | 2.31 | 0.52 |
| E × V × I × INT | 12 | 0.70 | 0.01 | 0.02 | 3.24 | 0.00 |
| Error | 142 | 31.15 | 0.02 | 0.01 | 3.60 | 0.45 |
| CV% | | 8.13 | 8.14 | 5.88 | 8.27 | 5.60 |
| $R^2$ | | 0.77 | 0.92 | 0.95 | 0.89 | 0.95 |

*, **, *** indicate significance at $p \leq (0.05)$, $p \leq (0.01)$ and $p \leq (0.001)$ level of probability; CV=Coefficient of Variation;

$R^2$ = coefficient of determination, df= degree of freedom; No.=Number; wt.=weight

### 4.3 Effect of location on growth and phenological development components of cowpea

In this study, significant differences were observed between the two locations for days to flowering, day to maturity, number of nodules at flowering, plant height, shoot dry weight at flowering stage, total dry matter, leaf number, and number of branches per plant (Table 4.4). Cowpea varieties took longer time to flower (53.9 days) and mature (105.8 days) at Bor than at Awerial where they took 43.4 days to flower and 94.6 days to mature, respectively. Similarly, cowpea grown at Bor had 25.9 nodules per plant which were significantly more than the 24.9 nodules per plant recorded at Awerial. This study also showed that plants were taller at Awerial (72.5 cm) than at Bor (62.4 cm). Similarly, cowpea grown at Awerial had a significantly higher mean number of leaves per plant (51.9 leaves) and the number of branches per plant (9.7 branches) than cowpea grown at Bor. In contrast, Cowpeas grown at Bor had significantly higher total dry weight (0.7 t/ha) than cowpea grown at Awerial (0.6t/ha) (Table 4.4).

**Table 4.4 Effects of location on number of days to flowering (DTF), number of days to maturity (DTM), nodule number at flowering, plant height, shoot dry weight at flowering, total dry matter, leaf number and number of branches of three varieties of cowpea at Bor and Awerial sites in South Sudan**

| Environment | No. of DTF | No. of DTM | NFS/ plant | PH (cm) | SDWF (t/ha) | TDM t/ha | No. of leaves/ plant | No. of branches/ plant |
|---|---|---|---|---|---|---|---|---|
| Bor | 53.9a | 105.8a | 25.9a | 62.4b | 0.12a | 0.70a | 37.5b | 6.50b |
| Awerial | 43.4b | 94.6b | 24.9b | 72.5a | 0.14a | 0.60b | 51.9a | 9.70a |
| **LSD** **(0.05)** | 0.4 | 0.9 | 0.3 | 0.6 | 0.04 | 0.01 | 0.6 | 0.04 |

Means followed by the same letter are not significantly different at $p \leq 0.05$; LSD = least significant difference; DTF= days to flowering; DTM= days to maturity; NFS = number of nodules at flowering stage; PH= plant height; SDWF=Shoot dry weight at flowering stage; No.=number

### 4.4 Effect of location on cowpea yield and yield components

It was evident that cowpeas grown at Awerial produced more pods (42.3 pods) compared to Bor (36.0 pods) (Table 4.5). Similarly, heavier pods were observed in Awerial (2.1 t/ha) than Bor (1.5 t/ha). However, there was no significant difference in number of seeds per pod between Awerial and Bor sites. Cowpeas grown at Awerial produced higher 100 seed weight (12.1 g) and grain yield (0.99 t/ha), number of leaves per plant (51.9 leaves) and number of branches per plant (9.7 branches) than cowpea grown in Bor.

**Table 4.5. Effects of location on the number of pods per plant, pod weight, number of seeds per pod, 100 seed weight, grain yield of three varieties of cowpea at Bor and Awerial sites in South Sudan**

| Environment | No. of Pods/ plant | Pods Wt. (t/ha) | No. of Seeds/ pod | Grain yield (t/ha) | 100 seed Wt. (g) | No. of leaves/ Plant | No. of branches/ plant |
|---|---|---|---|---|---|---|---|
| Bor | 36.0b | 1.5b | 12.6a | 0.84b | 11.9b | 37.54b | 6.5b |
| Awerial | 42.3a | 2.1a | 12.7a | 0.99a | 12.1a | 51.92a | 9.7a |
| **LSD** **(0.05)** | 0.6 | 0.1 | 0.2 | 0.02 | 0.16 | 0.60 | 0.2 |

Means followed by the same letters are not significantly different at $p \leq 0.05$; LSD = least significant difference; No.=number; Wt.=Weight

### 4.5 Effect of variety on growth and phenological development of cowpea

Variety Areng took a much longer time to flower and to mature compared to Lubia and M66 (Table 4.6). However, M66 had higher number of nodules at flowering stage (27.3 nodules) than Areng (26.7 nodules) which in turn had higher number of nodules than Lubia (22.2 nodules) (Table 4.6). Cowpea variety Areng was taller and had higher shoot dry weight, total dry matter, number of leaves per plant and number of branches per plant than Lubia and M66 (Table 4.6). Variety Lubia had fewer leaves per plant and branches per plant than M66.

**Table 4.6. Effect of variety on number of days to flowering (DTF), number of days to maturity (DTM), nodule number at flowering, plant height, shoot dry weight at flowering, number of leaves per plant and number of branches per plant of three cowpea varieties at Awerial and Bor sites in South Sudan**

| Variety | No. of DTF | No. of DTM | NFS/ Plant | SDWF (t/ha) | PH (cm) | No. of leaves/ Plant | No. of branch/ Plant |
|---|---|---|---|---|---|---|---|
| Areng | 52.3a | 108.8a | 26.7b | 0.06a | 36.8a | 47.9a | 8.9a |
| Lubia | 47.1b | 97.6b | 22.2c | 0.04b | 34.3b | 46.3b | 8.1b |
| M66 | 46.6c | 94.3c | 27.3a | 0.04b | 29.9c | 40.0c | 7.3c |
| **LSD$_{(0.05)}$** | 0.5 | 1.1 | 0.5 | 0.004 | 3.8 | 0.7 | 0.1 |

Means in the same column without common letter are different at $p \leq 0.05$; DTF-Days to flowering; DTM-Days to maturity; NFS-Number of nodules at flowering stage; SDWF-Shoot dry weight (t/ha) at flowering stage; PH= plant height; No.= number

### 4.6 Effect of variety on yield and yield components of cowpea

Areng had a significantly higher number of pods per plant and pod weight than both Lubia and M66 varieties (Table 4.7). Variety M66 had a higher number of seeds per pod (66 seeds) than Areng (63 seeds) which in turn had a higher number of seeds per pod than Lubia (57.4 seeds). Variety Areng had a higher 100-seed weight than M66 which in turn had a higher 100-seed weight than variety Lubia (Table 4.7). Cowpea variety M66 yielded higher grain yield (1.06 t/ha) than Areng (0.99 t/ha) which in turn had higher grain yield than Lubia (0.7 t/ha). Variety Areng had also a higher number of leaves and branches followed by Lubia and M66 (Table 4.7).

