EVALUATION OF MORINGA OLEIFERA/CASSAVA/MAIZE/SWEET POTATO INTERCROPPING SYSTEMS IN OWERRI HUMID RAIN FOREST ZONE OF SOUTHEASTERN NIGERIA

BY

ESSIEN, BASSEY ARCHIBONG

B.AGRIC (AGRONOMY) UNIUYO, M.Sc. (CROP SCIENCE) UNIUYO

Ph.D/20104772278

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CERTIFICATION

This is to certify that **Essien, Bassey Archibong** of the Department of Crop Science and Technology, School of Agriculture and Agricultural Technology, Federal University of Technology, Owerri, Imo State with Registration number Ph.D/20104772278 carried out this work on Evaluation of Moringa/Cassava/Maize/Sweet potato intercropping systems in Owerri humid rainforest zone of Southeastern Nigeria, and has satisfactorily completed the requirements for the award of Doctor of Philosophy. This work has not been submitted either in part or whole for the award of certificate or degree in this University or any other University.

.... Prof. I.J. OGOKE (Major Supervisor)	24/10/2024 Date
.... Prof. A.A. NGWUTA (Co-Supervisor)	24/10/2024 Date
.... Prof. F.O. OJIAKO (Co-Supervisor)	24/10/2024 Date
.... Prof. (Mrs) C.P. ANYANWU (Head of Department, CST)	24/10/'24 Date
.... Prof. (Mrs) O.P. ONYEWUCHI (Dean, Postgraduate School)	18/11/24 Date
.... Prof. (Mrs) J.N. NWOSU (Dean, Postgraduate School)	.... Date
.... Prof. K.I. UGWUOKE (External Examiner)	.... Date

DEDICATION

This work is dedicated to my amiable wife Dr. (Mrs.) Jane Uchechi B. Essien

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ESSIEN, BASSEY A.

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ABSTRACT

Achieving food security for a rapidly growing population in the Southeastern zone in particular and in Nigeria in general requires not only the intensification of food crop production on the existing cropland but also and most importantly through the use of good and sustainable agronomic practices and cropping systems. In an attempt to achieve this, an experiment was conducted at the Federal University of Technology, Owerri, Teaching and Research farm of the Department of Crop Science and Technology during 2015 and 2016 cropping seasons on the performance of component crops, weed species suppression, soil nutrient status and economic returns. The experimental design used was randomized complete block design (RCBD), with eleven treatments replicated three times. The treatments were: sole moringa (SMo), sole cassava (SCa), sole maize (SMa), sole sweet potato (SSp), moringa + cassava (Mo + Ca), moringa + maize (Mo + Ma), moringa + sweet potato (Mo + Sp), moringa + cassava + maize (Mo + Ca + Ma), moringa + maize + sweet potato (Mo + Ma + Sp), moringa + cassava + sweet potato (Mo + Ca + Sp), and moringa + cassava + maize + sweet potato (Mo + Ca + Ma + Sp). Results obtained showed that in 2015 and 2016 seasons, organic matter and nitrogen were significantly improved with intercropping. However, other fertility indices decreased with intercropping intensification. Results indicated that annual weed species were predominant with 57.39% and perennial weed species accounting for 32.17% of the total weed species composition in the study site. There were observed significant weed flora suppression due to intercropping compared to sole cropping systems. The agronomic parameters including plant height and leaf area of maize were significantly influenced by intercropping and the sampling durations (2, 4, 6, 8, 10 and 12 weeks after planting (WAP)) for both seasons. Sole maize produced the tallest maize plant (129.20 and 123.10cm), and the largest leaf area (441.75 and 418.60cm^2) in both cropping seasons. Similarly, maize grain yield was significantly ($P \geq 0.05$) influenced by intercropping and sampling periods and sole maize produced the highest grain yield (2.34 and 2.45t/ha) in 2015 and 2016 cropping seasons, respectively. Treatment and sampling period effects on cassava yield were statistically significant ($P \geq 0.05$). Sole cassava system produced the highest cassava storage roots (33.60 and 35.97t/ha) in 2015 and 2016 cropping seasons, respectively. As well as in dry matter accumulation (84.23%) in 2015. However, mo + ca system produced the highest dry matter accumulation of 89.07% in 2016. Both the growth performances and yield of sweet potato were significantly influenced by intercropping and the sampling periods. Sole cropping system consistently showed higher values of growth parameters and yield components for both seasons. However, in 2015, dry matter accumulation (DMC) was highest in mo + ma + sp combination. Also, the growth parameters and yield of moringa were significantly ($P \geq 0.05$) influenced by intercropping. The tallest plant (282.60cm and 324.80cm) and the highest number of branches for both seasons were produced by the sole moringa system at 10MAP. Also, the highest number of seeds (15.30 and 15.90), fresh leaf yield (18.67 and 16.05t/ha) and seed yield (1.04 and 1.08t/ha), respectively in 215 and 2016 seasons respectively were produced by sole moringa system but the highest number of seeds was produced in mo + ma + sp intercropping systems. However, the dry leaf yield was highest (3.33t/ha and 3.43t/ha) in mo + ma intercropping systems. The economic return to management, cost-benefit ratio and land equivalent ratio in the system (5.59, 2.95, 3.07, 2.78 and 4.99, 2.84, 2.10, 2.77) for 2015 and 2016 seasons indicated that intercropping had comparative advantage over sole cropping. Therefore, intercropping using better and appropriate crop combinations has proved profitable both in economic returns and land equivalent ratio to farmers in the study area and thus, farmers should adopt the moringa/cassava/maize/sweet potato intercropping system.

