EVALUATION OF GRAIN YIELDS, PESTS AND SOIL NUTRIENTS IN SORGHUM-GROUNDNUT CROPPING SYSTEM IN WESTERN BAHR EL GHAZAL, WARRAP AND ABYEI, SOUTH SUDAN

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

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This piece of work is dedicated to all my family members, my parents, four brothers Apuothjang, Beech, Kooch and Kachuol James Achuoth and my sisters, Achol and Nyakoor James Achuoth, my daughter Yier Makur, my sons, Thon, Apuothjang, Malou and Ahon Makur James, who have in one way or the other been patient, supportive and endured all challenges encountered during my studies. Special dedication goes to my dear wives, Emmah Kisia and Helen Aluel who have always been on my side, giving unwavering support throughout my studies.

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LIST OF ABBREBIATIONS AND ACRONYMS

ANLA	Annual Needs and Livelihood Analysis
ANOVA	Analysis of Variance
CFSAM	Crop and Food Security Assessment Mission (Crop Planting Assessment)
FAO	Food and Agriculture Organization of the United Nations
FEWSNET	Famine Early Warning Systems
IPC	Integrated Food Security Phase Classification
NBS	National Bureau of Statistics
NDVI	Normalized Vegetation Difference Indices
RMGs	Rebel Militia Group
TWG	Technical Working Group
WBGS	Western Bahr El Ghazal State
WFP	World Food Programme

ABSTRACT

South Sudan has recurrently experienced severe food shortage and is a net importer of food, mainly cereals from neighboring Uganda, Kenya and Sudan. The main problem is the cereal deficit. The average cereal yield is only about 0.95 ton/ha, which is lower than yields obtained in Uganda, as well as lowest in places with disadvantageous agro-ecological conditions like Ethiopia (3 tons/ha) and Kenya (2 tons/ha). A study was carried out in Western Bahr el Ghazal, Warrap and Abyei in South Sudan to determine the effect of cropping system on sorghum, groundnut and sesame yields. The study was conducted from September to November 2014 and September to November 2015. The counties covered by the study in Western Bahr el Ghazal state included Jur River, Wau and Raga. Counties covered in Warrap state included Gogrial West, stretching to Mading-Achueng and Wunpeeth locations in Abyei area. Data collected included existing cropping systems, planting methods, land preparation methods, seed types and sources, pests, diseases and weed infestation. The data were collected through interviews with farmers using questionnaires and direct observation. Soil samples were collected from five locations of Gogrial West, Udichi, Wau, Mading-Achueng and Wunpeeth. Soil analysis was done for soil reaction (pH), percentage organic carbon (%OC), percentage total nitrogen (%TN), potassium (K), sodium (Na), calcium (Ca) and magnesium (Mg). Grain yields were determined for various cropping systems. Data collected were subjected to analysis of variance and means separated using the least significant difference test at $p \leq 0.05$.

CHAPTER ONE: INTRODUCTION

1.1: Background information

Farming systems in South Sudan are characterized predominantly by semi-irrigated and traditional farming practices. Wide variation in farming systems and practices across the seven major agro-ecological zones and eleven recognized livelihood zones of South Sudan provide the basis for varying levels of cropping systems, agronomic practices, and choices of crops or livestock. However, despite abundant natural and agricultural resource potential in the country, both rural and urban households still face a big challenge of food insecurity. This is due to the fact that for many decades, existing agricultural resources (land, water, fish, livestock, forestry, pasture, field crops, horticultural and ornamental crops, farm related financial securities etc.) have never been effectively made use of, (You et al., 2012). The analysis further indicated that the largest part of the country is still under trees and shrubs (62.6 percent). Given the country's favorable agricultural climate condition, this ratio is clearly very low as the crop areas account for more than 28 percent of national land in Kenya and 8 in Uganda, (You et al, 2012). There is a huge gap between the county's actual farm yield and the biophysically achievable yield according to IIASA/FAO Agro-ecological Zone (AEZ) framework (Fischer et al. 2002). The average cereal yield is only about 0.95 ton/ha (FAO/WFP, 2011), but can actually be lower since the cropland area used in 2011) is much lower than the areas observed in 2009 (FAO, 2009). This average cereal yield is lower than Uganda where there is minimal use of tradeable inputs (1.6 tons/ha), as well as lowers in places with disadvantageous agro-ecological conditions like Ethiopia (3 tons/ha) and Kenya (2 tons/ha). Such wide yield gap in South Sudan points to a large opportunity to increase average cereal yields, (You, 2012). In spite of having 50% of its arable landmass as prime agricultural land, only 4% of this area is cultivated continuously or periodically. The very low ratio of cultivated to total land compares with 28% in Kenya and 8% in Uganda, (MoAF, 2011). Most of the land use in South Sudan is accounted for by smallholder subsistence farmers that, in the absence of fertilizers, pesticides and herbicides, practice some form of shifting cultivation. The choice of cropping systems therefore varies considerably depending on farming practices adopted in each of the above agro-ecological and/or livelihood zones. Because the practices are directly linked to specific agro-ecological zones, it is apparent that crop yields are not only influenced by existing cropping systems, but also by other factors such as crop varieties, fertilizer use, time of planting, rotation patterns, pests and disease incidence. However, this study has revealed that mixed and mono-cropping systems are the two commonly adopted by majority of local farmers since they are easy to work with and do not require much complicated skills to achieve and therefore have some effects on sorghum and groundnut yields up on interaction among components. In order to understand the effect of interactions between different practices and how these different components work in relation to each other, which eventually influence ultimate crop yield, the conceptual framework in figure 1 below gives a clear explanation.

1.2: Problem statement and justification

South Sudan is significantly underdeveloped in agricultural production (You et al, 2012). Further, it is estimated that cropland area is 2.7 million ha representing 4.1 percent of total land area in the country. South Sudan experiences severe food shortage and is a net importer of food, mainly cereals from neighboring Uganda, Kenya and Sudan (FAO/WFP CFSAM, 2013). The main problem is the cereal deficit (Wortmann, 2009, FAO/WFP, 2017).

The average cereal yield in South Sudan is only about 0.95 ton/ha (FAO/WFP, 2011).This average cereal yield is lower than yields obtained in Uganda, as well as lower in places with disadvantageous agro-ecological conditions like Ethiopia (3 tons/ha) and Kenya (2 tons/ha). Such a wide yield gap in South Sudan points to a large opportunity to increase average cereal yields (You et al., 2012, p. 150).

South Sudan is structurally import-dependent such that, on average, the country annually imports about 250,000 MT of cereals from Uganda, Sudan and Kenya (IPC update, 2016). Despite a marginal increase in the national cereal production in 2015 compared to the five-year (2011–2014) average, the aggregate cereal deficit for the year 2016 was estimated at 381,000 MT, higher than the 2015 deficit by over 100,000 MT.

FAO/WFP (2012) reported that with an estimated net cereal production from the traditional sector of approximately 761 000 tons, a cereal deficit of about 371 000 tons was forecasted for the 2013 marketing year, about 25 percent less than 2012 estimates. Cereal deficits were recorded as -290,993 tons in 2011, -473,653 tonnes in 2012 and -370,991 tonnes in 2013. The highly variable yield levels affect food availability to local households as manifested in form of severe food insecure households in most parts of South Sudan.

The low grain yields of crops such as sorghum and groundnut include insect pests diseases, weeds and birds. In addition, low soil fertility may also contribute to low sorghum and groundnut yields. To address these challenges, there is a need to develop agronomic management practices. However, in South Sudan, there is no baseline information on cropping systems, pests and diseases of sorghum, groundnut, and soil fertility levels. This information is critical for development of appropriate crop management practices that can improve crop productivity.

1.3: Objectives

The main objective of the study was to obtain baseline information on insects, weeds, soil nutrient levels and agronomic practices in sorghum-groundnut cropping system.

The specific objectives were:

1. To identify common pests, diseases and weeds in the sorghum – groundnut cropping system
2. To determine the influence of sorghum – groundnut cropping system, biotic and abiotic constraints on yield of sorghum and groundnut crops
3. To assess the levels of soil pH, percentage organic carbon, and plant nutrients (nitrogen, phosphorous and potassium) and their influence on grain yield of sorghum and groundnut crops in selected sites

CHAPTER TWO: LITERATURE REVIEW

2.1. Ecology and importance of sorghum production

2.1.1. Ecology of sorghum plant

Sorghum (Sorghum bicolor *(L.) Moench*) is adapted to a wide range of environmental conditions, particularly, drought (Ogbonna, 2005). Sorghum is mostly grown in semi-arid or sub-tropical regions of the world due to its resistance to harsh droughts and long dry spells during the rainy season are a common feature (Hassan, 2015, p.74). The crop is commonly grown under rain fed conditions by resource-poor subsistence farmers with very little or no capital inputs, such as fertilizers, pesticides, or irrigation (Tesfamichael et al., 2013, p.498). Compared to maize, just a100 mm of rainfall can support sorghum growth during the vegetation cycle. Also, its pollen is resistant to temperatures higher than 45-50 degrees (POPESCU AND CONDEI, 2014, p.297). . Sorghum can grow well in sandy soils, with pH of 4.5-8.5

Sorghum can withstand temperatures above 38 ^{0}C, but dry winds coupled with hot weather during pollination reduce yields. Best yields are realised when temperatures during the season are 24-27 ^{0}C (Mejia and Lewis, 1999, p.3). The crop performs well in areas of 500-1700 m above sea level (asl) with seasonal rainfall of 300 mm and above, Orr et al, (2013, p.16). Sorghum is fast - growing, warm weather annual crop that can provide plenty of feed in midsummer during lean period. Sorghum is best suited to warm, fertile soils whereas cool, wet soils limit its growth. The crop tolerates drought relatively well, though adequate fertility and soil moisture maximize sorghum yields, Singh et al, (2014). The water requirements for sorghum vary within the range 350-700 mm depending on the length of the growing cycle; short growing cycle is 90 days; long growing cycle, more than 130 days (Mejia and Lewis, 1999, p.3). The plant becomes dormant in the absence of adequate water, but it does not wilt readily. Weed control during the first 6 to 8 weeks after planting is crucial, as weeds compete vigorously with the crop for nutrients and water during this period, Singh et al, (2014).

2.1.2. Importance of sorghum

Sorghum [(*Sorghum bicolor* (L.) Moench] is one of the most important grain crops grown worldwide for food security. It ranks fifth after wheat, maize, rice, and barley globally and second after maize in Sub-Saharan Africa (Mofokeng et al., 2017). Africa accounts only for a quarter of world's sorghum production. Nigeria and Sudan contribute nearly half of the sorghum production in Africa. Sudan is one of the most important countries producing sorghum in the world. It ranks the fifth after China, India, USA and Nigeria in sorghum production, but it is leading in per capita area and grain consumption for human beings (Hassan 2015, p.74). The world consumption of sorghum reached 63,148 thousand metric tons and it is continuously increasing (Popescu and Condei, 2014). Sorghum is one of the crop species that could play an important role in the food security, income generation and food culture of the rural poor in Kenya (Muui et al., 2013b). According to the National Baseline Household Survey (NBHS) (2009), more than 75% of rural households in South Sudan consume cereals. At the state level, the percentage ranges from a low of 28% in Upper Nile state, 62% in Western Bahr el Ghazal and 95% in Northern Bahr el Ghazal. Sorghum blended with millet is commonly consumed by the poorer section of the population in many countries and it forms a major source of proteins and calories in the diet of large segments of the population of Africa (Belton and Taylor 2004). In many parts of Sudan, where sorghum is a major grain food, people depend on whole sorghum meals, as the main meal. It is generally consumed as fermented flat bread (Kisra), thick porridge (Aceda), thin fermented gruel (Nasha), boiled grain (Balela) and beverages like Abreh and Hulu-mur (Abd Elmoneim et al., (2007)). In Kenya, the grain is used in making fermented and non-fermented porridge, ugali, pilau, traditional dishes where it is mixed with legumes (Muui et al, (2013a, p.7341). Sorghum grain has moderately high levels of iron (> 40 ppm) and zinc (> 30 ppm) with considerable variability in landraces (iron > 70 ppm and zinc >50 ppm). Both micronutrients help reduce stunting. The protein and starch in grain sorghum are more slowly digested than other cereals, which is beneficial for diabetics, (Orr et al., 2016, p.10). Industrially, the grain is used to manufacture wax, starch, syrup, alcohol, dextrose agar, edible oils and gluten feed, Muui et al, (2013a, p.7341).

Production estimates in South Sudan have been made for sorghum only based on 11 800 transect-based pictorial evaluation tool (PET) scores and cross checking of crop cuts taken during the 70 case studies. The returns from transect walk, averaged by county for the main field crops, are summarized in table 1 (FAO/WFP, 2012).

Table 1. South Sudan - Estimated cereal harvested area, yield, production, consumption 2012-2013.

State/County	Cereal area 2012 (ha)	2012 gross yield (t/ha)	2012 gross cereal production (t)	2012 net cereal production (t)	Population mid-2013	2013 cereal reqt (t)	2013 surplus/deficit (t)
W Bahr el Ghazal	**56635**	**1.00**	**56460**	**45168**	**446123**	**50183**	**-5015**
Returnees to 2012	3560	0.9	3204	2563	64720	7119	-4556
Jur River	16608	0.9	14947	11957	146154	16077	-4120
Raga	7221	0.85	6137	4910	62158	6216	-1306
Wau	29247	1.1	32172	25737	173091	20771	4967
Warrap	163603	0.68	110886	88709	1193365	116203	-27494
Returnees to 2012	3242	0.45	1459	1167	80461	8048	-6881
Abyei	2631	0.68	1789	1431	60491	5444	-4013
Gogrial East	16247	0.75	12185	9748	118143	11224	-1476
Gogrial West	38970	0.77	30007	24005	279014	29297	-5292
Tonj East	20838	0.45	9377	7502	132828	13283	-5781
Tonj North	30333	0.65	19716	15773	188993	18899	-3126
Tonj South	15341	0.68	10432	8345	99050	8914	-569
Twic	36002	0.72	25921	20737	234385	21095	-358

Source: FAO/WFP (2012)

WFP/FAO Crop and Food Security Assessment Mission (CFSAM) in Greater Bahr el Ghazal carried out a comparative analysis of sorghum crop yield during 2008 to 2012 period. This analysis showed a cereal decline in average yields over the five-year period (figure 1). Average yields ranged from about 1.2 – 16 t/ha to about 0.5 – 0.8 t/ha in 2012. These figures mirror the trends of sorghum production in Kenya.