**Table 4.7 Effects of variety on number of pods per plant, seeds per pod, pod weight, 100 seed weigh, grain yield and total dry matter of three cowpea varieties at Awerial and Bor sites in South Sudan.**

| Variety | No. of Pods/ Plant | No. of Seeds/ Pod | Pods Wt. (t/ha) | 100 seed Wt. (g) | Grain yield (t/ha) | TDM (t/ha) |
|---|---|---|---|---|---|---|
| Areng | 32.1a | 12.6b | 1.9a | 14.8a | 0.90b | 0.73a |
| Lubia | 28.18b | 11.5c | 1.6b | 9.5c | 0.70c | 0.70b |

| | | | | | | |
|---|---|---|---|---|---|---|
| M66 | 31.86a | 13.2a | 1.8a | 11.8b | 1.06a | 0.66c |
| **LSD (0.05)** | 0.90 | 0.3 | 0.1 | 0.2 | 0.03 | 0.01 |

Means in the same column without a common letter are different at $p \leq 0.05$; No.=number, Wt.=Weight; TDM=Total dry matter

### 4.7 Effects of leaf harvesting intensity on growth and phenological development of cowpea

The number of nodules per plant at the flowering stage decreased with increase in the leaf harvesting intensities (Table 4.8). No significant differences in the number of nodules per plant were noted between 40% and 60% leaf harvesting intensities (Table 4.8).

At Awerial, total dry matter declined significantly from 60% leaf harvesting intensity relative to 0% and 20% intensities (Table 4.8). In contrast, at Bor leaf harvesting at 20%, 40% and 60% intensities significantly increased dry matter relative to no-leaf harvesting. No significant differences in total dry matter were noted among 20, 40 and 60% leaf harvesting intensities.

Days to 50% flowering and number of days to maturity increased with increase in the intensity of harvesting in both Awerial and Bor (Table 4.8). At Awerial, however, there were no significant differences in days to flowering and days to maturity between 0% and 40% leaf harvesting intensities and 0% and 20% leaf harvesting intensities, respectively. The test varieties in Awerial matured earlier than those in Bor. In Awerial, 60% intensity was associated with late maturity while 0 and 20% favored early maturity. Similar situation was observed in Bor where at 60% intensity, plants matured late while at 0 % intensity they matured early (Table 4.8).

**Table 4.8 Effects of leaf harvesting intensity on number of days to flowering (DTF), number of days to maturity (DTM), nodule number at flowering, and total dry matter of three cowpea varieties at Awerial and Bor sites in South Sudan**

| Intensity | NFS/plant | | TDM (t/ha) | | No. of DTF | | No. of DTM | |
|---|---|---|---|---|---|---|---|---|
| (%) | Awerial | Bor | Awerial | Bor | Awerial | Bor | Awerial | Bor |
| 0 | 26.9a | 28.6a | 0.60a | 0.60b | 43.1b | 45.3d | 93.1c | 95.4d |
| 20 | 25.4b | 26.8b | 0.60a | 0.70a | 42.0c | 52.2c | 93.0c | 101.4c |
| 40 | 24.9bc | 25.2c | 0.50b | 0.70a | 43.3b | 54.0b | 94.9b | 106.8b |
| 60 | 24.3c | 24.4c | 0.40c | 0.50c | 45.7a | 57.4a | 97.1a | 112.0a |
| **LSD $_{0.05}$** | 0.7 | 0.8 | 0.01 | 0.02 | 0.8 | 1.0 | 1.4 | 1.9 |

Means followed by the same letters are not significantly different at $p \leq 0.05$; DTF= Days to flowering; DTM=Days to maturity; No.=number; NFS=Nodule number per plant; TDM= Total dry matter

Harvesting leaves at 60% intensity resulted to a decrease in plant height of the test cowpea varieties in both sites. In both sites, there were no significant differences in plant height among cowpea plants whose leaves were harvested at 0, 20 and 40% intensities (Table 4.9). Harvesting cowpea leaves at 20% intensity in both sites and 40% intensity at Bor resulted in increases in the number of leaves per plant and number of branches per plant compared to all the other treatments (Table 4.9). No significant differences were noted in the two plant attributes between 60% leaf harvesting intensity and the control (0% leaf harvesting intensity) in both sites.

**Table 4.9 Effects of leaf harvesting intensity on plant height, number of leaves per plant and number of branches per plant of three cowpea varieties in Awerial and Bor sites in South Sudan**

| Intensity (%) | Plant height (cm) | | No. of leaves/ Plant | | No. of branches/ plant | |
|---|---|---|---|---|---|---|
| | Awerial | Bor | Awerial | Bor | Awerial | Bor |
| 0 | 48.4a | 52.5a | 52.6bc | 68.7b | 8.7b | 11.8b |
| 20 | 48.6a | 51.6a | 61.2a | 77.6a | 9.8a | 13.70a |
| 40 | 48.0a | 52.7a | 54.1b | 79.6a | 8.8b | 13.8a |
| 60 | 44.5b | 47.7b | 52.4c | 71.6b | 8.7b | 11.9b |
| **LSD $_{0.05}$** | 0.8 | 1.3 | 1.5 | 3.0 | 0.3 | 0.5 |

Means followed by the same letters are not significantly different at $p \leq 0.05$; No.=Number

### 4.8 Effect of leaf harvesting intensity on cowpea yield and yield components

At Awerial, 20% leaf harvesting intensity had a significantly higher number of pods per plant than 40% leaf harvesting intensity which in turn had a higher number of pods than 60% and 0% leaf harvesting intensities (Table 4.10). The latter two leaf harvesting intensities were not significantly different in number of pods per plant. In contrast, at Bor, the number of pods per plant decreased with an increase in leaf harvesting intensity. At Awerial, leaf harvesting intensity at 20% resulted in significantly higher pod weight per plant than all the other leaf harvesting intensities (Table 4.10).

Leaf harvesting at 40% intensity had a higher pod weight than 60% leaf harvesting intensity and no-harvesting (0%). In contrast, at Bor, pod weight significantly declined with an increase in leaf harvesting intensity, although there was no significant difference between 20% and 40% leaf harvesting intensities and between) 0% and 60% leaf harvesting intensities. In both sites, the number of seeds per pod significantly declined with the increase in leaf harvesting intensity (Table 4.10). In both sites, 40% and 60% leaf harvesting intensities had lower 100 seed weight than 0 and 20% leaf harvesting intensities. Moreover, at 0% and 20% leaf harvesting intensities 100 seed weight did not differ in both sites.

At Awerial, grain yield was significantly higher at 20% and 40% leaf harvesting intensities than at 0% and 60% leaf harvesting intensities. No-leaf harvesting (0%) was not significantly different in grain yield from 60% leaf harvesting intensity (Table 4.10). In contrast, at Bor, no-leaf harvesting treatment had the highest grain yield followed by both 20% and 40% leaf harvesting intensities which were not significantly different in grain yield. Leaf harvesting intensity of 60% resulted in significantly the lowest grain yield in Bor.