Keywords: Moringa, Cassava, Maize, Sweet potato, Intercropping, Humid Rain, Forest

CHAPTER ONE

INTRODUCTION

1.1 **Background of the Study**

Agricultural production in the humid rain forest zone as in many other zones in Nigeria, is dominated by subsistence farming which is basically tilted towards multiple/mixed cropping or rotational system (Chiaka, Zhen, Yunfeng, Xiao & Leng, 2022). In northern Nigeria, the mixtures are mostly sorghum/millet/cowpea, sorghum/millet, sorghum/groundnut, sorghum/millet/groundnuts and sorghum/cowpea. Others especially in Southern Nigeria, are cassava/maize/cowpea, cassava/maize/yam, yam/maize/cowpea, cassava/melon/vegetables and sorghum/millet/cowpea/okra/maize/benniseed/roselle (Muhamman & Gungula, 2006), as well as yam/cassava, yam/cassava/maize, yam/cassava/okra, yam/cassava/pepper, yam/fluted pumpkin, yam/maize/melon, yam/maize/cassava/melon/pepper. The cropping system in Southern Nigeria is yam or cassava based (Ibeawuchi & Ofoh, 2000, Amaefula, Farquhharsan, Ramidan & Asumugha, 2018), which could be in mixtures with maize and cocoyam and interspersed with tree crops such as oil palm, orange and mango trees (Galhena, Freed & Maredia, 2013).

The intensive crop production by farmers in Nigeria has impinged on land availability with attendant soil degradation, loss of fertility as a result of shorter or absence of fallow periods (Kopittke, 2019). Subsistence farmers therefore, depend mostly on intercropping as a means of crop and soil fertility management to augment dietary and cash requirements as well as benefiting from various advantages of intercropping such as better utilization of environmental resources, greater yield stability, variability of food supply and insurance against crop failure among others (Vanlauwa, Coe & Giller, 2017).

The reduction in crop residues to the soil is the main reason for traditional bush fallow systems, which accumulate nutrients, increase organic matter and improves soil structure. However, the ineffectiveness of this system in restoring soil fertility is attributable to short periods of fallow systems (Franke, van den Brand, Vanlauwe & Giller, 2018). The use of chemical fertilizers alone to sustain high crop yield has not been successful due to increase soil acidity and soil degradation. Studies have shown that the recycling of trees/shrubs into arable cropping systems do not only improve the balance in the agro-ecosystem but also enhance organic matter accumulation thereby increasing the efficiency of nutrient cycle in intercropping systems (Agrawal et al, 2013, Nwokoro et al., 2022). The techniques used by the farmer to maintain soil fertility and weed control, tend to enhance organic matter content, increase the efficiency of nutrients to cropland by closing the nutrient cycle. This is achieved through returning the exported nutrients to cropland thereby minimizing nutrient loss from the agro-ecosystem (Nwokoro et al., 2022).