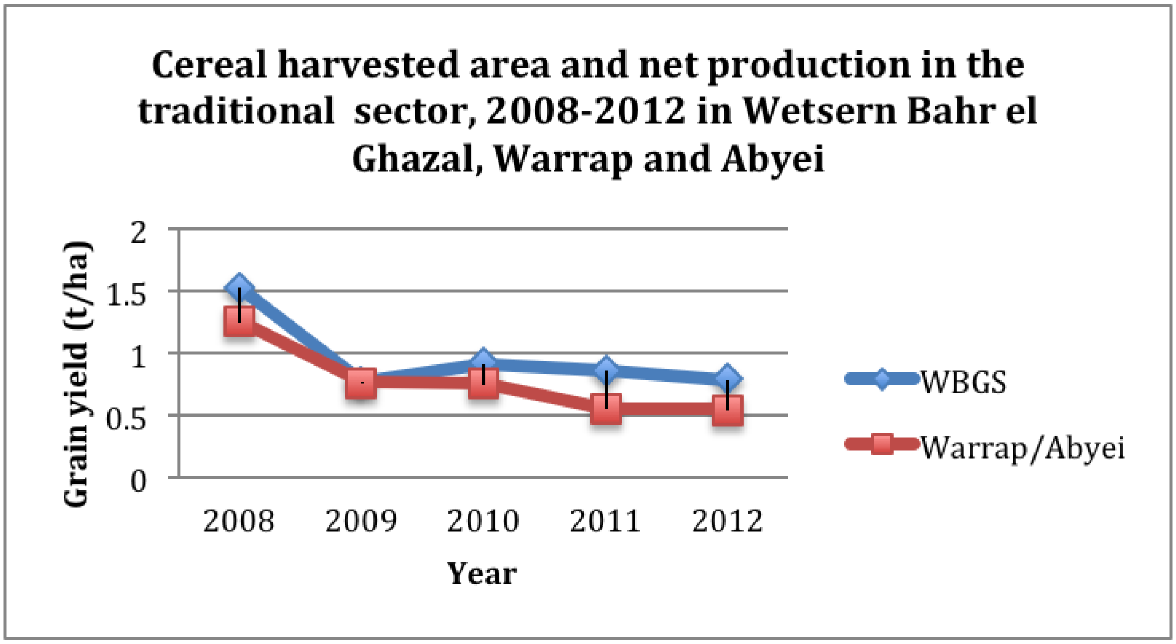

Figure 1: Sorghum grain yield over a period of five years in South Sudan

In Kenya, sorghum yields have shown little consistent improvement varying significantly from year to year. In 2005, sorghum yields peaked at 1.2 tonnes per hectare, but decreased to only 0.6 tonnes per hectare in 2011. The average yield from 1990 to 2011 remained low at 0.8 tonnes per hectare, despite the development of new seed varieties with the potential to yield 2 to 5 tonnes per hectare, (Kilambya & Witwer, 2013). Since 2009, however, there has been a steady increase in production, primarily because of the growing demand for sorghum for brewing, Orr, Mwema and Mulinge, (2013).

2.1.3. Constraints to sorghum production

Sorghum is the major dry land crop occupying nearly 10.5 m ha. The average yield levels are generally very low (around 1 $t.ha^{-1}$) due to various biotic and abiotic constraints operating at different crop developmental stages, Rao (2014). Sorghum production is affected by both biotic and abiotic constraints, including numerous pests and diseases, low soil fertility and water stress. These factors may significantly reduce yields. Striga, a parasitic weed, is considered a major pest of sorghum in Africa, (Orr, 2016).

In Ethiopia, sorghum production is mainly constrained by soil water and nutrient deficits, Tesfahunegn (2012). The soil fertility decline is as a result of a combination of processes such as high rates of soil erosion, nutrient leaching, removal of crop residues, continuous cultivation of the land without adequate fertilization and fallowing (Njeru et al., 2013)). The loss of nutrients through plant nutrient mining, removal of crop residues, erosion, leaching or volatilization, and the deterioration of soil physical properties can independently or interactively result in yield reduction (Bielders 2002, Eshetu 2016, p.23, Njeru et al., 2013). Wortmann et al. (2006) reported that drought, low soil fertility (nutrient deficiencies), insect stem borers, insect shoot fly, quelea birds, Striga and weeds were recognized as major production constraints affecting sorghum in eastern Africa. Although these constraints cause significant grain yield loss, the relative importance varies from region to region, within and among the countries. For example, shoot fly is reported to cause significant grain loss in Ethiopia and Uganda, but is of less importance in Mozambique (Amelework et al. 2016, p.207, Wortmann et al., 2006). In Ethiopia, drought and Striga weed have been found to be the most important constraints in the northern and north-eastern parts of the country (Gebretsadik et al. 2014). Germplasm conservation and use is fundamental for maintaining and increasing food security, especially because it is the basis for the development of improved varieties that will produce increased yields and have higher tolerance to abiotic and biotic factors, as well as other important characteristics beyond those attainable from varieties currently used by farmers, (FAO, 2011). Crop adaptation, including diversifying agriculture with crops and varieties that can perform better under various climatic stresses and substitution of plant types, is among the most cited strategies for adapting agriculture to climate variability and change (Adikant (2019)). Seed systems play a crucial role in providing farmers with access to adaptable crops and varieties, and the flexibility of obtaining seed when required (Kansiime and Mastenbroek, 2016). The broad rationale for focusing on seed sector interventions is that seed is a vehicle for delivering a range of advances, all of which can benefit smallholders. Seed can be the conduit for moving new varieties, giving farmers access to more productive, yield-enhancing traits (McGuire and Sperling, 2015). Socioeconomic factors (age, marital status, education, household size, farm size, social participation and so on) are important factors affecting productivity level in Nigeria. Therefore their effect will help policy makers in the country to make more informed decisions in improving production and livelihood of the farmers, Zalkuwi (2013). A number of empirical studies have attempted to investigate the relationship between technical efficiency and various socioeconomic variables and demographic factors such as levels of formal education, age, family size, access to credit, extension services, and experience, (Chepng'etich et al, 2015).

2.2. Pests, diseases and weeds affecting sorghum production

The stolk borer complex, including *chillo partellus* (Swinh), *Bussoela fusca* (Fuller) and *Sesamia calamistis* is found to be a very important to yield regionally. Total loss of production potential to stalk borer is estimated to more than 1.3 million Mg yr^{-1}

(Wortmann etal., 2009, p. 18). Busseolafusca, (Lepidopteran: Noctuidae) is an economically important pest of maize, sorghum and pearl millet in sub-Saharan Africa (Kfir et al., 2002). This pest is more important at high altitudes, but co-exists in mid-altitude zones of Kenya with C. partellus, another economically important stem borer introduced into Africa from Asia (De Groote et al., 2002;).

Pests in Africa continue to limit food crop harvests. Studies indicate that losses due to pests overall are in the region of 30 % Oerke and Dehne 2004), The major factor in determining the high crop losses due to pests, and their continuing impact on food security, is that most poor farmers in SSA do not have access to any effective pest control technology, (Grzywacz et al, 2013).

2.2.1. Diseases

The causes of low sorghum yields are complex and include losses due to disease and insect pests. The incidence of sorghum diseases may vary considerably with geographical location (Ngugi et al., 2002, p. 65). The most prevalent diseases of sorghum are ergot, grain mould, various smuts, roots and stalk rots, leaf diseases such as rust, zonate leaf spot, mildews, anthracnose and leaf blight among others. The most common viruses attacking sorghum include Johnson grass mosaic virus, maize dwarf mosaic virus, sugarcane mosaic virus, and sorghum mosaic virus. These viral diseases account for 2-5% yield loss annually (Mofokeng et al., 2017, p, 1078). The extent of direct losses varies with location, cultivar and prevalent climatic conditions. The reduction in 1000-seed mass and seed density, and early abortion of seeds are the most important factors in yield reduction (Marley et al., 2004, p. 45). Grain mold infection occurs any time from flowering to grain filling and harvest (Balota, 2012).

2.2.2 Weeds

Yield losses caused by weeds can vary enormously from almost negligible yield loss to the complete loss of a crop. Weeds also cause harvest problems; reduced grain quality; weed-seed contamination of grain; and re infestation of paddocks (Fleming et al., 2013). *Striga*, a parasitic weed, is considered a major pest of sorghum in Africa, (Orr, 2016). . Striga infests crops like sorghum, maize, millet, rice and sugarcane. Witch weed (*Striga hermonthica*), a member of the family Orobanchaceae (Olmstead *et al*., 2001), is the major biotic constraint to cereals production, especially in the non-fertile semi-arid region of Sub-Saharan Africa (Haussmann *et al*., 2000)   *Striga asiatica* is found in the Coast Province and seriously damaged upland rice (Esilaba, 2006). Hassan and Ransom (1998) confirmed that *Striga* incidence in maize is increasing in the moist transitional zone in Kenya with a total affected area of about 300,000-500,000 ha. *Striga hermonthica* problem has been in existence as early as 1936 in the fields of farmers within Lake Victoria Basin and western Kenya (Khan et al., 2006). During the last 20-30 years, it has attained devastating proportions due to cereal mono-cropping (Oswald, 2005). The parasite is reported to be infecting about 217,000 ha in Kenya, causing annual crop loss of US $53 million (Woomer and Savala, 2009). Witch weed (*Striga* spp.) is one of the pests constraining sorghum production in most parts of Uganda including Isonghorero sub-county in Ibanda district (Bua and Nowamani, 2014).

2.2.3. Management of insect pests, diseases and weeds in sorghum

Sorghums are quick growing grasses that have the potential to shade out and/or smother weed populations when planted at a high density. In addition, root exudates of sorghum have been shown to reduce the growth of weeds such as velvetleaf, thorn apple, redroot pigweed, crabgrass, yellow foxtail and barnyard grass (Stapleton et al., 2010). Sorghum is also recommended for control of nutsedge infestations (Clark, 2007). Several measures have been tried and adopted for control of *Striga*. Many potentially successful approaches developed to control this weed include using resistant/tolerant varieties, sowing clean seeds that are not contaminated with *Striga* seeds, rotating cereal hosts with trap crops that induce abortive germination of *Striga* seeds, intercropping, applying organic and inorganic soil amendments such as fertilizer or manure fumigating soil with ethylene, hoeing and hand pulling of emerged *Striga*, applying post emergence herbicides, push-pull technology and using biological control agents (Sibhatu, 2016). A major component for adopting integrated weed management is the identification of the optimum time for weed control throughout the crop cycle (Adegas et al., 2010).

Various approaches towards minimizing the effects of crop diseases in general and anthracnose of sorghum in particular have been tried with different successes depending on the pathosystems (Gwary, 2008). These approaches include adjustments of sowing dates (Gwary 2008)), the use of resistant cultivars (Marley, 2004) and the use of fungicides (ICRISAT, 1982); Gwary and Asala, (2006). The basis why farmers prefer growing sorghum landraces over improved varieties is because of the farmers' ability to adapt to various temperatures, rainfall, soil type, and ecological settings (Mekbib, 2006, Tesfamichael, 2013). However, there is limited information about major weeds, pests and diseases associated with sorghum production in South Sudan, given the fact that very little has been done in this area so far in terms of research.

2.3. Ecology and importance of groundnut production

2.3.1. Ecology of groundnut

Groundnut can be grown in both rainy (*kharif*) and post-rainy (*rabi*/summer/ spring) seasons. The optimum air temperature for growth and development of groundnut is between 25°C and 30°C (Janila and Mula, 2015). Groundnuts grow best on soils limed to a pH of 5.8 to 6.2, provided other essential elements are in balance and available to the plant (Kalule et al., 2013). Timely planting dates should take advantage of periods of higher rainfall and avoiding end of the season drought effects. Groundnut is not suited to growing in very dry areas or at altitudes above 1500m. Optimum temperatures are 27 - 30^{0}C for vegetative growth and 24 – 27^{0}C for reproductive growth (Page et al., 2002). Between 450mm and 1250mm of evenly distributed rainfall is required annually for good growth and yield. The poor productivity of groundnut cultivation in African countries may be attributed to a combination of factors such as unreliable rains, mostly non-irrigated nature of cultivation, traditional small-scale farming with little mechanization, outbreaks of pests and diseases, use of low-yielding varieties, increased and/or continued cultivation on marginal land, poor adoption of agronomic practices and limited extension services (Ajeigbe, 2015)

2.3.2. Importance of groundnut production

Groundnut (*Arachis hypogaea* L.) is an important legume grown and consumed globally and in particular in sub-Saharan African countries (Okello et al., 2010a;). Groundnut is the second most widely grown legume in Uganda, after beans. There has been a substantial increase in the growing of groundnut as both food and cash crop because of increased awareness of its value as a source of protein (23-25% content) and oil (45-52% content) (Page et al., 2002). In western Kenya, the crop is not only the principal source of protein but also a major source of smallholder cash income, (CEFA seeds of solidarity, 2011). In South Sudan, the short maturing groundnuts varieties have the possibility to be used as both staple and cash crop for sale. Groundnuts offer an important safety net for family farms in Western Bahr el Ghazal State. In as much as they are often planted as an alternative to sorghum if the first planting of sorghum fails, groundnuts also act as lucrative cash crops where seasons are longer and a second planting is possible (CFSAM, 2015).