**Table 4.10 Effects of leaf harvesting intensity on number of pods, pod weight, number of seeds per pod, 100 seed weight and grain yield of three cowpea varieties at Awerial and Bor sites in South Sudan**

| Intensity % | No. of Pods/ Plant | | Pod weight (t/ha) | | No. of Seeds/ Pod | | 100 Seed weight (g) | | Grain yield (t/ha) | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Awerial | Bor | Awerial | Bor | Awerial | Bor | Awerial | Bor | Awerial | Bor |
| 0 | 40.20c | 38.6a | 2.0c | 1.70a | 14.0a | 13.6a | 12.6a | 12.3a | 0.90c | 0.90a |
| 20 | 44.60a | 37.1b | 2.2a | 1.40b | 13.2b | 12.8b | 12.5a | 12.0ab | 1.00a | 0.80b |
| 40 | 43.10b | 35.1c | 2.1b | 1.30b | 12.3c | 12.1c | 12.0b | 11.9b | 1.00a | 0.80b |
| 60 | 40.10c | 33.3d | 2.0c | 1.20c | 11.1d | 11.7d | 11.3c | 11.3c | 0.90c | 0.70c |
| **LSD $_{0.05}$** | 1.18 | 1.26 | 0.08 | 0.07 | 0.5 | 0.3 | 0.4 | 0.3 | 0.03 | 0.05 |

Means followed by the same letter are not significantly different at $p \leq 0.05$; No.=Number

### 4.9 Effect of harvesting interval on growth and phenological development of cowpea

Harvesting at two weeks' intervals significantly increased the number of days to flowering relative to the rest of the harvesting intervals in both Awerial and Bor (Table 4.11). At Bor, four weeks' harvesting interval had significantly fewer days to flowering than three weeks harvesting interval which in turn had fewer days than the control. Similar observations were made at Awerial but there was no difference between the control and three-weeks harvesting interval. There was an increase in the number of days to physiological maturity at two weeks intervals (Table 4.11).

Dry matter was well accumulated by the cowpea at 3 and 4 weeks' intervals and least accumulated at 2 weeks' interval in Awerial. On the other hand, highest dry matter was observed in 3 weeks' intervals at Bor followed by 2 and 4 weeks' intervals with the control having the least dry matter accumulation (Table 4.11).

In both sites, 2-weeks harvesting interval significantly reduced the number of nodules per plant at flowering compared to the control, 3 weeks harvesting interval and 4 weeks harvesting interval (Table 4.11). At Awerial, 3 and 4 weeks harvesting intervals had lower nodule number than the control but higher than 2 weeks' interval. Similar observations were made at Bor except that there were no significant differences among control, 3 weeks harvesting interval and 4 weeks interval.

**Table 4.11 Effects of leaf harvesting interval on dry matter, number of days to flowering, number of days to maturity, number of nodules per plant of three cowpea varieties evaluated at Awerial and Bor sites in South Sudan**

| Interval | Dry matter(t/ha) | | No. of DTF | | No. of DTM | | NFS/plant | |
|---|---|---|---|---|---|---|---|---|
| (Weeks) | Awerial | Bor | Awerial | Bor | Awerial | Bor | Awerial | Bor |
| 0 | 0.4a | 0.6c | 43.1bc | 45.3d | 93.1c | 95.4c | 27.0a | 28.6a |
| 2 | 0.6b | 0.7b | 45.2a | 56.0a | 96.6a | 109.0a | 23.8c | 23.4b |
| 3 | 0.4a | 0.7a | 43.5b | 54.7b | 94.7b | 106.2b | 25.1b | 26.2a |
| 4 | 0.6a | 0.7b | 42.4c | 52.9c | 93.6bc | 104.9b | 25.5b | 26.8a |
| **LSD $_{0.05}$** | 0.01 | 0.02 | 0.8 | 1.0 | 1.4 | 1.9 | 0.7 | 0.8 |

Means followed by the same letter are not significantly different at $p \leq 0.05$; No.=Number; DTF= Days to flowering; DTM=Days to maturity; NFS-Number of nodules at flowering stage.

Leaf harvesting intervals of 4 weeks resulted to higher cowpea plant height in both Awerial and Bor sites (Table 4.12). At Awerial, cowpea plants subjected to two weeks harvesting interval were significantly the shortest in height. No differences were noted in plant height between 3 and 4 weeks' leaf harvesting intervals at Awerial and between 2 and 3 weeks' leaf harvesting intervals at Bor. Leaf harvesting at intervals of 2 weeks and more significantly increased the number of leaves relative to the control in both sites (Table 4.12). Harvesting intervals of 3 and 4 weeks had significantly the highest number of leaves per plant at Awerial and Bor, respectively. No differences were noted in the number of leaves per plant between 2 and 4 weeks harvesting intervals at Awerial whereas 3 weeks harvesting interval had significantly higher. Generally, leaf harvesting at intervals of 2 weeks and more significantly increased the number of branches per plant relative to the control in both sites (Table 4.12).

**Table 4.12 Effects of leaf harvesting interval on plant height, number of leaves per plant and number of branches per plant of three cowpea varieties at Awerial and Bor sites in South Sudan**

| Interval | Plant height (cm) | | No. of leaves/plant | | No. of branches/plant | |
|---|---|---|---|---|---|---|
| (Weeks) | Awerial | Bor | Awerial | Bor | Awerial | Bor |
| 0 | 48.4a | 52.5a | 52.6c | 68.7d | 8.7b | 11.8c |
| 2 | 45.8c | 49.4b | 55.0b | 72.2c | 9.2a | 12.4b |
| 3 | 47.3b | 49.7b | 57.3a | 76.2b | 8.9ab | 13.4a |
| 4 | 48.0ab | 52.9a | 55.4b | 80.4a | 9.2a | 13.5a |
| **LSD $_{0.05}$** | 0.8 | 1.3 | 1.5 | 3.0 | 0.3 | 0.5 |

Means followed by the same letters are not significantly different at $p \leq 0.05$; No.=Number

### 4.10 Effect of harvesting interval on cowpea yield and yield components

At Awerial, harvesting cowpea leaves at 3- and 4-weeks intervals resulted in significantly higher cowpea pod weight than the control and 2 weeks harvesting interval. However, there no significant differences in pod weight between the former two intervals and between the latter two intervals (Table 4.13). At Bor, harvesting cowpea leaves at two weeks interval significantly reduced pod weight relative to control, 3 weeks harvesting and 4 weeks harvesting interval. The latter two harvesting intervals were not significantly different in pod weight but had significantly lower pod weight than the control.