Moringa *(Moringa oleifera* Lam), is one of the most useful 'multi-purpose' plants known to man with virtually every part of the tree beneficial in some way to both rural and urban dwellers who depend on it for their livelihood (Ojiako, Adikuru & Emenyonu, 2011). Moringa plant has been considered as having high potential for the development of agricultural-based cropping systems as environmentally-friendly crop fertilizer, thereby reducing the need for chemical fertilizers and all that goes along with using them on crops (Thomas, 2011). Studies on the development of fertilizers from maize cob and *Moringa oleifera* seed cake, rather than using chemical based fertilizer, indicated a generous 30 to 40 percent cost reduction by using the plant-based fertilizers rather than chemical fertilizers (Trigo, Castello, Ortola, Garcia-Mares & Desamparados, 2021). Studies have also shown that the new plant-based fertilizers will be more readily available, sustainable, reduce production cost and will be less detrimental to the health of the soil (Masih, Singh, Elamathi, Anandhi & Abraham, 2019). Moringa extracts in 80% ethanol serves as an effective plant growth hormone (Foidl *et al*, 2001) capable of increasing yields by 25-30% in several crops like maize, soybean, sorghum, tea and melon (Rahman & Basra, 2010).

There is evidence that the cultivation of *M. oleifera* tree on cropping systems in India dates thousands of years ago and has been grown in home gardens and as living fences in Thailand to improve soil physical and chemical properties thereby increasing crop yield (Ranjangam, Azahkia-Manavalan, Thangaraji, Vijayakumar & Muthukrishar, 2001, Ajayi, Milliams, Famuyide & Adebayo, 2013). Moringa has been considered as a suseful plant with high potentials for the development of agricultural based cropping systems, with the capacity to alleviate poverty, improve nutrition of the rural dwellers (Essien, Essien, Nwite & Agunnannah, 2014). Moringa is also reported as being actively cultivated by the World

Vegetable Centre in Taiwan, a Centre for vegetable research, with a mission to reducing poverty and malnutrition in developing countries through improved production and consumption of vegetables (Agbogidi, Eruotor & Ohwo, 2010).

Growing a high calorie food crop such as cassava, maize and sweet potato with a vegetable crop like *Moringa oleifera* would ensure the supply of dietary carbohydrate, vitamins and minerals of the rural populace. The need to improve crop yield and soil fertility to support the rapid growing population has led to a renewed interest in the use of moringa in intercropping system for soil nutrient management and productivity and to sustain food security to meet the present population expansion. The integration of Moringa (*Moringa oleifera*) as a tree crop in cropping system will be the most promising strategy to increase sustainable food production and at the same time restore degraded farmlands in tropical areas especially in the humid rain forest zone of southeastern Nigeria.

1.2 **Statement of Problem**

Intercropping has been an important production practice in many parts of the world and it continues to be an important farming practice in developing countries. Despite its potential and multiple advantages, mainstream agronomic research has largely focused on monocrop systems, with little interest in ecological interactions between species in intercropping systems (Malezieux et al, 2009). Although intercropping has been traditionally practiced for thousands of years and is widespread in many parts of the world, it is still poorly understood from an agronomic perspective and research, due to the wide use of pure crop cultures in the developed world, the relative lack of resources in the developing world, and the complexity of the problems involved in terms of crop compatibility, different crop growth requirement, maintenance etc. Thus, more research is needed to better understanding how intercrops function and to develop intercropping systems that are compatible with current farming systems. It has been emphasized already that for an intercrop combination to be biologically sound and advantageous, the mixture components need to be chosen with care. Moreover, the intensive and continuous cultivation as practiced by farmers in South-eastern Nigeria has caused significant decline in soil pH, exchangeable calcium and magnesium levels, loss of soil organic matter (SOM) leading to poor soil structure, soil degradation, loss of ecosystem services and general loss of farmland due to loss of fertility as a result of shorter or absence of fallow period (Ijoyah, Bwala & Iheadindueme, 2012). Little or no research has been done on moringa based cropping systems in the humid rainforest zone of Southeastern Nigeria.

1.3 **Objective of the Study**

The broad objective of the study is evaluation of Moringa/Cassava/Maize/Sweet potato intercropping systems in Owerri Humid Rain Forest Zone of Southeastern Nigeria.