2.3.3. Constraints to groundnut production

The groundnut (*Arachis hypogaea* L.), also known as peanut, is the second most important food legume in Uganda after beans (*Phaseolus vulgaris* L.) Okello et al., 2014, 2015). Its production however, has been constrained by numerous factors including pests and diseases, unreliable rains with recurrent droughts, poor agronomic practices, low access to high yielding cultivars and low levels of inpuMugisa I. O et al., 2015). Foliar d1seases are a major constraint to groundnut production in We"t Afnca. Early Jcaf spot caused by *Cercospora arachid1coia* Horî,late leaf spot caused by *Cercosporidium* *personatumb* (Berk and Curt.) Deighton *(Phaeoirnriopsis personata* (Berk and Curt.) V. Arx) and rust caused by *Puccinia arachid1s* Speg are the most common diseases in the region. Severity of these foliar d1scase~varied from locat10n to location (Waliyar et al., 1993).Groundnut is commonly cultivated by farmers under rain-fed conditions. Groundnut mono-cropping in the same field is not advisable as it leads to build-up of diseases and insect pests in the soil. Groundnut should be rotated with a well-fertilized cereal crop (Janila and Mula, 2015).

2.4. Pests, diseases and weeds of groundnut

2.4.1. Pests

The sucking insect pests complex comprising thrips *Thrips dorsalis* Hood and *Megalurothrips usitatus* Bagnall; leaf hoppers *Empoasca motti* Pruthi, *Batracomorphus angustatus* Osborn, *Cicadulina bipunctata* Melichar, *Empoascanara prima* Distant and *Leofa mysorensis* Distant and aphids *Aphis craccivora* Koch are the major pests of importance on groundnut crop specially when raised under rain fed conditions and bunch varieties are severely infested (David and Ramamurthy, 2011).

Thrips mainly feed by lacerating and sucking the sap from leaves and are known to transmit groundnut bud necrosis virus (Kandakoor et al., 2012). Thrips cause serious crop stunting and yield loss from both direct feeding and virus transmission (tomato spotted wilt). Lesser cornstalk borers attack pods, pegs, lateral stems, and the plant crown at the soil line during extended drought stress.

Burrower bugs primarily attack reduced-tillage peanut fields under drought stress (Dan Anco and J. S Thomas (2018), 2014). In a study conducted in Ghana by Tanzubil (2016), Farmers were able to namemost of the field pests and diseases often associated with groundnuts. Of these, the soil-borne arthropods, termites, millipedes and white grubs were the most recognizable. Foliar pests of importance mentioned by farmers included aphids, grasshoppers, crickets and leaf-eating caterpillars.

2.4.2. Diseases

Among the biotic constraints, fungal diseases are some of the major factors affecting the production and productivity as well as the quality of the crop (Debele and Ayalew, 2015). Contamination of groundnut with aflatoxin occurs under pre harvest, postharvest handling and storage conditions. The main factors leading to aflatoxin contamination include poor cultural practices; use of damaged and loose-shelled kernels as seed. Delayed harvesting after physiological maturity aggravates biological and physical effects of aflatoxin. Timely planting, adequate fertility, good weeding and insect control, supplementary irrigation, suitable plant population and hybrid selection considerably reduce aflatoxin contamination (Gebreselassie et al., 2015).

Yield losses due to *Cercospora* leaf spots are as high as 50% in the USA (Debele and Ayalew, 2015). Because they occur frequently all over the world, early leaf spot (caused by Cercospora arachidicola) and late leaf spot (caused by Cercosporidium personatum) are generally regarded as the most important diseases of peanuts(Bellgard, 2004). Leaf scorch is common early in the season and is often mistaken for a leaf spot. CLS are the most important diseases that seriously reduce groundnut production in Cameroon (Ambang, 2011). Effective control of *Cercospora* leaf spot can be achieved by applying recommended fungicides. The disease can be effectively managed by a combination of fungicides and host plant resistance (Pande et al., 2001). The use of resistant varieties to a particular disease is one of the main methods of disease management (Debele and Ayalew, 2015). Soil water deficit is the most important constraint to production, accounting for over 2 million Mg yr^{-1} of yield loss (FAOSTAT, 2008). This situation has led to extremely low yields at farmer level averaged at 0.8 tons per hectare of dried pods which is in contrast to yields as high as 2.5 to 3.0 tons per hectare reported at research stations within Uganda and other countries with developed agriculture (ICRISAT, 1986; Busolo-Bulafu, 2004; Okello *et al.*, 2014).

Groundnut rosette disease (GRD), which is endemic to sub-Saharan Africa (SSA) and its off-shore islands, is widespread and one of the most destructive diseases of groundnuts (Waliyar et al., 2007,). Groundnut rosette virus disease (GRVD) is the most destructive disease of groundnut in Uganda. It is the most common and most significant disease of groundnut in all regions where this crop is grown. It is widespread in sub-Saharan Africa and has been a major factor in the decline of the Nigeria groundnut pyramids (Ajiegbe *et al,* 2014). Though there are increasing cereal yield trends in most Sub-Saharan Africa countries, these yield levels remain low compared to other regions of the world (AGRA, Africa Agriculture Status Report, 2014).

2.4.3. Weeds

The total annual production of groundnut (*Arachis hypogaea* L.) in the Guinea savanna zone of Ghana has been fairly static over the past years despite yearly increases in the total acreage under the crop (Tsigbey et al., 2003). These poor yields result from a cocktail of factors including infertile soils, weed problems, inappropriate varieties and sub-optimum plant population densities among others (Konlan et al., 2013). Weeds are a major constraint to crop production in the Teso Farming System of Eastern Uganda and weeding labour constraint severely limits the area that a household can sow (Obuo et al., 2003). Yield losses caused by weeds during *kharif* are more because of frequent rains and favourable temperature for luxuriant growth of weeds which requires repeated weeding operations; which is expensive, tedious and labour oriented (Dutta et al., 2005). Groundnut weeds comprise diverse plant species from grasses to broad-leaf weeds and sedges, and cause substantial yield losses (15-75%) which are more in rainfed Spanish bunch type than in irrigated Virginia type groundnut (Jat et al., 2011). Among all the crop pests, weeds alone are responsible for about one third loss in crop production. In groundnut, the loss in pod yield ranges from 13 to 100% depending on the season, cultivars, weed composition and duration of crop- weed competition, and the packages of practices adopted (Yaduraju et al., 1980; Kalaiselvan et al., 1994; Rajendran and Louduraj, 1999; and Dayal and Ghosh, 1999).

2.4.4. Management of groundnut diseases, insect pests and weeds

The use of biocides from plant origin in crop protection is an important means of promoting bio-pesticides in crop production (Ambang, 2011). In recent years, efforts to control GRD have focused on improving cropping practices to delay the onset and spread of both the vector and the disease and on breeding for host-plant resistance (Okello et al., 2014). Deep ploughing in summer to expose soil - borne pathogens, white grubs, nematodes, hibernating defoliators and rhizomes of perennial weeds. Deep ploughing in summer to expose soil - borne pathogens, white grubs, nematodes, hibernating. To rotate the crop with sorghum or pearl millet or rice or maize after kharif crop may reduce the incidence of early leaf spot, late leaf spot, rust and PBND or with wheat/cotton/maize/onion/ garlic to reduce the incidence of soil borne pathogens. Intercropping (National Centre for Integrated Pest Management - India, 2014). Early control of weeds (first 30 days) in groundnut is very critical) and if not done, the yield reduction due to weeds ranges from 17 to 88% depending upon season (Dutta et al., 2005). Cultivation of groundnut in narrow rows can lead to maintenance of a complete crop cover over the soil which inhibits weed seed germination and reduces the need to carry out weeding Konlan et al., 2013). The use of low growing legume cover crop to supplement other control measures for season long weed control have been suggested by various workers Ojelade, 2004;). There is however paucity of information on the use of groundnut in this regard (Lagoke et al., 2014)

2.5. Cropping systems of sorghum and groundnut

In Africa and India, groundnut is very commonly intercropped with sorghum (Behanu et al., 2016).

Langat et al., (2006, p. 98) conducted a study in Western Kenya (Buisia District) during the short rains of 1998 and long rains of 1999. The results showed that the highest yield of intercropped groundnut was 1045 and 790 kg/ha in 1998 and 1999 seasons respectively and both yield figures were in treatment GS2 (75% groundnut and 25% sorghum).

Proportionately, yields declined with declining proportion of groundnut in the mixture except in GS4. The lowest number of pods was realized in GS1 and in pure groundnut. The lowest pod number was in pure groundnut (8) and GS1 (12). In 1999, the highest number of pods per plant, though much lower than in 1998, was in GS2 (7.0 pods/plant). The values of LERs indicated better land use in all intercrop treatments in both seasons. Yield advantages of between 39% (LER = 1.39) in GS3 and 112% (LER = 2.12) in GS4 were registered in 1998 and between 32% (LER = 1.32) in GS1 and 101% (LER = 2.01) in GS4 in 1999. Therefore in both seasons, GS4 had a yield advantage above 100%.

CHAPTER THREE: MATERIALS AND METHODS

3.1. Description of study sites

The study was conducted in two states of Western Bahr el Ghazal, Warrap and Abyei Administrative area. Five counties were selected namely;

(Wau, Raga and Jur River in Western Bahr el Ghazal. Gogrial West in Warrap state and Abyei Administrative area, covering Mading-Achueng and Wunpeth.

(1) Western Bahr el Ghazal state

(a) Wau County.

Wau is situated between the coordinates, latitude 7^0 42’N and longitude 28^0 0’ E at an altitude of 438m above sea level (1,437ft). Köppen-Geiger climate classification system classifies its climate as tropical savanna, wet and dry. It has an average relative humidity of 54% with annual precipitation of 1098 mm and an annual mean temperature of 27.8^0c. Characterized by livelihood zone 4 (SSD 04) known as “Western groundnuts, sesame and sorghum zone”. The soil of WBGS is ironstone, alluvial and it is red with high content of iron oxide, iron stone gravels, predominantly lateritic, low fertility due to leaching erosion losses (Odra *et. al*, 2004). The rainfall data during the experimental period is located in appendix 3a.

(b) Raga County

Raga town is located in Raga County, Western Bahr el Ghazal State, in the northwestern corner of South Sudan, near the International borders with the Republic of Sudan and the Central African Republic. It is located approximately 300 kilometers (190 miles), by road, northwest of Wau, the capital of Western Bahr el Ghazal State. This location lies approximately 950 kilometers by road, northwest of Juba, the capital and largest city in that country. The coordinates of Raga are: 8° 28' 12.00"N, 25° 40' 48.00"E (Latitude: 8.4700; Longitude: 25.6800). Raga is located at an altitude of 545 meters above sea level. Köppen-Geiger climate classification system classifies its climate as tropical wet and dry. Raga has average precipitation of 1,141.6 mm per year with an average relative humidity of 54.4% and average temperature of 26^0C. Raga falls under livelihood zone 4 (SSD 04) known as "Western groundnuts, sesame and sorghum zone" as Wau County.

(c) Jur River County

With its headquarters at Nyinakok, Jur River County lies between the coordinates, 8^0 39' 0"N and 29^0 18' 0" E of the Equator. It's located at 359 meters above sea level. No humidity records exists for Jur River County, however, it shares more or less the same humidity levels of up to 54% as that of Wau since it partly falls in livelihood zone 4 as Wau county, though at relatively lower altitude than in Wau.

(2) Warrap State

Warrap State lies between longitudes 28 and 30 degrees east of the meridian and latitudes 7 and 9 degrees north of the Equator. Its altitude ranges between 456 m above sea level in the south and 428 m above sea level in the north. The state is bordered by the following six states: Western Equatoria in the southwest, Western Bahr El Ghazal in the west, Northern Bahr El Ghazal in the northwest, Southern Kordofan in the north, Unity in the northeast and Lakes in the southeast (UNMISS,2010).

(a) Gogrial West County, Warrap Stat

Gogrial West borders Twic County in the north, Abyei in the west, Wau in the south, and Gogrial East. The total population in Gogrial West is estimated at 243,921. Community Consultation report, Warrap state (May 2012). Elevated at an altitude of 415 meters above sea level, Köppen-Geiger climate classification system classifies its climate as tropical savanna, wet and dry. The precipitation of up to 967mm annually with an average humidity of 60% has been recorded. Gogrial West has an average temperature of 27.7^{0}C. Warrap and Abyei together with parts of Western Bahr el Ghazal Jur River County fall under livelihood zone number 7 (SSD 07), known as the greater Bahr el Ghazal sorghum and cattle. (FEWSNET, 2013)

(3) Abyei Area

Abyei lies at an latitude of 9.5292 and longitude of 28.433. The coordinates: 8^0 34' 16''N and 280 E. It is located at an altitude of 508 m above sea level. Köppen-Geiger climate classification system classifies its climate as tropical wet and dry (Aw). Generally, average temperatures stand at 27.7^{0}c, average precipitation of 972 mm and average humidity of 54%. Day temperatures range from 28^{0}C to 37^{0}C and night temperatures range from 29^{0}C to 34^{0}C. Abyei, Warrap and parts of Western Bahr el Ghazal Jur River County fall under livelihood zone number 7 (SSD 07), known as the *Greater Bahr el Ghazal sorghum and cattle.* (FEWSNET, 2013).

3.2. Geographical description of farmers by states and counties

Disaggregating data by states, t 50% of the farmers sampled were from Western Bahr el Ghazal State (WBGS) and 50% from Warrap state and Abyei Administrative area (Table 2).

Table 2: Number of respondents by states

	Frequency	Percent	Valid Percent	Cumulative Percent
Western Bahr el Ghazal	115	50	50	50
WARAP	117	50	50	100.0
Total	**232**	**100.0**	**100.0**	

In Table 3 below, the data was further disaggregated by counties in which, 7% of respondents were drawn from Raga, 24% from Wau, 20% from Jur River County, 24% from Gogrial West County while the remaining 25% were drawn from Abyei area. These percentages explain the difficulties the researcher had in accessing some areas due to insecurity, coupled with poor road infrastructure hence, low percentages of population reached. Again, places like Wau County, Gogrial West and Abyei with higher percentages have high concentration of local farming population compared to places like Raja and Jur River Counties and this further explains the rate of internal population migration from one location to another in pursuit of livelihoods.