At Awerial, leaf harvesting at 3- and 4-weeks intervals produced significantly higher number of pods per plant than control and 2 weeks harvesting interval. No significant differences in number of pods per plant were noted between control and two weeks harvesting interval and between 3- and 4-weeks leaf harvesting intervals (Table 4.13). In contrast, at Bor, leaf harvesting at 2-, 3- and 4-weeks intervals significantly reduced the number of pods per plant relative to the control. Harvesting leaves at two weeks interval resulted in significantly lower number of pods per plant than leaf harvesting at 3 and 4 weeks intervals (Table 4.13).

At both Awerial, harvesting leaves at 3 and 4 weeks harvesting interval had significantly higher grain yield than the control and harvesting leaves at two weeks intervals. No differences in grain yield were noted between the control and two weeks interval and between 3 and 4 weeks intervals. At Bor, harvesting leaves at 2, 3 and 4 weeks intervals significantly reduced grain yield relative to the control (Table 4.13). In both Awerial and Bor, the number of seeds per pod was high in the control compared to 2, 3 and 4 weeks harvesting intervals. Harvesting interval of 4 weeks had higher number of seeds per pod than 2 and 3 weeks harvesting intervals.

**Table 4.13 Effects of leaf harvesting interval pod weight, number of pods per plant, , 100 seed weight, grain yield and number of seeds per pod of three cowpea varieties at Awerial and Bor sites in South Sudan**

| Interval | Pod weight (t/ha) | | No. of pods/ Plant | | 100 seed weight (g) | | Grain yield (t/ha) | | No. of seeds/ pod | |
|---|---|---|---|---|---|---|---|---|---|---|
| (Weeks) | Awerial | Bor | Awerial | Bor | Awerial | Bor | Awerial | Bor | Awerial | Bor |
| 0 | 2.0b | 1.7a | 41.3b | 38.6a | 12.6a | 12.3a | 0.9c | 0.9a | 14.0a | 13.6a |
| 2 | 2.0b | 1.3c | 40.7b | 33.3c | 11.3c | 12.2c | 0.9c | 0.7c | 11.1d | 11.5d |
| 3 | 2.2a | 1.4b | 43.1a | 35.8b | 11.9b | 11.8b | 1.0b | 0.8ba | 12.4c | 12.3c |
| 4 | 2.2a | 1.4b | 44.0a | 36.2b | 12.6a | 12.2a | 1.0a | 0.8bc | 13.2b | 12.8b |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **LSD $_{0.05}$** | 0.1 | 0.1 | 1.2 | 1.25 | 0.4 | 0.3 | 0.02 | 0.05 | 0.49 | 0.31 |

Means followed by the same letter are not significantly different at $p \leq 0.05$; No.=Number

### 4.11 The effect of the interaction between variety and environment on dry mater accumulation and 100 seed weight of three cowpea varieties.

All the varieties had significantly higher dry matter accumulation at Bor than at Awerial (Figure 4.2). No significant differences were noted among the varieties in dry matter accumulation at Awerial. At Bor, Areng had higher dry matter accumulation than M66 which in turn had higher dry matter than Lubia.

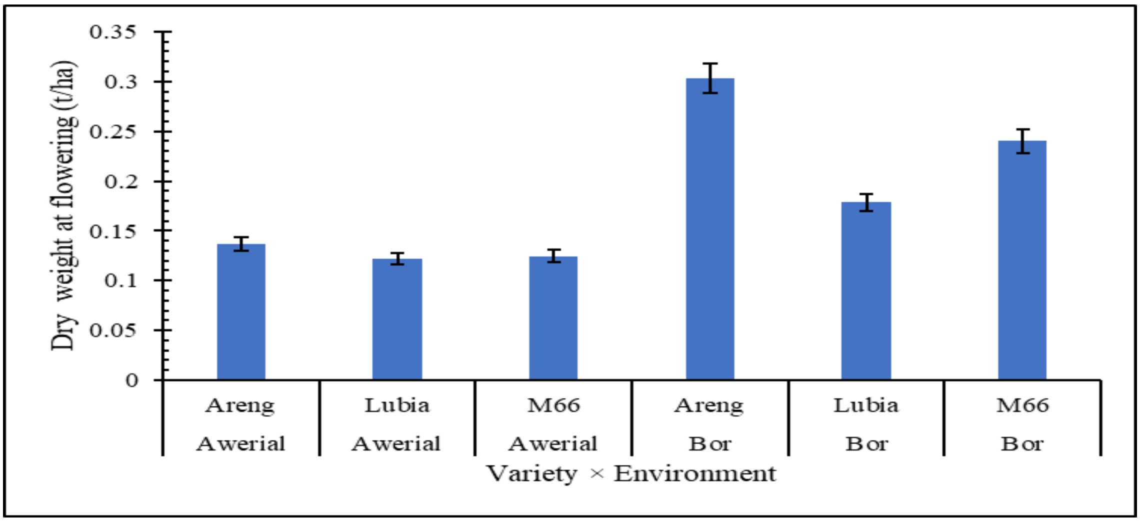


**Figure 4.2. Accumulation of dry matter of three Cowpea varieties at flowering stage grown across two environments (Awerial and Bor) site in South Sudan.**

The highest seed weight was observed in variety Areng in both Awerial and Bor environments followed by variety M66 while Lubia had significantly the lowest seed weight (Figure 4.3). However, the performance of the three cowpea varieties in seed weight did not differ significantly between the two environments suggesting inherent stability in seed weight traits among the varieties. In both sites, M66 had higher grain yield than Areng which in turn had higher grain yield than Lubia (Figure 4.4). All the varieties had higher grain yield in Awerial than in Bor.

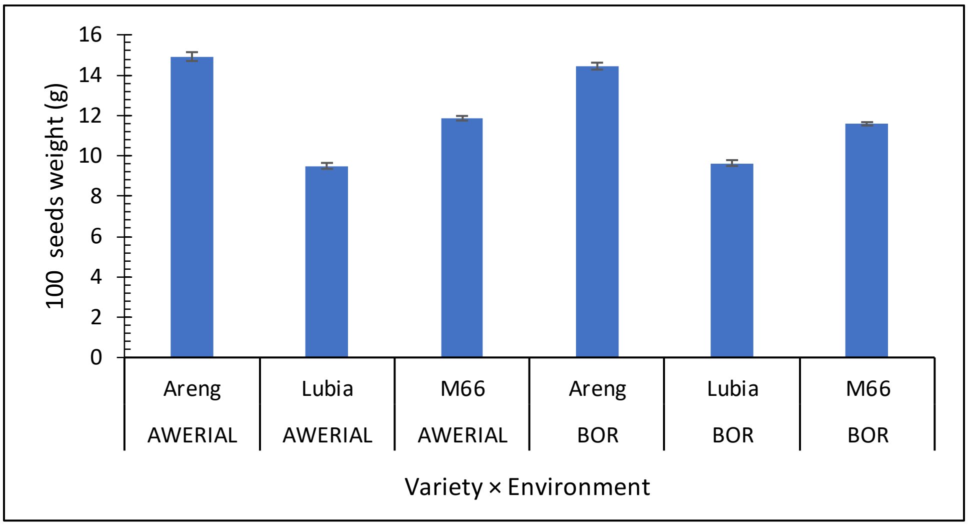


**Figure 4.3. Mean Seed weight from three cowpeas varieties evaluated across two environments (Awerial and Bor) site in South Sudan.**