The specific objectives were to:

i. evaluate the effect of intercropping on the performance of Moringa.
ii. assess the effect of intercropping on the performance of component crops
iii. ascertain the potentiality of the system to suppress weeds
iv. determine the effect of intercropping system on the soil nutrient status
v. evaluate the cost of production and economic returns as influenced by different intercropping.
vi. determine the effect of intercropping on soil microbial population.

1.4 **Justification of the Study**

Agricultural diversification is useful for agronomic, environmental, and dietary reasons. Here, field experiment confirm that the simultaneous cultivation of two or more crop species in the same plot (intercropping) leads to substantial land savings over single crops when the objective is to produce a diversified set of crop products and soil fertility sustainability. In addition, it provides further ecological services. Intercropping thus has the potential to diversify crop production and make cropping systems more sustainable.

Moringa is one of the world's most useful multipurpose plants considered as having high potential for the development of agricultural – based cropping systems as environmentally-friendly plant. It is a fast – growing tree, grown for food, feed, medicine and industrial use. There is evidence that the cultivation of moringa tree in cropping system improves soil physical and chemical properties thereby increasing crop yield, ensuring the supply of dietary carbohydrate, vitamins and minerals for the populace.

The multiple uses and potential of Moringa oliefera have attracted the attention of researchers in recent times. Although the plant is not completely strange in Nigeria, it has been grossly underexploited as it is restricted to northern region where it is used as mainly as live fence and as vegetable salad. The preliminary investigation showed that the plant grow fast, has potentially high biomass production and exceptional biochemical properties, but there has been no systematic attempt to exploit Moringa oleifera either in term of its agronomic or cropping system. Moringa oleifera, because of its socio-economic and cultural importance, is raising a growing interest among researchers, NGOs, scientists, public and private sectors. But then, it is imperative to note that while a number of studies have been carried out on the origin, morphology, chemistry and nutritive attributes of moringa, little or no efforts has been made to unearth the prevailing profitability of growing of the crop amogst its custodian. While research on cropping systems of moringa could lead to invention or new discovery, investigation on its prevailing profitability in cropping system could accelerate the cultivation of the crop and enhance sustainable development, most expecially among rural farming families.

Improving land for sustainable productivity and weeds suppression requires system that will not be detrimental to life, the land and the environment; and this has led to the renewed interest in the use of moringa in intercropping system. The integration of moringa into the farming system could be beneficial and advantageous to the farmer in terms of increase in crop yield, soil fertility improvement and bio-diverse and sustainable agro-ecosystem. Against this background, there is need to assess the effect of moringa/cassava/maize/sweet potato intercropping systems in Owerri humid rain forest zone of Southeastern Nigeria. The study will generate information on the best moringa crop combinations in the Southeastern Nigeria, provide appropriate cropping system technique, soil fertility status and sustainable environment.

1.4 **Scope of the Study**

The study was delimited to Evaluation of Moringa/Cassava/Maize/Sweet potato Intercropping Systems in Owerri Humid Rain Forest Zone of Southeastern Nigeria. It also focused on how evaluate the effect of intercropping on the performance of Moringa, assess the effect of intercropping on the performance of component crops, ascertain the potentiality of the system to suppress weeds, determine the effect of intercropping system on the soil nutrient status, evaluate the cost of production and economic returns as influenced by different intercropping as well as determine the effect of intercropping on soil microbial population during 2015 and 2016 cropping seasons.

CHAPTER TWO

LITERATURE REVIEW

2.1 **Origin and Distribution of Moringa, Cassava, Maize and Sweet potato**

2.1.1 **Moringa**

Moringa *(Moringa oleifera* Lam) originated from the sub-Himalayan tracts of northern India (Patil et al, 2022). It is believed to have originated from Agra and Oudh in north western region of India to south of the Himalayan mountains (FAO, 2014). *M. oleifera* is also commonly found throughout other parts of India including Punjab plains, Sind, Baluchistan and North West Frontier Province areas in Pakistan. However, it is now widely cultivated throughout the tropical and sub-tropical regions of the world (Patil et al, 2022), as well as large parts of southern and eastern Asia such as Afghanistan, Israel, Iran, Nepal, Bangladesh, China, Taiwan, Sri Lanka, Myanmar, Malaysia, the Philippines, Thailand, Vietnam, Indonesia and Papua New Guinea (Papillo, 2007).