Table 3: Disaggregated data of respondents by states and counties

State	County	No. of respondents	Percent
	Raga	16	7
Western Bahr el Ghazal	Wau	56	24
	Jur River	46	20
	Gogrial West	56	24
Warrap including Abyei	Abyei	58	25
Total		**232**	**100.0**

3.3 Study design

The survey data was collected using questionnaires (Appendix 6), through field interviews with individual farmers at farm level. The data was collected in two seasons from the months of September to November 2014 and September to November 2015 respectively. Applying a simplified formula by Glenn D. Israel (1992), a sample size of 240 farmers was drawn from a population of six hundred (600) households. However, due difficulty in accessing some locations during the survey, the actual number of 232 households represented by household heads/respondents was finally achieved.

3.3.1. Sample size determination formula

$n = N/1+N\,(e)^2$

Where, n is the sample size, N is the population size and e is the level of precision which is 0.05.

Therefore;

$n = 600/1+600(0.05)^2$

$= 600/1+600(0.0025)$

= 600/1+1.5

= 600/2.5 = **240 households**

3.3.2. Sampling procedure

Considering the fact that majority of farmers practice sorghum – groundnut cropping system in surveyed locations, common sampling techniques used by FAO and WFP were applied in the sampling process (WFP/FAO, 2015).

(i) Community members were asked to locate the approximate center of each selected site/location

(ii) A pencil was span to identify the direction to walk to select the sample households

(iii) As enumerators walked to the identified direction, the numbers of households encountered were counted from the center to the perimeter of the site/location

(iv) The sample size of 240 households was divided by the number of desired households (n=30) in order to determine the sampling interval (X/30=SI) i.e. 240/30 = 8 households

(v) A random starting household was selected between 1 and the sampling interval of 8 households arrived at. However, sampling intervals varied from one location to another depending on the population of households in that particular location.

(vi) The sampling interval was added to the first household to select the second household, the sampling interval again added to the second household to select the third household and the process went on until the required number of households were interviewed.

(vii) If the number of households in that direction were < 30, all households in that direction were interviewed and the process repeated to choosing a 2nd direction in order to identify the remaining households for inclusion.

A combination of two-stage cluster sampling and systematic random sampling were used. The first stage (cluster sampling) involved random selection of data collection sites/clusters. In Western Bahr el Ghazal, Warrap and Abyei, four counties of Raga, Wau, Jur River, Gogrial West and Abyei were selected from which 19 locations/villages known as “sentinel sites” were randomly selected for inclusion in the assessment based on (a) their accessibility and (b) the extent to which they collectively represented the target population. In the second stage (systematic random sampling), a list of households was made out of which the final sample size of 240 households was drawn using the Glenn D. Israel’s formula. Table 4 below shows the data collection sites and number of households selected per location.

Table 4: Data collection sites and number of selected households

State	County	Location/village	Number of households/respondents
Western Bahr el Ghazal	Raga	Maberga	10
		Khorshamam	10
		Diemzubeir/Uyujuku	10
	Wau	Basselia	9
		Bussere	20
		Ngobagari	10
	Jur River	Mbili	10
		Mapel	10
		Udichi	15
		Sub-total	**104**
Warrap	Gogrial West	Manalom	10
		Panthoi	10
		Agei	10
		Ayiel	10
		Gogrial Wut	15
		Rumker	5
		Machar	8
	Abyei	Mading Achueng	18
		Malual Aleu	13
		Wunpeeth	29
		Sub-total	**128**
Grand total			**232**

3.3.3 Data collection

To assess the proportion of population at productive age that is involved in active farm activities, data on women participation in farm activities, demographic data on gender (sex of household heads) as well as data on geographic locations such as state and counties were collected. Other parameters that consist of elements that influence ultimate yield of sorghum and groundnut crops were also considered. These included farming practices such as time of planting, application of farm yard manure, fertilizer use, incidence of pests, diseases and weeds, planting time, cropping systems adopted by local farmers, tools used for land preparation, type of seeds, onset of rains and methods of planting. Soil data was also collected to determine the levels of key elements such as percentage organic carbon, percentage total nitrogen, phosphorous, potassium and other microelements in relation to ultimate yields of sorghum and groundnut crops under the sorghum – groundnut cropping system in selected sites. Data also collected on yields of sorghum and groundnut crops.

3.4. Soil analysis

3.4.1 Determination of soil nutrient status in surveyed states/counties

Soil sampling was done in September 2015. The soil was sampled at 0.20 cm depth from three farms in each of the five sites. The five sites were; Besselia, Udichi, Gogrial West, Mading-achueng and Wunpeeth. After collecting samples, they were placed in separate envelopes and appropriately labeled. Samples were air-dried, ground using a motor and pestle and sieved through a 2 mm sieve. Laboratory analyses were conducted for soil pH, percent total organic carbon, percent total nitrogen, exchangeable bases (K^+, Na^+, Ca^+ and Mg^+) and available phosphorus.

The Walkley-Black chromic acid wet oxidation method was used to determine the soil total organic carbon. Oxidisable matter in the soil was oxidized by 1 N $K_2Cr_2O_7$ solution. However, to increase the homogenization of the sample and to facilitate the oxidation, a soil sample, which had previously been passed through a 2 mm sieve to remove the coarse fraction, was ground to pass an 0.5 mm sieve. The pH (reaction) of the soil was determined using a pH meter and glass electrodes. The pH of the soil was determined using one part of soil to 2.5 parts of water or solution, for example,10.0 g soil to 25 ml water. Exchangeable bases were determined using an ammonium acetate extract by flame photometry (K^+, Na^+) and atomic absorption spectrophotometry (Ca^+ and Mg^+). Phosphorus test was done using MEHLICH's method-calorimetric determination of soil phosphorus. The N-Kjedhal's method (equipment with die and chemical) was used in total nitrogen analysis.

3.5. Data analyses

After data collection, it was coded and entered in the SPSS program, analyzed and presented in form of frequency distribution tables, cross tabulation, pie charts and bar charts. Factor analysis was run in SPSS program to establish the order of importance of the factors that influence cropping systems on sorghum and groundnut yields in Western Bahr El Ghazal and Warrap States and Abyei area in South Sudan. Yield and soil data were subjected to analysis of variance (ANOVA) using Genstat software and means separated using the least significant difference (LSD) test at p = 0.05. Regression and correlation analysis were also run in the SPSS program to determine the relationship between the yields of sorghum and groundnut, sorghum – groundnut cropping system, pests, diseases and weeds incident as well as soil nutrients, mainly percentage organic carbon, percentage total nitrogen, phosphorous, potassium, magnesium, calcium, and sodium.

CHAPTER FOUR: RESULTS

4.1. Demographic characteristics of farmers in surveyed areas

In the study, two main age categories as used in the FAO/WFP food security assessment missions have been adopted. These age categories are respondents in the age bracket of 18 – 60 years old and 60 years and above. The study shows that men were 40% while 60% were women, (Table 5).

Seventy per cent of households were male-headed while thirty per cent were female-headed. Forty per cent, all males and household heads were 18-60 years of age. Sixty-nine female respondents in the study (table 5) below, aged 18-60 years reported that their households were female headed. The other 60% above the age of 60 years indicated that their households were female headed. There were no male respondents in this category.

Table 5: Demographic characteristics of respondents who participated in the study
N = 232

Characteristics of respondents		Gender		Total	Percent		Percent total
		Male	**Female**		**Male**	**Female**	
Gender of respondents		93	139	232	40.1	59.9	100.0
Gender of household head		163	69	232	70.3	29.7	100.0
Age category of household's head	18-60 years	93	0	93	40.0	0.0	40.0
	> 60 years	70	69	139	60.0	0.0	60.0

4.2 Farm practices and routine activities

It was observed that 99% of respondents cultivated sorghum, groundnut or a mixture of different crops including sesame, maize and cow peas in the previous year (Table 6). This indicates that majority of people in these areas largely depend on farming as a major source of livelihood. Sixty-eight (68%) used local sorghum and groundnuts seeds while the rest improved seeds. With regards to sources of seeds, 9% of the respondents obtained their seeds from the local market, 4% from Food and Agriculture Organization of the United Nations (FAO), 9% from other farmers (friends and relatives) while majority of them, 78% used their own seeds from local granaries.

Table 6: Cultivation history and inputs use in Greater Bahr el Ghazal region (2015)

Farm practice/Routine activities	Farmers' responses	No. of respondents	Percent
Cultivation history	Did not cultivate previous season	1	1
	Cultivated last season	231	99
Types of seeds	Improved varieties	75	32
	Local	157	68
Sources of Sorghum and Groundnut seeds for local farmers	Local market	20	9
	Food and Agriculture Organization (FAO)	10	4
	Other farmers (Friends and relatives)	21	9
	Own seeds	181	78

4.3. Choice of crops, preferred cropping systems, tools and farm practices

It was observed that 32% of the respondents preferred a combination of sorghum with sesame, 24% a combination of sorghum with groundnut, 14% a combination of other mixtures for example sorghum, cowpeas, green gram and vegetables, 11% maize alone, 11% groundnut alone, 7% sorghum alone and finally a very small proportion of 1% preferred a combination of sorghum with cowpeas (Table7). Though the most preferred cropping system was sorghum-sesame, the commonly observed cropping system in Wau and Jur river counties as well as Gogrial west was sorghum-groundnut (plates 1 – 4).

4.3.1. Land preparation practices

Forty-nine per cent of respondents indicated that they did not plough before planting while the rest ploughed the land before planting (Table 7). For those who do not plough before planting, they broadcasted sorghum seeds and plough into the soil the seeds together
with grass (Plate 1).

Plate 1: Farmers in Udichi, Jur River County used local hand hoes (molodas) to work into the soil the broadcasted sorghum seeds together with grass before ploughing the land. The vegetative materials/grass removed in the process is spread over as mulch.

4.3.2. Tools used for ploughing

The study showed that 81% used hand hoes (local molodas) in land preparation, 9% used oxen and 10% used hand hoes (Jembe), Table 7. Thus, majority of farmers used local molodas which do not dig deep into the sub-layer of the soil and this has negative effects in terms of crop performance. The reason being that shallow ploughing does not allow adequate and uniform water distribution at the root zone. Shallow ploughing also restricts roots expansion to explore the surrounding environ for effective utilization of soil nutrients by the plant.

Plate 2: Locally manufactured hand tools displayed for sale in Wau Market as the cheapest source of tools for local farmers.

4.3.3. Planting time

The majority, 61 per cent planted in May while 10% planted in June. None of the respondents planted in March (Table 7).

Table 7: Farm routine activities in Greater Bhar el Ghazal region (2015)
n = 232

Farm practices/Routine activities	Farmers' responses	No. of respondents	% respondents
Cropping systems	Sorghum/Groundnut	55	24
	Sorghum/cowpeas	2	1
	Sorghum/Sesame	75	32
	Only ground nut	26	11
	Only Sorghum	15	7
	Only maize	27	11
	Other (Sorghum, green gram, maize, cowpea)	32	14
Planting methods	Broadcasting	155	67
	Row planning	77	33
Land preparation	Did not plough before planting	114	49
	Ploughed before planting	118	51
Farming tools used by local farmers	Hand hoe (local molodas)	187	81
	Oxen	22	9
	Others (Jembe)	23	10
Time of planting	February	1	1
	March	0	0
	April	66	28
	May	141	61
	June	24	10

4.3.4. Use of organic and inorganic fertilizers and fertilizer sources

Thirty-three (33%) of respondents applied animal/farmyard manure to their crops and 67% did not. Eighty-four (84%) applied synthetic fertilizers while 16% did not . Only 22% of respondents reported that they sourced fertilizers from local markets.

4.3.5 Common cropping systems observed in farmers' fields during the study

Based on the livelihood zones, four different cropping systems were observed in Wau and Jur River counties (Plates 3 – 6). The common cropping systems observed were sorghum-groundnut and sorghum-cassava, sorghum as monocrop and a mixture of sorghum, cassava, groundnut and other crops like cowpea.

***Plate 3**: Sorghum intercropped with groundnut, Udichi, Jur River County*

***Plate 4:** Cassava intercropped with groundnut, Gumaba-Bazia, Wau County*

***Plate 5:** Sorghum at grain filing stage, Wau County*

***Plate 6:** An intercrop of sorghum, cassava and groundnut, Wau County*

4.3.6. Factor analysis

Total Variation explained

Reference to column four labeled "Rotation Sums of Squared Loadings" in table 8 below, there were seven components with eigenvalues greater than 1 out of eighteen factors. Five factors on rotated component matrix which included the state, county, location, whether the farmer received extension advice in the previous season and planted in rows or not had loaded strongly on component one and accounted for 16% of total variability out of eighteen factors. This is true because the grain yield obtained from sorghum and groundnut crops are largely dependent on the cropping systems and farming practices adopted by farmers in each state, county and/ or geographical location for that matter. Linking these results to correlation analysis (Table 8), these factors were statistically significant at 0.01 level, $p<0.01$. The month in which planting started, application of animal manure or inorganic fertilizers loaded strongly on component two and accounts for 10% of the total variability. These factors were statistically significant on sorghum and groundnut yields at 0.05 and 0.01 levels (table 8). Other factors like dry spell, pests and diseases and weeds incident strongly loaded on component three and accounted for 9% of total variability. However, these factors were not statistically significant at 0.05 levels (Table 8). Other factors loaded strongly on components four to seven respectively.