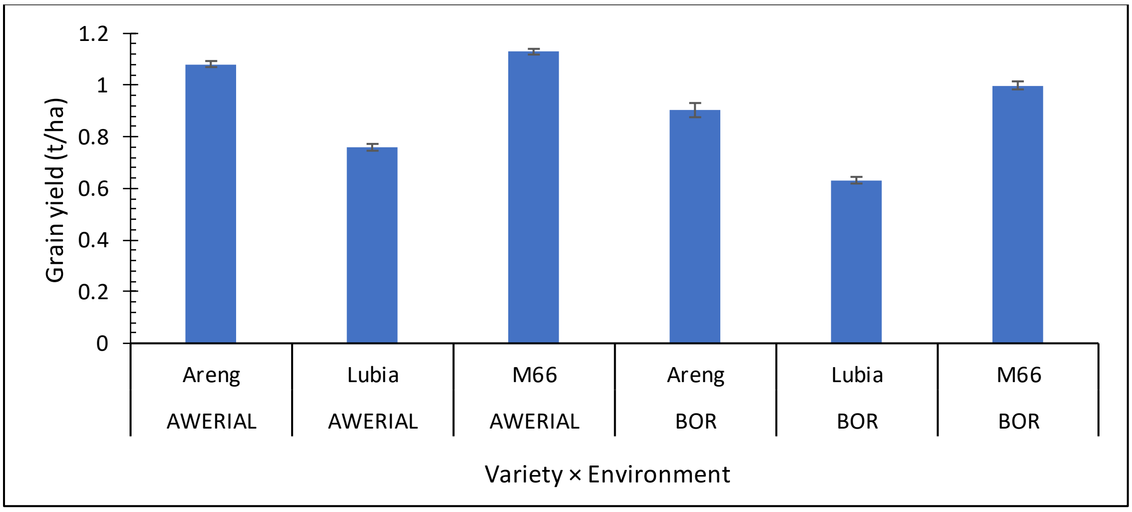


**Figure 4.4 Grain weight of cowpea varieties evaluated across two environments (Awerial and Bor site) in South Sudan.**

### 4.12 Regrowth of cowpea varieties at different intensities of defoliation

Among the three varieties evaluated for defoliation, variety Areng took a much longer time to flower compared to the other two varieties. It took about 48 days to 55 days, Areng (Y=47.472+1.722x; R^2=0.923) to reach anthesis stage compared to varieties Lubia

(Y=39.722+2.578x; R^2=0.962) and M66 (Y=38.639+2.827x; R^2=0.999) (Figure 4.5).

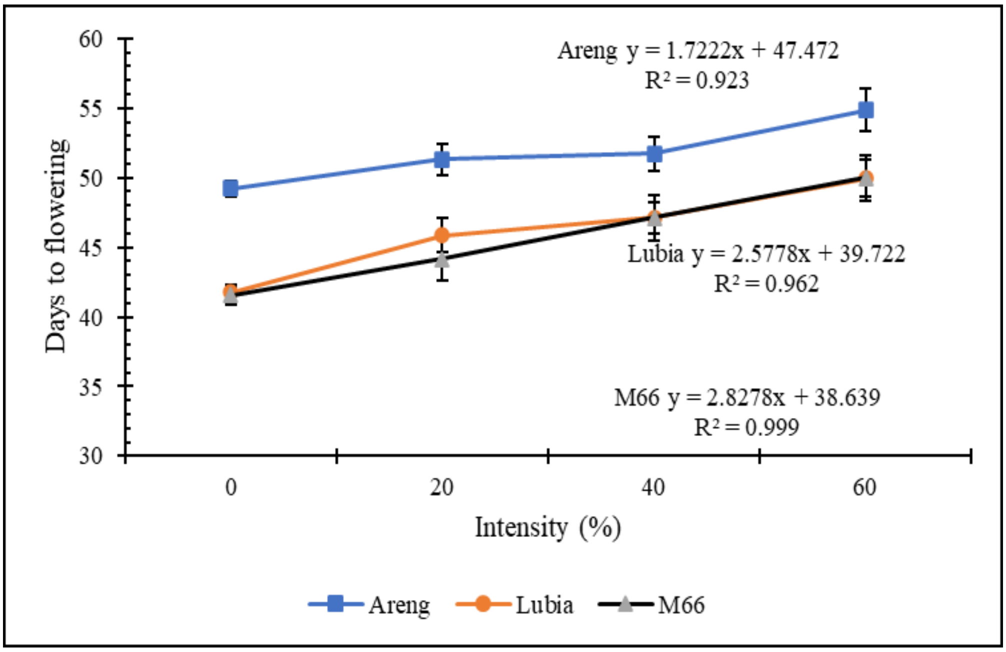


**Figure 4.5 Linear relationship between harvesting intensity and number of days to 50% flowering of selected cowpea varieties at Awerial and Bor sites in South Sudan.**

Dry matter in cowpea is an important trait for the farmers who produce cowpea for herbage consumption. An increase in the intensity of defoliation decreased the dry matter weight of all the cowpea varieties used in this study. However, the decrease in the dry matter at the flowering stage was less pronounced in variety Areng ($Y = 5.844 - 0.322x; \beta = -0.322;\ R^2 = 0.953$) than in the other two varieties with the increase in defoliation intensities. Variety *M66* accumulated the least dry matter at different intensities ($Y = 13.05 - 0.1339x; \beta = -0.1339;\ R^2 = 0.879$) and rate consequently, it is less suitable for foliage harvesting after flowering (Figure 4.6).

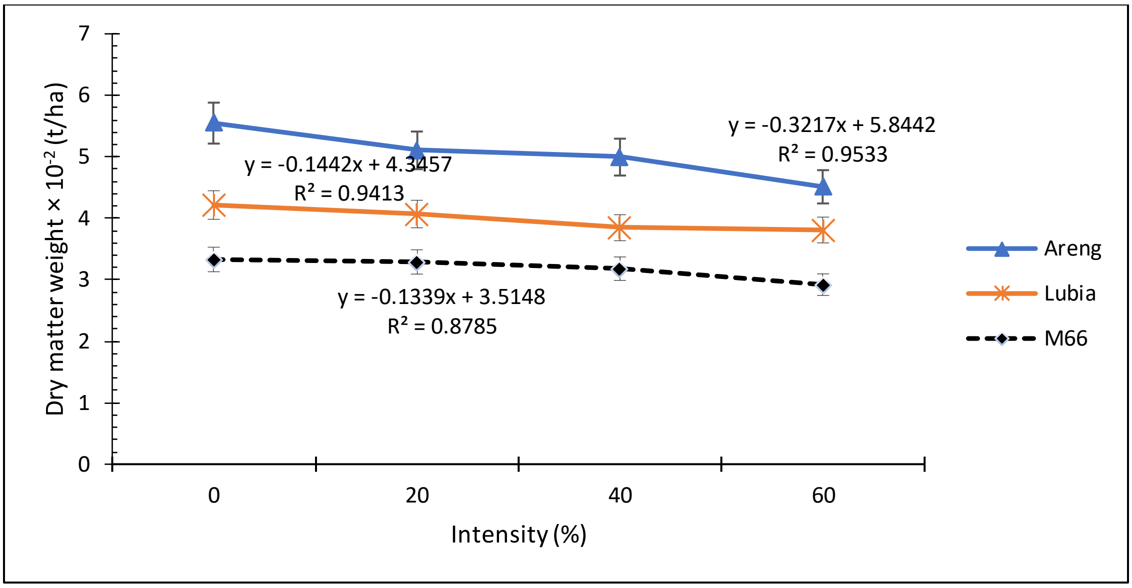


**Figure 4.6 Linear relationship between harvesting intensity and dry matter of selected cowpea varieties at Awerial and Bor sites in South Sudan.**

Linear regression describes the response of seed weight to different intensities of defoliation on cowpea varieties Areng, Lubia and M66 in Awerial and Bor environments. Variety Areng had the highest weight of 100 seed with $Y = 16.08 - 0.56x; \beta = -0.56;\ R^2 = 0.85$ followed by M66 $Y = 12.28 - 0.22x; \beta = -0.22;\ R^2 = 0.93$ and Lubia $Y = 10.42 - 0.34x; \beta = -0.34;\ R^2 = 0.76$. (Figure 4.7).

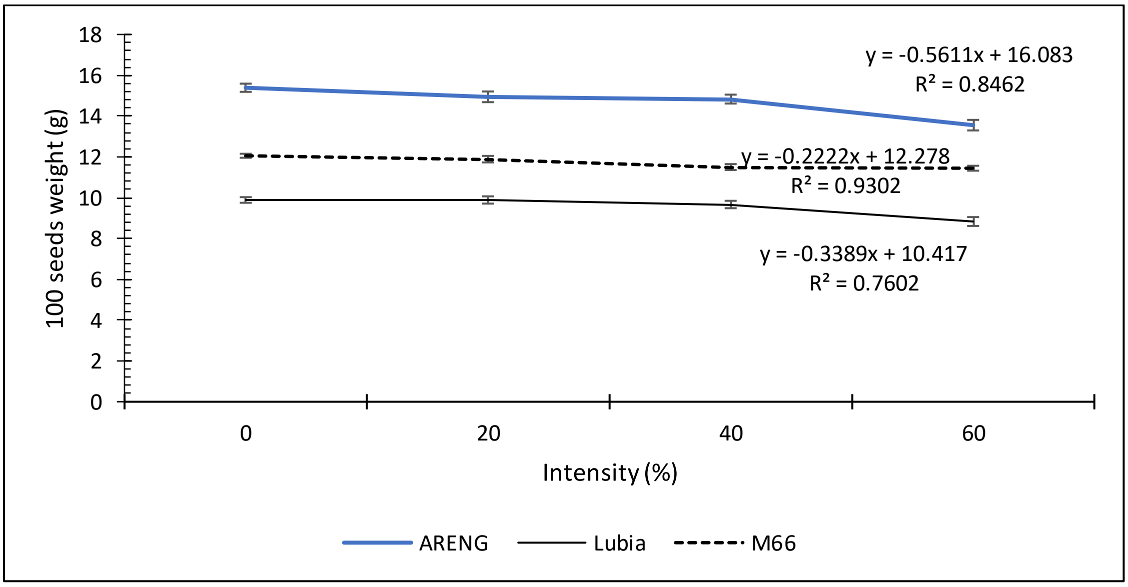

**Figure 4.7 Linear relationship between harvesting intensity and 100 seed weight of selected cowpea varieties at Awerial and Bor site in South Sudan**

Linear regression describes the response of grain weight to different intensities of defoliation in cowpea varieties Areng, Lubia and M66 in Awerial and Bor environments. Variety M66 with high total grain weight with $Y = 1.13 - 0.02x; \beta = -0.02;\ R^2 = 0.63$ followed by Areng $Y = 1.1 - 0.05x; \beta = -0.05;\ R^2 = 0.92$ and Lubia $Y = 0.79 - 0.04x; \beta = -0.04;\ R^2 = 0.91$ (Figure 4.8). The correlation coefficient ($r$) response of total grain weight to intensity was significant at all intensity levels due to the performance of variety across the two environments the difference was seed sizes which varied from varieties of cowpea remain constant.

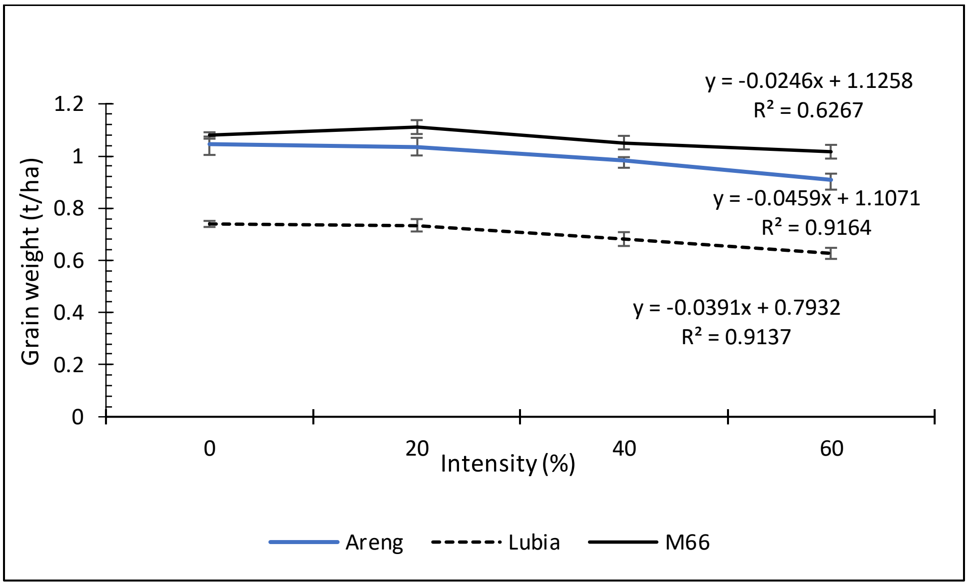


**Figure 4.8 Linear relationship between harvesting intensity and grain weight of selected cowpea varieties at Awerial and Bor site in South Sudan.**

# CHAPTER FIVE: DISCUSSION

Increases in the intensity of defoliation decreased cowpea dry matter weight in both Awerial and Bor sites. This may be attributed to the reduction in leaf area resulting in limited photosynthesis which adversely affects biomass accumulation and transfer of assimilates to the sinks (Zhang et al., 2020). However, the decrease in the dry matter at the flowering stage was less pronounced in variety Areng ($Y=5.844-0.322x$; $\beta=-0.322$; $R^2=0.953$) than in M66 and Lubia varieties with the increase in defoliation intensities. Variety M66 accumulated the least dry matter at different intensities ($Y=13.05-0.1339x$; $\beta=-0.1339$; $R^2=0.879$) and rate, consequently, it is less suitable for foliage harvesting after flowering due to slow regrowth. An increase in the intensity of defoliation delayed flowering and time to maturity and this was also reported by Saidi et al. (2007). This might be due to frequent leaf harvesting stimulating leaf production to which more assimilates are directed to instead of the reproductive structures.