Table 8. Total Variance Explained

Component	Initial Eigenvalues			Extraction Sums of Squared Loadings			Rotation Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	3.434	19.077	19.077	3.434	19.077	19.077	2.975	16.526	16.526
2	2.070	11.502	30.578	2.070	11.502	30.578	1.887	10.481	27.007
3	1.672	9.289	39.868	1.672	9.289	39.868	1.702	9.454	36.461
4	1.414	7.857	47.724	1.414	7.857	47.724	1.512	8.398	44.859
5	1.298	7.209	54.934	1.298	7.209	54.934	1.408	7.824	52.683
6	1.131	6.286	61.220	1.131	6.286	61.220	1.325	7.360	60.043
7	1.059	5.886	67.106	1.059	5.886	67.106	1.271	7.063	67.106
8	.917	5.096	72.202						
9	.836	4.643	76.845						
10	.764	4.244	81.089						
11	.659	3.662	84.751						
12	.590	3.276	88.027						
13	.510	2.831	90.858						
14	.484	2.686	93.544						
15	.429	2.381	95.925						
16	.339	1.882	97.807						
17	.297	1.650	99.457						
18	.098	.543	100.000						

Extraction Method: Principal Component Analysis.

Rotated component matrix

Factor analysis is derived using the statistical package for social science (SPSS) software. As shown in the rotated component matrix (Table 9) below, factor analysis groups key variables/factors affecting crop yields into major components. Based on the data collected during this study, seven key components were derived out of eighteen factors. Component one is composed of five factors namely; row planting versus broadcasting, extension service deliver, state, county and location where farming activity took place. Component two is composed of three factors i.e. planting time, application of inorganic fertilizers and manures. Component three is also composed of three factors which include dry spell, pests and diseases and weeds. Component four has two factors namely; cultivation history and the onset of rains. Component five has two factors i.e. cropping system and ploughing method. Component six also has two factors of seed types and the time rainfall started and finally, component seven has only one factor which is ploughing before planting.

Table 9: Rotated Component Matrix[a]

	Component						
	1	2	3	4	5	6	7
Did you plant in rows?	.790	-.110	.238	.166	-.147	-.016	.035
County	.760	.409	-.177	.030	-.233	-.089	.106
Location	.748	-.079	.104	-.016	.201	-.158	.198
Did you receive extension last year?	.678	.095	.066	-.093	.044	.432	-.249
State	.569	.501	-.385	-.035	-.008	-.095	.311
In which month did you started planting?	.038	.696	-.081	.025	-.048	.232	.137
Did you apply fertilizers	-.138	.695	.369	-.105	.022	.072	-.035
Did you apply animal manure?	.227	.588	-.143	.205	.037	-.260	-.092
Was there dry spell	.056	-.236	.737	.050	-.231	.032	-.038
Did you notice pests and diseases	.051	.112	.637	.013	.001	-.043	.053
Did weeds infest your crops?	.333	.126	.488	.224	.243	-.132	-.443
Did you cultivate last year	.001	-.007	.049	.812	-.143	.180	-.034
In which month did rains started?	.035	.059	.028	.759	.195	-.149	.019
Which combinations do you prefer most?	.127	.060	-.056	-.025	.810	.140	.104
How did you plough?	-.417	-.147	-.128	.136	.655	-.039	-.060
Type of seed used	-.101	.035	-.160	-.085	.029	.715	-.089
Did Rains started earlier?	.080	.065	.222	.324	.140	.602	.240
Did you Plough before planting?	.178	.094	.028	.022	.099	-.015	.866

Extraction Method: Principal Component Analysis.

Rotation Method: Varimax with Kaiser Normalization.

4.3.7. Effect of cropping systems, weeds, pests and diseases and farm practices on the mean yields of sorghum and groundnut in Greater Bahr el Ghazal

4.3.7.1. Regression analysis

In the model summary (Table 10) below, the correlation coefficient (R) is 0.135 which indicates a low degree of relationship between sorghum yield and effect of weeds, pests and diseases. The total variation that can be explained by these biotic factors is also very low at 1.8%. The result of one way analysis of variance (ANOVA), Table 11 showed that the relationship between sorghum yields and abiotic factors (weeds, pests and diseases) is not statistically significant at 0.05 level, $p>0.05$. However, the relationship between sorghum yield and sorghum-groundnut cropping system is statistically significant at 0.05 level, $p<0.0001$ which strongly indicates that sorghum-groundnut cropping system has a high influence on ultimate yield of grain sorghum in selected sites.

Table 10. Model Summary of a relationship between sorghum yields and the effect of pests, diseases and weeds

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.135[a]	.018	.000	2.03891

a. Predictors: (Constant), Weeds incident, Pests & diseases, Cropping system

b. Dependent Variable: Sorghum yield in kg

Looking at ANOVA table below, the significant level of 0.386 is more than 0.05. This indicates that, overall, the regression model does not statistically significantly predicts the outcome variable (i.e., it is a good fit for the data).This further explains that the regression equation does not predict the dependent variable which is ultimate yields of sorghum and groundnut crops in the case of this study. These results are in agreement with the results in the model summary (Table 10) above.

Table 11. ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	12.705	3	4.235	1.019	.386[b]
	Residual	681.771	164	4.157		
	Total	694.476	167			

a. Dependent Variable: Sorghum yield in kg

b. Predictors: (Constant), Weeds incident, Noticed pests diseases, Cropping system

4.3.7.2. Correlation analysis

Analysis of variance showed that the effect of weeds, pests and diseases is not significant at 0.05 level, but a combination of pests, diseases and weeds is significant at 0.01 level (Table 12) on cropping systems.), $p > 0.01$.

However, the effect of cropping system on ultimate yields of sorghum and groundnut was s significant at 0.01 level, $p<0.0001$(Table 12), but the groundnut yields were negatively correlated with cropping system. The sorghum and groundnut yields obtained under sorghum-groundnut cropping system were more than yields obtained under monoculture of each crop. However, there was negative correlation between the cropping system, ploughing before planting and groundnut yields (Table 12). Again, linking the yield with soil nutrients, the relationship between sorghum and groundnut yields and per cent organic carbon, potassium and per cent nitrogen were statistically significant 0.05 level, $p<0.01$. Looking at the results of soil analysis in the graphs (Figure 2 – 3) below, increases in nitrogen, phosphorous and potassium levels in the soil resulted to proportional increase in sorghum yields.

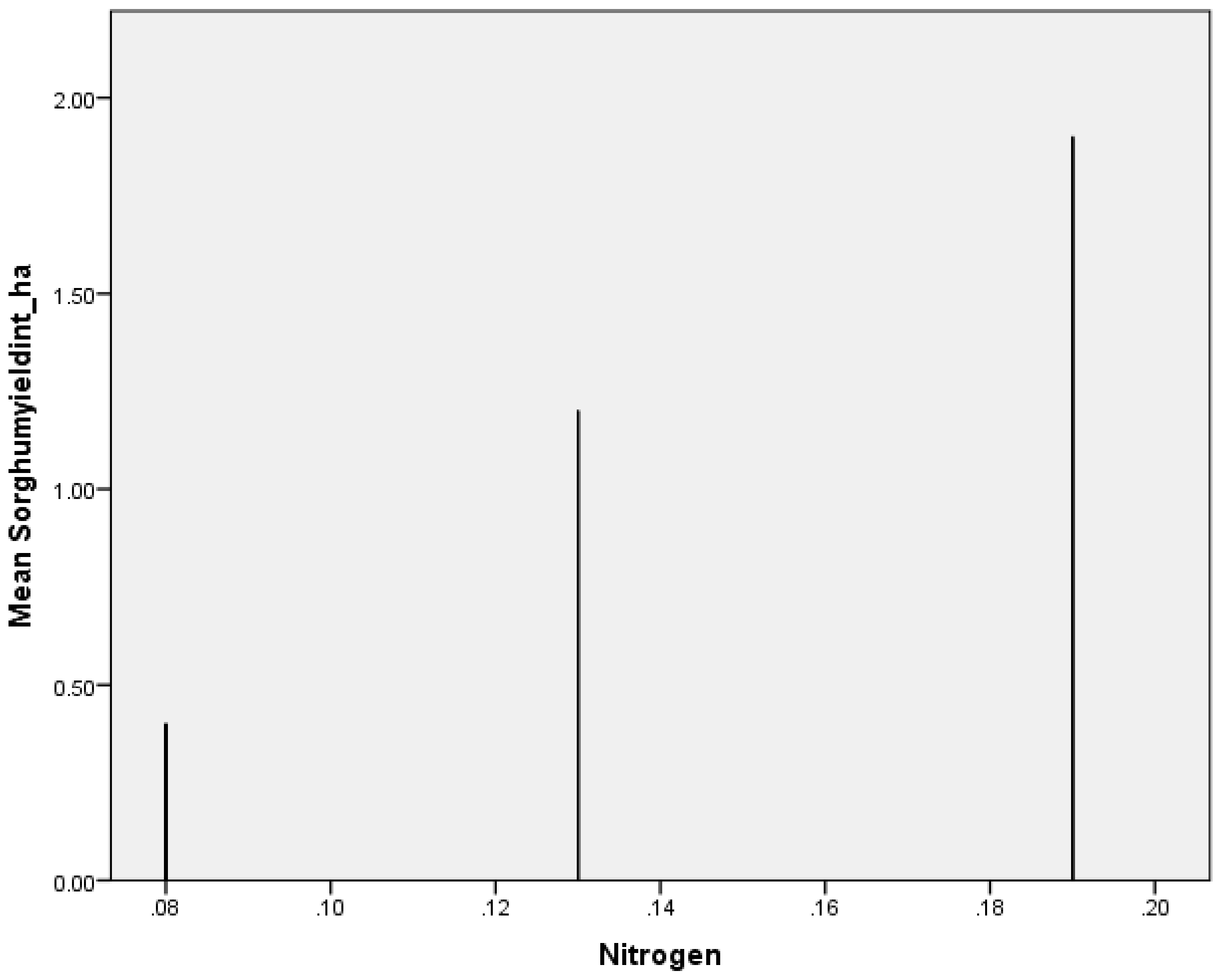

Figure 2: The relationship between nitrogen and mean sorghum yield in Greater Bahr el ghazal

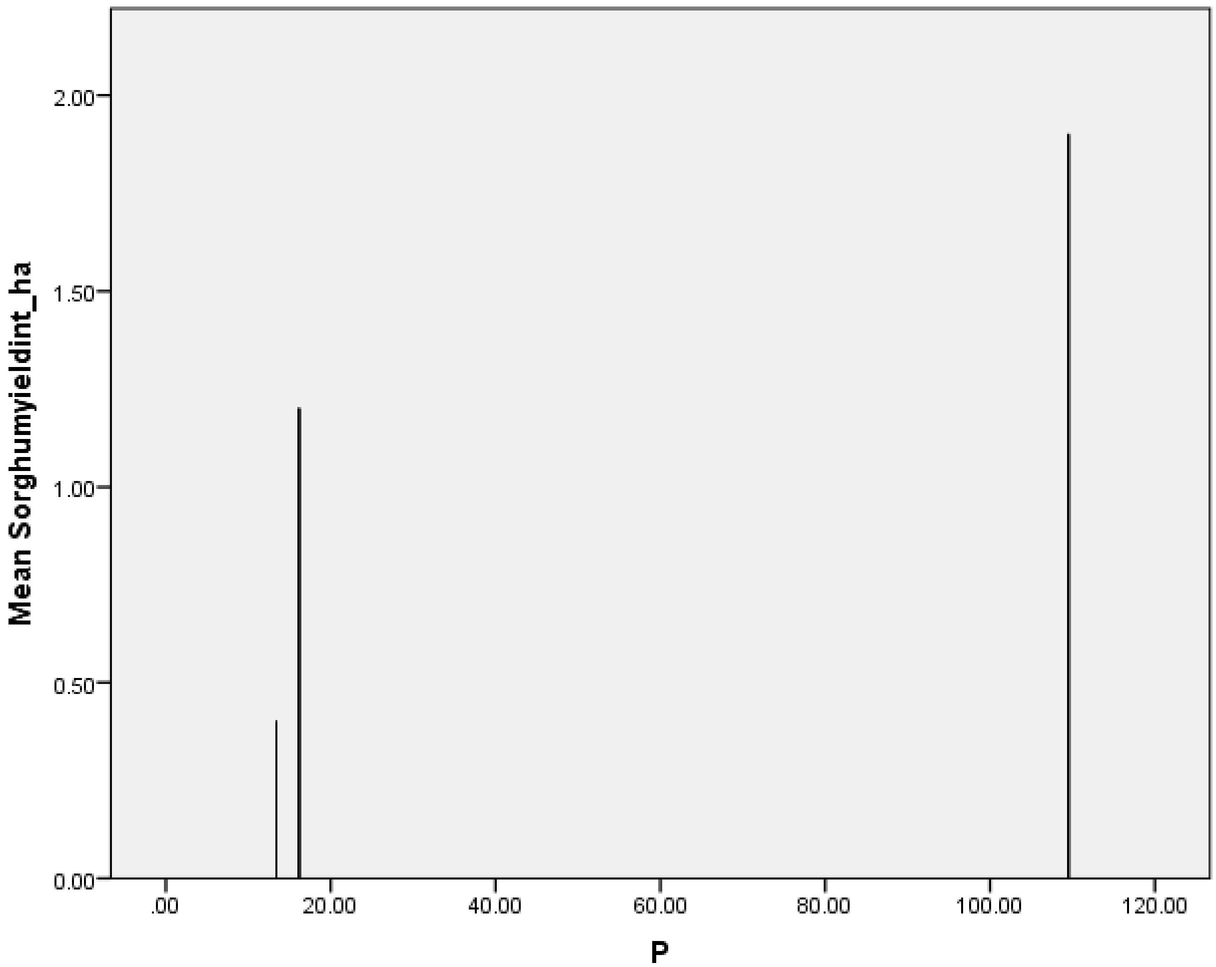

Figure 3: The relationship between phosphorous and mean sorghum yield in Greater Bahr el ghazal