Cowpea plants grown in the Bor environment took longer days to reach the anthesis and maturity stage and exhibited better performance than those grown at Awerial. This suggests that in Bor the varieties had enough time in biomass accumulation and assimilate production and re-translocation of assimilates at maturity to storage organs. The difference in flowering and maturity in the two environments might be due to photoperiodism which influences flowering, bud dormancy, and other structures like tuber initiation.

The number of nodules at the vegetative stage, number of nodules at anthesis, fresh weight, and dry shoot weight were higher in Bor than in Awerial. However, at Bor, the low number of seeds, pod weight, and grain weight were observed. This shows the effect of contrasting environments on the performance of cowpea genotypes. Significant effects due to environment × variety suggest that the three cowpea varieties responded differently to environmental factors for which the traits were evaluated. Significant effects due to environment, variety, interval, and intensity indicate that there were differences between environment and among cowpea varieties, harvesting interval, and intensity of defoliation for the number of nodules, number of pods per plant and shoot weight which was similarly reported by Saidi et al. (2007). Cowpea varieties have been improved to allow canopy growth which is important for yield increase (Ishiyaku and Singh, 2003). It was suggested that the vegetation phenology of crops in Africa is controlled by environmental factors such as photoperiod, soil fertility, rainfall, temperature, and insolation (Adole *et al*., 2019).

This study revealed that the effect of the intensity of defoliation varied with the environment. Cowpea varieties in different environments may require different defoliation intensities. Piece harvesting increased the number of leaves per plant, number of branches per plant, pod weight, and pods per plant. Longer harvesting intervals (3 and 4 weeks) increased these parameters relative to the 2-week harvesting interval. At Awerial, 3- and 4-week harvesting intervals had higher grain yield than the control while the converse was the case at Bor. Leaf harvesting intervals significantly influence the rate of photosynthesis which affects grain filling and production. Further, grain yield is reduced with an increase in leaf harvesting frequency (Saidi *et al*., 2007). Research conducted (Gerrano *et al*., 2019) on 22 cowpea varieties in two contrasting environments in South Africa showed that an increase in leaf width increased grain yield.

The differential performance of cowpeas in contrasting environments might be due to the influence of weather-related factors that prevail in specific environments (Ishiyaku *et al*., 2005) that photosensitive varieties matured early than photo insensitive. In this case, the plant is affected by short days and late long-days duration. Significant effects due to environment × variety suggest that varieties had variable fresh weight across the test environment. In this study, significant ($p \leq 0.01$) effects due to environment × interval interaction for the number of nodules at the flowering stage indicated that cowpea varieties established nodules on the roots differently across the two environments in South Sudan indicating an influence of environment on growth and physiology of cowpea.

Significant variety × intensity interaction showed that flowering and seed weight of cowpea varieties are influenced by the intensity of defoliation during harvesting. In this study, significant ($p \leq 0.01$) effects due to environment × variety × intensity interaction for shoot fresh weight at the flowering stage revealed that the fresh weight of cowpea varieties varies with the environment under which they are grown. Effects due to environment were significant ($p \leq 0.05$) for shoot dry weight indicating that dry matter across environments varied. Consequently, the accumulation of dry matter in cowpea depends on the environment. The harvest index (HI) is also reduced due to the high total dry matter of the shoot and low grain yield per plant in case of high population density (Ahmed *et al*., 2012). In addition, significant ($p \leq 0.05$) environment × interval, environment × intensity and variety × intensity interactions for the number of seeds per plant, number of nodules at the flowering stage, and number of seeds per plant suggested that the intensity of defoliation of cowpea varieties is influenced by the interval.

In this study, significant effects due to environment × intensity and environment × interval × intensity indicate that the intensity of defoliation and interval of defoliation are influenced by the environment shoot weight. The effects due to Environment × variety × interval interaction for days to maturity, grain weight and shoot dry weight at flowering demonstrated that cowpea varieties respond differently to environment and frequency of defoliation for maturity, grain weight, and dry matter accumulation. The observed effects due to interval × intensity and environment × interval × intensity was significant for the weight of the pod and shoot dry weight at the flowering stage suggesting that the weight of the pod which is a determinant factor for seed varies with intensity and interval of defoliation across environments. Similarly, the grain weight of cowpea varieties was influenced by interval and intensity of defoliation which is a common practice on cowpea consumed as vegetables.

The high number of nodules observed on variety M66 suggests that it may contribute to high levels of nitrogen fixation in the soil and may be beneficial for soil nutrient improvement and grain development translating to high yield (Ayisi et al., 2000).

The high yield in M66 indicated that this variety could be adopted for grain production by the farmers in South Sudan. Even though M66 exhibited the highest mean grain weight, there was no significant ($p \geq 0.05$) difference between variety Areng and M66 for shoot dry weight which indicated that harvesting cowpea leaves at one-week intervals resulted in high leaf and grain yields when no leaf harvesting is done during vegetative growing stage (Saidi *et al*., 2010).

Often, allometric relationships between traits of plants have been observed in wheat (Barkshandeh *et al*., 2012). The photosynthetic area is increased by the high number of leaves on a plant. Reduction in leaf harvesting frequencies results in a high rate of photosynthetic processes on leaf surface area which result in a low rate of leaf development, grain, and nodule formation (Saidi *et al*., 2007). In this study, variety Areng had 240 leaves compared to 231 and 200 observed on variety Lubia and M66, respectively, and leaves harvesting weekly with low intensity resulted in increased leaf yield (Matikiti *et al*., 2012). The results of this study showed that generally, all three varieties accumulated more dry matter at Bor than at Awerial. This environmental difference was attributed to the weather factors that favor the growth of cowpea in the former environment. Ideally, the relationship between morphological traits and the potential productivity of a genotype is rarely stable across contrasting environments (Asiwe *et al*., 2021). Therefore, this study detected a differential accumulation of dry matter of cowpea across the two environments where the evaluation was conducted. At Awerial, the cowpea variety Areng significantly accumulated dry matter at flowering compared to the remaining two varieties. Regarding the seed weight of the cowpea grain, there were no marked environmental differences in seed weight suggesting that the seed weight of the cowpea variety evaluated was not sensitive to changes in environmental conditions. This shows static stability for this trait which might be due additive nature of minor genes controlling yield production in cowpea. Similar results were obtained by (Leonard *et al*,.2018).