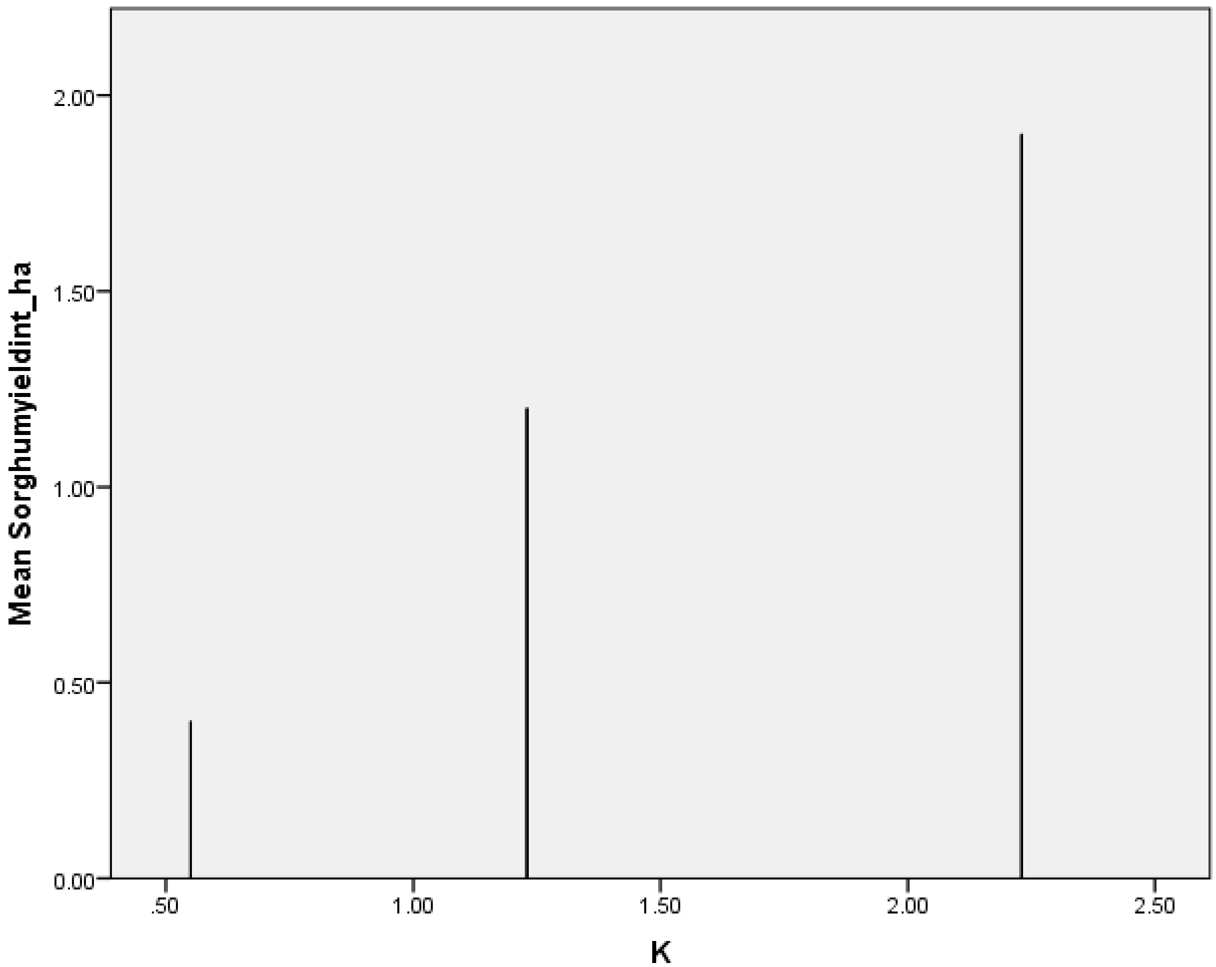

Figure 4: The relationship between potassium and mean sorghum yield in Greater Bahr el ghazal

Considering both biotic and abiotic factors in correlational analysis, (table 8), weak positive relationship was observed between ploughing before planting, application of animal/farmyard manure and sorghum yield. The relationship was statistically significant at 0.05 level, $p<0.05$. This explains that land preparation one to two or three times before planting and application of animal/farmyard manure have positive influence on ultimate yields of sorghum and groundnut crops. A high positive correlation was also observed between ploughing of land before planting and extension service delivery. The correlation was statistically significant at 0.01 level, $p<0.01$. This further explains that those farmers who received extension advice were able to plough their fields before planting which had in turn positively influenced the sorghum and groundnut yields.

However in contrast, there was a negative correlation between ploughing of land before planting and groundnut yield which was statistically significant at 0.05 level, $p<0.05$. This also explains that the less number of times farmers plough land or no ploughing at all before planting especially for groundnut crop, the lower the ultimate yield.

, There was a negative correlation between dry spell and the onset of rain (month rain started) and groundnut yield. The relationship was statistically significant at 0.05 level, $p<0.05$. As rains start late in the season, coupled with intensified dry spell, the lower the groundnut yield.

A high positive correlation was observed between extension service delivery, seed types and sorghum yields which was statistically significant at 0.01 level, $p<0.01$. This means that a few number of farmers who used improved seeds have achieved good sorghum yields compared to the majority who used local seeds. However, there was a negative correlation between seed types and groundnut yields. The relationship was statistically significant at 0.05 level, $p<0.05$. This may be attributed to use of unimproved seeds by a few number of farmers in the selected sites. There was also a positive correlation between seed types, weed incident, dry spell and extension service delivery at 0.01 level, $p<0.01$.

Table 12. Correlations

		Sorghum grain yield	Groundnut grain yield	Cropping system	Ploughing before planting	Applied animal/ farmyard manure	Noticed pests diseases	Weeds incident	Seed types	Month rain started	Dry spell	Received extension services
Sorghum grain yield	Pearson Correlation	1	-.057	.102	.133*	.095	-.075	.035	.167*	.011	.063	.091
	Sig. (1-tailed)		.231	.095	.043	.111	.168	.328	.015	.444	.209	.119
	N	168	168	168	168	168	168	168	168	168	168	168
Groundnut grain yield	Pearson Correlation	-.057	1	-.449**	-.152*	-.270**	.096	-.075	-.160*	.121	-.167*	-.038
	Sig. (1-tailed)	.231		.000	.025	.000	.108	.168	.019	.059	.015	.314
	N	168	168	168	168	168	168	168	168	168	168	168
Cropping system	Pearson Correlation	.102	-.449**	1	.009	.099	.107	.304**	.103	-.034	.039	-.006
	Sig. (1-tailed)	.095	.000		.453	.101	.083	.000	.092	.333	.309	.469
	N	168	168	168	168	168	168	168	168	168	168	168
Ploughing before planting	Pearson Correlation	.133*	-.152*	.009	1	.167*	-.017	.071	-.054	-.020	.043	.285**
	Sig. (1-tailed)	.043	.025	.453		.015	.412	.181	.245	.397	.290	.000
	N	168	168	168	168	168	168	168	168	168	168	168
Applied animal manure	Pearson Correlation	.095	-.270**	.099	.167*	1	.018	-.050	.018	-.120	.043	.061
	Sig. (1-tailed)	.111	.000	.101	.015		.409	.259	.407	.061	.292	.215
	N	168	168	168	168	168	168	168	168	168	168	168
Noticed pests	Pearson Correlation	-.075	.096	.107	-.017	.018	1	.239**	-.018	.073	.017	.156*

diseases	Sig. (1-tailed)	.168	.108	.083	.412	.409		.001	.408	.172	.414	.022
	N	168	168	168	168	168	168	168	168	168	168	168
Weeds incident	Pearson Correlation	.035	-.075	.304**	.071	-.050	.239**	1	.298**	-.029	.110	.121
	Sig. (1-tailed)	.328	.168	.000	.181	.259	.001		.000	.353	.078	.059
	N	168	168	168	168	168	168	168	168	168	168	168
Seed type	Pearson Correlation	.167*	-.160*	.103	-.054	.018	-.018	.298**	1	-.050	.378**	.332**
	Sig. (1-tailed)	.015	.019	.092	.245	.407	.408	.000		.258	.000	.000
	N	168	168	168	168	168	168	168	168	168	168	168
Month rains started	Pearson Correlation	.011	.121	-.034	-.020	-.120	.073	-.029	-.050	1	.133*	-.014
	Sig. (1-tailed)	.444	.059	.333	.397	.061	.172	.353	.258		.043	.430
	N	168	168	168	168	168	168	168	168	168	168	168
Dry spell	Pearson Correlation	.063	-.167*	.039	.043	.043	.017	.110	.378**	.133*	1	.102
	Sig. (1-tailed)	.209	.015	.309	.290	.292	.414	.078	.000	.043		.094
	N	168	168	168	168	168	168	168	168	168	168	168
Received extension services	Pearson Correlation	.091	-.038	-.006	.285**	.061	.156*	.121	.332**	-.014	.102	1
	Sig. (1-tailed)	.119	.314	.469	.000	.215	.022	.059	.000	.430	.094	
	N	168	168	168	168	168	168	168	168	168	168	168

***. Correlation is significant at the 0.05 level (1-tailed).**

****. Correlation is significant at the 0.01 level (1-tailed).**

4.8.3. Effect of Pests, diseases and weeds

Seventy-eight per cent (78%) of the respondents noticed some pests and diseases in their farms. Squirrels were reported to be the main pests by 90% of the respondents while 10% reported monkeys.

Table 13: Pests, diseases and weed infestation

Level of infestation/incidence	Farmers' responses	No. of respondents	Percent
Pests infestation	Squirrel,	210	90
	Monkeys	22	10
Disease incident	Did not notice any pest or disease	51	22
	Noticed pests and diseases	181	78
Weed infestation	Noticed weeds	50	21
	Did not notice any weed	182	79

4.8.4. Observed pests of sorghum on farmers' field during surveys in Western Bahr el Ghazal in September 2015

Common name	**Scientific name**
1. Cut worms	Argotis sp.
2. Rutherglen bug (RGB)	Nysius vinitor
3. Red banded stink bug of sorghum	Piezedorus guildinii
4. Corn aphids	Rhophalosiphum maidis
5. Stem borer	Chilo partelus/sesamia inferens)

Plate 7: Cut worms (Argotiis sp.) Mapel-Jur River County

Plate 8: Rutherglen bug (RGB) (Nysius *vinitor*)

Plate 9: Corn aphids (Rhophalosiphum maidis) Mapel – Jur River County

Plate 10: Red banded stink bug of sorghum (Piezedorus guildinii) Mapel – Ju River County

Plate 11: Downy mildew, caused by the fungus (Peronosclerospora sorghi). Mapel – Jur River County

4.8.5. Observed diseases of sorghum during field surveys

Name	Causal agent
1. Downy mildew	Peronosclerospora sorghi
2. Sorghum leaf rust	Puccinia purpurea
3. Sorghum shoot fly	Atherigona soccata
4. Sorghum head smut	Sphacelotheca reiliana


Plate 12: Sorghum leaf rust. Caused by fungus (P. purpurea) Mapel – Jur River County


Plate 13: Sorghum shoot fly (Atherigona soccata) Mapel Jur River County


Plate 14: Stem borer, Gosinga – Raga County


Plate 15: Sorghum head smut. Caused by the fungus Sphacelotheca reiliana. Soil borne. Gosinga – Raga County

4.8.6. Observed pests and diseases of groundnut during field surveys

Name	**Casual agent**
1. Caterpillar insect pests	Spodoptera spp
2. Groundnut leaf spot	Cercospora spp

Plate 16: Leaf miners/Caterpillars (Spodoptera spp.) Mapel – Jur River County

Plate 17: Groundnut leaf spot (Cercospora spp.) Mapel – Jur River County

4.8.7. Effects of weeds on crops

Seventy-nine per cent of the respondents mentioned many negative effects of weeds, which included reduction in crop yield as weeds compete highly with crops for nutrients from the soil, reduced crop growth especially striga which they said, had affected sorghum performance so much. The most notorious weeds being tropical spiderwort *(Camelina bengalensis), Striga* and nut sedges. Estimated crop losses due to weeds sometimes reach up to one acre if fields are not cleaned earlier enough. Some farmers recalled losing up to half of sorghum crop to weeds (Tale 14).

Table 14. Weeds infestation on crops in Greater Bahr el ghazal

Responses on weeds infestation	No. of respondents	Percent
No	50	21
Yes	182	79
Total	**232**	**100.0**

4.8.8. Observed common weeds of South Sudan in farmers' fields

Common name	Scientific name	Family
1. Spear grass	*Imperata cylindrica*	Poaceae
2. Tropical spiderwort	*Camelina benghalensis L*	Commelinaceae
3. Striga weed	*S. Hermonthica*	Orobanchaceae

Plate 18: Mature Spear grass (After flowering) Udichi – Jur River County

Plate 19: Tropical Spiderwort (Camelina benghalensis L.) Wau County

Plate 20: Striga hermontheca, Wau County

4.8.9. Frequency with which farmers weed their crop fields

Nine per cent of the respondents indicated that their fields weren't affected by weeds, so they did not require weeding, 19 % indicated that they weeded once, 43% indicated that they weeded twice, 21% indicated they weeded thrice and 8% reported weeding their farms four times during the last season (Table 15).

Table 15. No of times a farmer weed sorghum and groundnut field, intercropping system

No. of times farmers weed their fields in the season	No. of respondents	Percent
None	22	9
Once	45	19
Twice	99	43
Thrice	48	21
Four times	18	8
Total	**232**	**100.0**

Forty-three (43%) of respondents weeded their farms at least two times. Fifty nine percent reported that rains started in April across the selected sites (Table 16). Ninety per cent agreed that rains were earlier in the previous season and 59% reported dry spell. Seventy-three percent did not receive any extension support.

Table 16: Seasonal changes

Seasonal change/variation	Farmers' responses	No. of respondents	Percent
Number of times a farmer weeds field	0	22	9
	1	45	19
	2	99	43
	3	48	21
	4	18	8
Months in which rains start in the area	January	6	3
	February	2	1
	March	3	1
	April	137	59
	May	25	11
	June	59	25
Onset of rains	Started late	23	10
	Started early	209	90
Dry spell incidence	No	94	41
	Yes	138	59
	No extension services	170	73
	Received extension services	62	27

4.9. Onset of rains

In Figure 5, 3% indicated that rains started in January in the previous season, 1 % indicated February, another 1% reported March, 59% reported April, 11% indicated May an 25% indicated June.

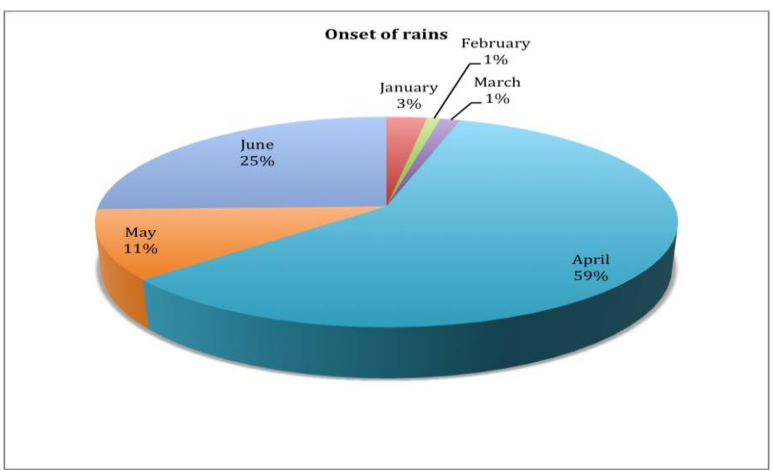

Figure: 5. Disaggregated data by percentage of farmers indicating the month in which rain usually start in their area

4.9.1. The effect of dry spell on crop yield in Raga County, Western Bahr el Ghazal state

Plate 21: Bambara groundnut intercropped with sorghum affected by dry spell in Raga County, Diem-Jalab

Plate 22: Dry spell affected sorghum field in Raga County-Gosinga village

4.9.2. Extension services delivery

Table 17 shows that seventy-three (73%) of the respondents didn't receive extension services .

Table 17. Extension services delivery

Responses		**No. of respondents**	**Percent**
	No	170	73
Valid	Yes	62	27
Total		**232**	**100.0**

4.9.3. Soil chemical characteristics in selected states of Greater Bahr el Ghazal

No significant differences in pH and Na levels were noted in the study site (Table 14). The pH ranged from 6 to 7.2 while Na ranged from 0.6 to 7.5 Cmol kg^{-1}.

Gogrial West had significantly higher organic carbon than all locations except Wau (Basselia). Organic carbon levels were not significantly different among Wunpeeth, Mading-Achueng and Jur River (Udichi) sites. Wau (Basselia) site had significantly higher organic carbon than Gogrial West, Madin-achueng and Wunpeth, but not Udichi. Percent organic carbon ranged from 0.8% in Mading-Achueng to 3.4% in Gogrial West.

Gogrial West had significantly higher % total N than other locations except Wau (Basselia). No differences in % N were noted among Wau (Basellia), Jur River (Udichi), Mading-Achueng and Wunpeth sites. Total N ranged from 0.07% in Wunpeth to 0.19% in Gogrial West. Gogrial West had significantly higher potassium levels than other locations. Potassium levels ranged from 1.7 Cmols kg $^{-1}$ in Gogrial West to 0.5 Cmols kg $^{-1}$ in Jur River (Udichi). Udichi had significantly lower potassium levels than all the sites except Mading-Achueng (Table 18).

Gogrial West had significantly higher Ca than all other locations. While Jur River (Udichi) had significantly the lowest Ca content, there were no significant differences in Ca content among Mading-Achueng, Basellia and Wunpeth sites. Calcium content ranged from 0.7 Cmol kg $^{-1}$ in Jur River (Udichi) to 2.5 Cmol kg $^{-1}$ in Gogrial West. Gogrial West had significantly higher P than all other locations. No significant differences in P were noted among Basellia, Udichi, Mading-Achueng and Wunpeth. Phosphorous levels ranged from 10.8ppm to 28.5 ppm.

Table 18. Mean averages for %OC, %T.N, available P (ppm), K^+, Na^+, Ca^+ and Mg^+ ($Cmoleskg^{-1}$) in selected states of Greater Bahr el Ghazal

Location	pH	OC	TN	K	Na	Ca	Mg	P
		%		Cmol kg $^{-1}$				
Basselia	6.7a	2.9bc	0.13ab	1.2cd	0.6a	1.4b	0.8ab	13.5a
Udichi	6.7a	1.9ab	0.08a	0.5a	0.6a	0.7a	0.6a	15.1a
Gogrial West	6.1a	3.4c	0.19b	1.7d	0.7a	2.5c	1.4c	28.5b
Mading-Achueng	7.0a	0.8a	0.08a	0.7ab	0.75a	1.5b	1.2bc	10.8a
Wunpeeth	7.2a	1.0a	0.07a	1.1bc	0.6a	1.6b	1.0ab	15.9a
Mean	**6.8**	**1.98**	**0.109**	**1.03**	**0.631**	**1.538**	**0.99**	**16.74**
P -value	0.536	0.011	0.038	0.004	0.803	0.001	0.016	<. 001
LSD 0.05	1.489	1.42	0.0771	0.4756	0.415	0.5415	0.427	5.864
CV%	11.7	37.9	37.7	24.5	34.9	18.7	22.9	18.6

Key:
OC – Organic Carbon
TN – Total Nitrogen

CHAPTER FIVE: DISCUSSION

5.1 Demographic characteristics and gain yield of sorghum and groundnut crops

The geographical location (state, county and location/village) in which farming activities occurred had high influence on cropping systems and ultimate grain yield of sorghum and groundnut crops in the selected sites (Special report, FAO/WFP, 2018, p. 19). According to this study, many farmers in Warrap and Western Bahr el Ghazal have adopted sorghum-groundnut cropping system while the majority of farmers in Abyei area practiced sorghum-sesame cropping system. This depends on soil types in a given geographical location. Many farmers in Abyei grow sorghum and sesame because many parts of Abyei are predominantly clay unlike soils in Warrap and Western Bahr el Ghazal. However, this is a phenomenon that is yet to be corroborated since there is no baseline information at the moment on classification of soils of South Sudan. It's also worth mentioning that during the study, it is observed that women participation in farming activities in the selected survey areas was very significantSixty per cent of respondents in the survey were females while forty per cent were males.(Adeniyi, 2010, p. 5)..

5.2 Effect of cropping systems and farm practices on grain yield of sorghum and groundnut crops.

The sorghum and groundnut yields obtained under sorghum-groundnut cropping system were more than yields obtained under monoculture of each crop (Langat et al., 2006, p. 87, Chaudhari et al., 2017). Application of animal/farmyard manure had improved grain yield of sorghum and groundnut cops in Greater Bahr el ghazal region (Okello et al., 2010). However, there was negative correlation between the cropping system, ploughing before planting and groundnut yields. This can be attributed to the fact that when farmers plant groundnut before proper ploughing of the land, the sub-layers of the soil become hard for groundnut pegging process and pod development (Okello et al., 2010, Ajeigbe 2014). Negative correlation was also observed between crop yields and onset of rains and dry spell. This may be attributed to late onset of rains in some seasons which negatively affected grain sorghum and groundnut yields (Okello et al., 2010, Amelework 2016).

5.3 Effect of biotic and abiotic factors on ultimate grain yields of sorghum and groundnut crops.

Observations were made during the survey on incidence of pests, diseases and weeds. Pests of sorghum that were observed in the study areas included cut worms *(Agrotis sp.),* corn aphids (*Rhopalosiphum maidis*), Ruthergien bug *(Nysius vinitor),* sorghum shoot fly (*Atherigona soccata),* stem borers (*Chilo partellus* and birds. Prevalence of grasshoppers was high in Gogrial West. Termites were observed in all surveyed locations of Gogrial West, Jur River and Wau. Sorghum bug was more prevalent in Gogrial West than in Wau and Jur River. Destruction of crops by domestic animals was also high in Gogrial West. Insect pests and the parasitic weed *Striga hermonthica* were also identified as the most severe constraints by 57% and 55% of the interviewed farmers (Amelework 2016, p. 214), Wortmann et al. (2006) indicated that drought, poor soil fertility, striga and stalk borer were the most severe yield-reducing constraints in the eastern parts of Africa. Diseases include sorghum leaf rust *(P.purpurea),* Downy mildew caused by fungi *(perenosclerospora sorghi)* and sorghum head smut (caused by fungi *Sphacelotheca*).

Powdery mildew was also common in Gogrial West. Striga weed was more common in Gogrial West.

Common pests of groundnut included squirrels, millipedes *(Diplopoda)* and Oriental armyworm (*Mythimna separate).* Observed diseases were groundnut early leaf spot caused by *Cercospora arachidicola*, late leaf spot caused by *Cercosporidium personatum*and groundnut rosette virus. Because they occur frequently all over the world, early leaf spot (caused by *Cercospora arachidicola*) and late leaf spot (caused by *Cercosporidium personatum*) are generally regarded as the most important diseases of peanuts. (Bellgard, 2004). Groundnut rosette virus disease (GRVD) is the most devastative disease of groundnut in Uganda (Mugisha et al., 2015). Common weeds included thatch grass or jaragua grass *(Hyparrhenia rufa),* tropical spider wort *(Camelina benghalensis),* and spear grass *(Heteropogon contortus).*Based on the results analysis, biotic factors like pests, diseases and weeds did not have significant influence on ultimate grain yields of sorghum and groundnut crops (table 7c). With these results we partly reject the research hypothesis in favor of null hypothesis that "a choice of cropping system, coupled with biotic factors does (weeds, pests and diseases) does not have significant influence on ultimate yields of grain sorghum and groundnut". However, in regards to cropping system, we accept the research hypothesis that "cropping system, coupled with abiotic factors (soil nutrients) has significant influence on ultimate grain sorghum and groundnut yield. The relationship between sorghum/groundnut yields and per cent organic carbon, potassium and per cent total nitrogen were positive.. An increase in nitrogen, phosphorous and potassium levels in the soil resulted to proportional increase in sorghum yields. However, looking at the soil reference values in relation to values obtained for each nutrient during analysis, there were deficiencies in per cent organic carbon, per cent total nitrogen and potassium in most selected parts but only phosphorous levels were adequate in most areas. Degraded soils are characterised by low fertility, associated with low levels of organic matter and nitrogen: total SOC in the upper 100 cm of dryland soils amounts to about 40 t ha-1 (Corsi et al., 2012). Nutrient deficiencies generally cause stunted growth, chlorosis, interveinal chlorosis, purplish-red coloring and necrosis (Ann McCauley, 2011, p. 4). Nutrient deficiencies impact plant growth and development negatively which eventually lead to low yields.

5.4 Extension services

Extension services delivery and seed types had high positive correlations with grain yields of sorghum and groundnut crops. Seeds distribution by Food and Agriculture Organization (FAO) and other humanitarian agencies accompanied by training support positively impacted farmers' performance as well as crop yields.

CHAPTER SIX: CONCLUSION AND RECOMMENDATIONS

6.1. Conclusion

This study has addressed the set objectives. The first objective was to identify common pests, diseases and weeds in the sorghum – groundnut cropping system. However, the results of one way analysis of variance (ANOVA),showed negative relationships between sorghum yields and abiotic factors (weeds, pests and diseases)

Linking the results to second objective of determining the influence of sorghum – groundnut cropping system, biotic and abiotic factors on yields of sorghum and groundnut crops., mean yields of up to 1.52t/ha for sorghum and 0.841t/ha for groundnut were recorded under sorghum/groundnut intercrop. These yields were significantly higher than yields recorded for the same crops under sole cropping system in South Sudan. The effect of cropping system on yields of sorghum and groundnut was statistically significant at 0.01 level, $p<0.0001$. The sorghum and groundnut yields obtained under sorghum-groundnut cropping system were more than yields obtained under monoculture of each crop.

The third objective of the study was to assess the levels of soil pH, percentage organic carbon, and plant nutrients (N.P.K) and how they contribute to ultimate yield of sorghum and groundnut crops in selected sites. It was observed that an increase in nitrogen, phosphorous and potassium levels in the soil resulted to proportional increase in sorghum yields. However, there were deficiencies in per cent organic carbon, per cent total nitrogen and potassium in all surveyed areas (table 14), but phosphorous levels were adequate in most areas.

6.2. Recommendations

Based on the results of this study, the gap areas that need to be addressed by future research are:

(i) Strengthening of agricultural extension services by government with more farmer tailored training on integrated pests and production management (IPPM) practices.

(ii) Sensitization of farmers and promotion of sorghum – groundnut intercropping system or sorghum – sesame intercropping system in clay soil areas and more training on the benefits of increased yields and pests reduction under intercropping.