The results showed that the varieties did not perform differently across the environments with respect to seed weight as it was reported by (Kamara *et al*,.2016). The mean grain weight from the three varieties was a replicate of the seed weight observed across the environments. It is evident that variety Lubia is the poorest performer across the test environments, and this is due to growth habit. Similar observations were reported in a study conducted by (Nwofia *et al*., 2014). The results suggest that there was no significant differential response of varieties for grain yield across the environments. It is therefore clear that variety Areng is the best performer across the two environments.

Defoliation of cowpea is an important event because, in most sub-Saharan countries, cowpeas are grown for leaf consumption. Therefore, the rate of regrowth and recovery is an important phenomenon in cowpea physiology. According to (Lin *et al*., 2018), an Increased defoliation rate might result in reduced photosynthesis, therefore, reallocation of non-structural carbohydrates to support the regrowth of leaves and other photosynthetic tissues. In all the varieties evaluated, as the intensity of defoliation increases, positive effects of delaying anthesis was observed. The result from defoliation intensity on the 3 varieties suggests that anthesis occurs much early in variety Lubia and M66 however, this was not reflected in the yield performance in which variety Areng produced the highest mean grain quantity as reported by (Addo-Quaye *et al*.,2011). The yield of cowpeas could be increased by judicious defoliation of the older leaves or by topping the growing apices at the onset of flowering. Cowpea defoliated at the early stages just prior to podding significantly reduces growth, developmental characters' yield, and yield components (Ibrahim *et al*., 2010).

In this study, it was evident that the intensity of defoliation delayed flowering as depicted in the results, but the delay was more pronounced in variety Areng which showed the highest mean yield contrary to the study conducted by Ibrahim et al. (2010). Defoliation results suggest that the cowpea variety Areng is suitable for foliage harvesting because irrespective of intensity, the dry matter was not reduced to a level that can affect production. Increased defoliation also increased with a decrease in dry weight, seed weight, and grain weight. The ability to regrow after defoliation is a function of the remobilization of carbon reserves from roots and stems. However, the rate of photosynthesis is limited by the defoliation intensity thereby decreasing the carbohydrates stored in stem and roots since they are rapidly mobilized to sinks in this case leaf growing regions (Meuriot et al., 2018; Zhang et al., 2020).

# CHAPTER SIX: CONCLUSIONS AND RECOMMENDATIONS

## 6.1 Conclusions

Generally, an increase in leaf harvesting intensity (40 and 60% intensities) delayed flowering and maturity, and decreased shoot dry weight at flowering, seed weight, grain yield, pod weight, and the number of seeds per pod. At Awerial, the low harvesting intensity (20%) significantly increased the number of pods per plant, pod weight, and grain yield relative to the control and higher intensities. In contrast, at Bor, the no-leaf harvesting control treatment had the highest grain yield. Harvesting cowpea leaves at 20% intensity in both sites and 40% intensity at Bor resulted in increases in the number of leaves per plant and the number of branches per plant compared to all the other treatments.

Piece-meal harvesting delayed flowering and maturity and increased dry matter accumulation. It also increased the number of leaves per plant, number of branches per plant, pod weight, and number of pods per plant. Longer harvesting intervals (3 and 4 weeks) increased these parameters relative to the 2-week harvesting interval. At Awerial, 3- and 4-weeks harvesting intervals had higher grain yield than the control while the converse was the case at Bor, indicating that the impact of harvesting interval is dependent on the environmental conditions. Piece-meal harvesting reduced the number of nodules per plant at flowering with a two-week harvesting interval having the most depressive effect. Piece-harvesting had less impact on nodulation at Bor than at Awerial, possibly due to better rainfall conditions in the former than in the latter.

Cowpea plants grown at Awerial had superior growth and yield components compared to plants grown at Bor. Variety Areng took a significantly longer time to flower and had a higher number of branches, leaves, and yield components than Lubia and M66 but a lower grain yield than variety M66.

### 6.2 Recommendations

1. The most suitable leaf harvesting intensity is 20% which realized higher leaf foliage, nodules pod weight, 100 seed weight, and grain weight. It also had a higher influence on the physiology of the crop.
2. Cowpea variety Areng is the most suitable variety for both foliage and grain yield with very minimal environmental influence. Cowpea variety Areng is suitable for foliage harvesting because irrespective of intensity, the dry matter was not reduced to a level that can affect production.
3. This study revealed that the intensity of defoliation varied with the environment. Cowpea varieties in different environments may require different defoliation intensities therefore, a multi-environmental trial is necessary to determine the stability of the varieties.
4. The most suitable harvesting interval was 4-weeks interval followed by 3-weeks interval. At this stage, the crop has been given enough time for regrowth and production which translates to high foliage and yield. In this circumstance, the rate of regrowth and recovery is important phenomena on cowpea physiology. Research on cowpea varieties through crosses that have high regrowth ability and yield is necessary to increase harvest duration. Biparental crossing could be developed between two distinct varieties with the aim of exploiting the genetic basis of pod yield and yield components of cowpea varieties.
5. There is need to select varieties that are suitable for specific environments for different purposes hence Awerial environment is suitable for the cowpea that are grown for grain production. However, Bor environment is good for the cowpea grown for leaf production.

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## APPENDICES

**Appendix A. First Derivatives of the equations derived from the intensity levels of defoliation.**

| **Cowpea variety** | **Predictive equation from the graphs** | **First Derivative *dy/dx* (Slope)** | $R^2$ | **Comment** |
|---|---|---|---|---|
| 50% flowering | | | | |
| Variety: Areng | $Y = 47.472 + 1.722x$ | 1.722 | *0.923* | Flowered the earliest at all levels of |
| Lubia | $Y=39.722 + 2.578x$ | 2.578 | *0.962* | |
| M66 | $Y=38.639 + 2.828x$ | 2.828 | *0.999* | |
| Dry matter weight at flowering (t/ha) | | | | |
| Variety: Areng | $Y = 5.844 - 0.322x$ | -0.322 | *0.953* | |
| Lubia | $Y = 4.3457 - 0.1442x$ | -0.1442 | *0.9413* | |
| M66 | $Y = 13.05 - 0.1339x$ | -0.1339 | *0.8785* | |
| 100 seed weight (g) | | | | |
| Variety: Areng | $Y = 16.083 - 0.5611x$ | -0.5611 | *0.85* | |
| Lubia | $Y = 10.417 - 0.3389x$ | -0.3389 | *0.76* | |
| M66 | $Y = 12.278 - 0.2222x$ | -0.222 | *0.93* | |
| Grain weight (t/ha) | | | | |
| Variety: Areng | $Y = 1.1071 - 0.0459x$ | -0.0459 | *0.91* | |
| Lubia | $Y = 0.7932 - 0.0391x$ | -0.0391 | *0.91* | |
| M66 | $Y = 1.1258 - 0.0246x$ | -0.0246 | *0.63* | |