(iii) Farmer sensitization and more training on soil management practices including intensive training on agroforestry systems

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APENDICES

Appendix 1: Summary of crop yield data

Area/Location	**Yield of Sorghum (Pure stand)**		**Yield of G/nut (pure stand)**		**Yield of Sorghum in Sorghum/nut intercrop**		**Yield of groundnut in Sorghum Groundnut intercrop**	
	# of feddans	**t/ha**	**# of feddans**	**t/ha**	**# of feddans**	**t/ha**	**# of feddans**	**t/ha**
Warrap (Gogrial West)	1	0.3	1.5	0.5	4.8	1.9	1.5	0.05
WBG (Jur River)	3.1	0.8	2.7	0.6	2.7	0.4	0.6	0.02
WBG (Wau)	1.7	0.6	1.4	0.6	3	1.2	1.3	0.1
WBG (Raga)	2.6	1.8	3	2.9	3.3	3.4	2.0	0.04
Average	**2.1**	**0.9**	**2.2**	**1.2**	**3.5**	**1.7**	**1.4**	**0.05**

Appendix 2: Soil sample data

				cmol/kg				ppm
Sample description	pH	% Organic carbon	%Total.Nitrogen	K	Na	Ca	Mg	P
Udichi s2	6.87	1.09	0.04	0.3	0.44	0.55	0.39	17.25
Udichi s1	6.51	1.36	0.07	0.35	0.70	0.55	0.43	15.5
Udichi s3	6.85	3.19	0.14	1	0.53	1.60	0.95	7.5
Gogial S1	5.4	4.36	0.25	1.5	0.55	2.50	1.20	35
Gogial S3	4.88	3.04	0.17	4.5	1.01	2.00	1.43	274.25
Gogial S2	8.05	2.73	0.14	0.7	0.48	5.00	2.10	19.25
Bassalia S1	6.37	3.04	0.12	1.1	0.48	1.10	0.79	14
Bassalia S2	7.04	3.04	0.13	1	0.46	1.60	0.80	11.25
Bassalia S3	6.75	2.57	0.13	1.6	0.86	1.50	0.85	23.25
Abyei-Mading achueg S3	6.77	1.48	0.07	0.7	0.53	2.40	1.71	11.25
Abyei-Mading achueg S2	6.86	0.78	0.65	0.45	0.92	1.50	1.05	6.75
Abyei-Mading achueg S1	7.42	0.16	0.06	1.8	0.79	1.00	0.71	11.25
Abyei-Unpeeth S1	7.58	1.05	0.08	0.35	0.70	1.40	0.65	7.80

Abyei-Unpeeth S2	7.18	1.01	0.09	1.3	0.57	1.70	1.05	15.5
Abyei-Unpeeth S3	6.9	0.86	0.04	1	0.44	1.70	1.21	17.25

Source: University of Nairobi soil science laboratory

Appendix 3. Soil nutrients critical levels

Nutrient	Low		Adequate		High	
Nitrogen %	<0.2		0.2-0.4		>0.4	
Phosphorus ppm	<10		10-35		>35	
Potassium cmol/kg	<0.5		0.5-0.8		>2.0	
Calcium cmol/kg	<1		1-3.0		>5.0	
Magnesium cmol/kg	0.5		0.5-1.5		>1.5	
Sodium cmol/kg			>2 toxic			
Organic carbon %			>4.0%			
Soil reaction pH	>5.5	5.5-6.5	6.5-7	7-7.5	7.5-8.5	>8.5
	Acidic	Moderate acidic	Slightly acidic	Slightly alkaline	Moderate alkaline	Alkaline

Source: University of Nairobi soil science laboratory

Appendix 4 a. Rainfall data for Wau (mm)

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	Total
2010	20.2	21.5	22.7	25.9	23.8	22.8	22.0	21.7	21.7	21.9	22.5	20.5	**267.2**
2011	19.4	21.6	23.1	25.3	24.3	23.1	21.7	21.8	21.8	22.1	23.0	21.1	**268.3**
2012	18.7	19.5	24.1	24.2	23.1	22.2	21.5	22.1	21.3	22.4	91.6	19.8	**330.5**
2013	20.8	22.7	25.0	25.3	23.0	22.3	21.3	20.3	21.0	33.0	20.9	17.5	**273.4**
2014	18.8	20.1	21.8	21.0	21.8	19.2	21.4	19.7	20.1	21.0	20.9	17.8	**243.6**
2015	16.5	20.5	22.8	22.6	22.0	21.3	20.8	20.6	18.4	20.4	19.8	17.9	**227.1**

Appendix 4 b. Rainfall data for Raga (mm)

RAGA MONTHLY RAINFALL FOR (2010-2015)

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	Total
2010	0	0.0	12.7	61.5	104.8	129.7	226.3	228.1	171.3	79.9	6.7	0.0	**981.3**
2011	0	0	0	69.4	228	98.8	216.7	264.4	170.9	79.8	6.6	0	**1,134.6**
2012	0	0	0	38.9	66.7	278.9	76	239.6	291.7	47.8	0	0	**1,039.6**
2013	0	0	1	5	202	211.2	249.2	293.8	302.6	47.9	0	0	**1,312.7**
2014	0.1	0	12	106.8	260.1	164	141.3	431	349	92	0	0	**1,556.3**
2015	0	0	50.6	0	211	160.1	97.5	140.7	139.1	228	0	12	**1,039**

Appendix 5. Multiple Comparisons

LSD							
Dependent Variable	(I) Cropping system	(J) Cropping system	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
Yield in kg sorghum	Sorghum -groundnut	Sorghum -sesame	.12210	.31530	.699	-.5005	.7447
		Sorghum monocrop	.92657*	.41262	.026	.1118	1.7413
		groundnut monocrop	-4.84615*	.51085	.000	-5.8549	-3.8374
		Other (Both sorghum & groundnut monocrops or mixture of all including cowpeas, cassava, millet etc)	.37260	.36911	.314	-.3563	1.1014
	Sorghum -sesame	Sorghum -groundnut	-.12210	.31530	.699	-.7447	.5005
		sorghum monocrop	.80447*	.38323	.037	.0477	1.5612
		groundnut monocrop	-4.96825*	.48742	.000	-5.9307	-4.0058
		other (Both sorghum & groundnut monocrops or mixture of all including cowpeas, cassava, millet etc)	.25050	.33593	.457	-.4128	.9138
	Sorghum monocrop	Sorghum -groundnut	-.92657*	.41262	.026	-1.7413	-.1118
		Sorghum -sesame	-.80447*	.38323	.037	-1.5612	-.0477
		groundnut monocrop	-5.77273*	.55535	.000	-6.8693	-4.6761

		Other (Both sorghum & groundnut monocrops or mixture of all including cowpeas, cassava, millet etc)	-.55398	.42859	.198	-1.4003	.2923
	Groundnut monocrop	Sorghum -groundnut	4.84615*	.51085	.000	3.8374	5.8549
		Sorghum -sesame	4.96825*	.48742	.000	4.0058	5.9307
		Sorghum monocrop	5.77273*	.55535	.000	4.6761	6.8693
		other (Both sorghum & groundnut monocrops or mixture of all including cowpeas, cassava, millet etc)	5.21875*	.52383	.000	4.1844	6.2531
	Other (Both sorghum & groundnut monocrops or mixture of all including cowpeas, cassava, millet etc)	Sorghum -groundnut	-.37260	.36911	.314	-1.1014	.3563
		Sorghum -sesame	-.25050	.33593	.457	-.9138	.4128
		Sorghum monocrop	.55398	.42859	.198	-.2923	1.4003
		groundnut monocrop	-5.21875*	.52383	.000	-6.2531	-4.1844
Yield in kg groundnut	Sorghum -groundnut	Sorghum -sesame	-2.77045*	.50763	.000	-3.7728	-1.7681
		Sorghum monocrop	-2.89744*	.66431	.000	-4.2092	-1.5857
		groundnut monocrop	2.85256*	.82246	.001	1.2285	4.4766
		other (Both sorghum & groundnut monocrops or mixture of all including cowpeas, cassava, millet etc)	3.13381*	.59426	.000	1.9604	4.3072
	Sorghum -sesame	Sorghum -groundnut	2.77045*	.50763	.000	1.7681	3.7728
		Sorghum monocrop	-.12698	.61699	.837	-1.3453	1.0913
		groundnut monocrop	5.62302*	.78473	.000	4.0735	7.1726

		other (Both sorghum & groundnut monocrops or mixture of all including cowpeas, cassava, millet etc)	5.90427*	.54084	.000	4.8363	6.9722
	Sorghum monocrop	Sorghum -groundnut	2.89744*	.66431	.000	1.5857	4.2092
		Sorghum -sesame	.12698	.61699	.837	-1.0913	1.3453
		groundnut monocrop	5.75000*	.89411	.000	3.9845	7.5155
		other (Both sorghum & groundnut monocrops or mixture of all including cowpeas, cassava, millet etc)	6.03125*	.69002	.000	4.6687	7.3938
	Groundnut monocrop	Sorghum -groundnut	-2.85256*	.82246	.001	-4.4766	-1.2285
		Sorghum -sesame	-5.62302*	.78473	.000	-7.1726	-4.0735
		Sorghum monocrop	-5.75000*	.89411	.000	-7.5155	-3.9845
		other (Both sorghum & groundnut monocrops or mixture of all including cowpeas, cassava, millet etc)	.28125	.84336	.739	-1.3841	1.9466
	Other (Both sorghum & groundnut monocrops or mixture of all including cowpeas, cassava, millet etc)	Sorghum -groundnut	-3.13381*	.59426	.000	-4.3072	-1.9604
		Sorghum -sesame	-5.90427*	.54084	.000	-6.9722	-4.8363
		Sorghum monocrop	-6.03125*	.69002	.000	-7.3938	-4.6687
		groundnut monocrop	-.28125	.84336	.739	-1.9466	1.3841

*. The mean difference is significant at the 0.05 level.

Appendix 5. Questionnaire (Survey data collection tool)

COMPLETE BEFORE THE INTERVIEW	
Date	|____||____|/|____||____|/2015Day Month
Interviewer name	
State Code:	|_____|_____|
County Code:	|_____|_____|
Village/Location	
Cluster Number	|_____|_____|
Household	|_____|_____|

INTRODUCTION
First of all, inform and ask for households consent We are conducting a survey on the effect of cropping systems on sorghum and groundnut yields in South Sudan. I would like to ask you some questions about your farm activities. The survey usually takes 30 minutes to complete. Any information that you provide will be kept strictly confidential and will not be shown to other people. The outcome of this information is NOT IN ANY WAY linked to a food response. It is to enable the researcher to obtain a relevant data that may eventually lead to a valid information on existing cropping adopted by rural households in South Sudan, how these systems and farming practices ultimately affect crop yield and the household food security in general This is voluntary and you can choose not to answer any or all of the questions if you want; however we hope that you will participate since your views are important. Do you have any questions? May I begin now?

1. DEMOGRAPHICS				Female	
1.1	What is the sex of the	Male			
1.2	What is the sex of the	Male		Female	
1.3	What is the age of the	1 = (< 17	2 = (18-60yrs)		3 = (>60 yrs)

2. LAND PREPARATION			
2.1	Did you prepare any land for planting last year?	Yes |_____|	No |_____|
a)	If yes, how many feddans did you prepare?	Specify here the number of feddans you had prepared for planting ………………………………………………	
2.2	Did you plough before planting?	Yes |_____|	No |_____|
a)	If yes, how many times have you ploughed	Specify here the number of times you have ploughed the land |_____|	|_____|
2.3	What tools did you use to plough? (Tick as appropriate)	Hand hoe |_____| Ox-plough |_____| Others, specify |_____|	

3. TIME OF PLANTING			
3.1	When (which month) did you start to plant last year?	Yes |_____|	No |_____|
3.2	When (which month) did rains start?	Specify here the number of feddans you had prepared for planting |_____|	
a)	What do you think about onset of rains last year?	Early |_____|	Late |_____|
b)	Was there any dry spell?	Yes |_____|	No |_____|
c)	If yes, how has this affected sorghum and groundnut yields in your farm	Low harvest |_____| High harvest |_____| Normal |_____| Other specify |_____|	
3.3	Did you plant in rows?	Yes |_____|	No |_____|
4. MANURE/FERTILIZER USE, SEED RATE, SEED TYPES AND SOURCES			
4.1	Did you apply animal manure last year during planting?	Yes |_____|	No |_____|
4.2	Did you apply any fertilizer?	Yes |_____|	No |_____|
a)	If yes, what type of fertilizer did you use?	Specify |_____|	
b)	Where did you get the fertilizer?	Market |_____| NGO |_____| Friend |_____| Other |_____|	
4.3	a) In the area planted last year, how malwas of sorghum seeds did you plant?	|_____|	
	b) How many malwas of groundnut seeds did you plant?	|_____|	

4.4	Where did you get the seeds last year?	Market |_____| NGO |_____| Friend |_____| Own seeds |_____| Other specify |_____|

5.1 Land preparation and planting			
5.1.1	Did you prepare any land for planting last year?	Yes |_____|	No |_____|
a)	If yes, how many feddans did you prepare?	Specify here the number of feddans you had prepared for planting ………………………………………………………	
5.1.2	Did you plough before planting?	Yes |_____|	No |_____|
a)	If yes, how many times have you ploughed	Specify here the number of times you have ploughed the land |_____|	|_____|
5.2	**Crop pests and diseases**		
5.2.1	What type of crop pest and disease did you notice in your crop field last year?		
5.2.2	What control measures did you use for both pests and diseases?		
5.2.3	What effect did pest and disease have on your crop harvest?		
5.3	**Weeds**		
5.3.1	What types of weeds have you observed in your crop field last year?		
5.3.2	How did weeds affect your final harvest?		

5.3.3	How many times did you weed your field last year?	

6. AVAILABLE AGRICULTURAL EXTENSION SERVICES			
6.1	Did you have any agricultural advisory services last year?	Yes |_____|	No |_____|
6.1.1	If yes, who delivered the services?	Government |_____| NGO |_____| Private extension services |_____| Other specify |_____|	
6.1.2	What extension advice did you receive?	Crops |_____|	Livestock |_____|

7. CROP PRODUCTION AND HARVEST				
2.1	What did you plant last year? (Tick as appropriate)	Yes |_____|		No |_____|
			Yield obtained	
	Crop combination	Number of feddans	Malwas (1 malwa = 3.5kg)	Kg
a)	Groundnut + Sorghum |_____|			
b)	Sorghum + Cowpeas |_____|			
c)	Groundnut + Maize |_____|			
d)	Sorghum + Sesame |_____|			
e)	Only groundnut |_____|			
f)	Only sesame |_____|			
g)	Only maize |_____|			
h)	Others (Specify) |_____|			