Moringa (*M. oleifera* Lam) is also widely naturalized in some tropical regions of the world including some sub-Saharan African countries like Zimbabwe, Madagascar, Zanzibar, South Africa, Tanzania, Malawi, Benin, Burkina Faso, Cameroon, Chad, Ghana, Guinea, Kenya, Liberia, Mali, Mauritania, Nigeria, Niger, Sierra Leone, Sudan, Ethiopia, Somalia, Zaire, Togo, Uganda and Senegal (Paliwal & Sharma, 2011).

In tropical America, *M. oleifera* is naturalized in south-eastern United States (i.e. Florida), in Caribbean (i.e. Cuba, Haiti, the Dominican Republic, the Bahamas, Jamaica, Puerto Rico and the Virgin Island), Mexico, Central America (i.e. Belize, Costa Rica, El Salvador, Guatemala, Honduras. Nicaragua and Panama) and South America (i.e. Colombia, Guyana, Venezuela, Brazil and Paraguay) (FAOSTAT, 2022). It is also naturalized on several Pacific islands including Kiribati, Guam, the Marshall Islands, the Northern Mariana Islands, the Solomon Islands and the Federated States of Micronesia (Sheldon & Steve, 2010).

2.1.2 **Cassava**

Cassava has its genetic, geographical and agricultural origin in Latin America. Its domestication began 5000 – 7000 years BC in the Amazon, Brazil (Mbanjo et al, 2021) and it was distributed by Europeans to the rest of the world (Sangoyomi & Ayandiji, 2013). Cassava was taken from Brazil to the West coast of Africa by Portuguese navigators in the 16^{th} century (Nweke, Spencer & Lynam, 2002). Cassava was brought to East Africa in the 18^{th} century by the Portuguese from Cape Verde and into Mozambique from Zanzibar Island and was introduced to most of Asia and the Pacific in the late 18^{th} and early 19^{th} centuries (NAERLS, 2010; Onwueme, 2002).

Cassava was unknown to the Old World before the discovery of America. There is archaeological evidence of two major centres of origin for this crop, one in Mexico and Central America and the other in North-eastern Brazil. The first Portuguese settlers found the native Indians in Brazil growing the cassava plant and Pierre Martyr wrote in 1494 that the "poisonous roots" of a yucca were used in the preparation of bread. It is believed that cassava was introduced to the western coast of Africa in about the sixteenth century by slave merchants. The Portuguese brought it later to their stations around the mouth of the Congo River, and it then spread to other areas. In 1854 Livingstone described the preparation of cassava flour in Angola, and subsequently Stanley described its use in the Congo. Cassava cultivation increased after 1850 in the east African territories as a result of the efforts of Europeans and Arabs who were pushing into the interior and who recognized its value as a safeguard against the frequent periods of famine (Sangoyomi et al, 2013).

In the Far East, cassava was not known as a food plant until 1835. In about 1850 it was transported directly from Brazil to Java, Singapore and Malaya. When the more profitable rubber plantations were started on the Malay Peninsula, cassava growing moved to other parts of Indonesia where it flourished. During the period 1919 - 41 about 98 percent of all cassava flour was produced in Java, but during the Second World War; Brazil increased and improved its production. Now grown throughout the tropical world, cassava is second only to the sweet potato as the most important starchy root crop of the tropics. Cassava was introduced to Africa by Portuguese traders from Brazil in the 16th century. Maize and cassava are now important staple foods, replacing native African crops (Wossen et al, 2023).

2.1.3 **Maize**

Maize is perhaps the most completely domesticated of all the field crops. Wild maize has not been found to date, and there has been much speculation on its origin. There are a number of theories regarding the origin of maize, but it seems most probable that it originated at least 5000 years ago in the highlands of Mexico or central America, because this area is considered to be the home of teosinte grass (*Euchlaena mexicana*, Schrad), a near relative of maize, which shows a wide range density of native forms and types in this area (Iken & Amusa 2014).

Probably the first European to see and describe maize was Christopher Columbus. It is most likely that Columbus or some of his contemporaries were the first to introduce maize from Central America to Spain and Portugal. Once established in these two European countries, its passage to the African continent was simply a matter of time and with the Portuguese, its transfer to Asia can be easily envisaged.

There have been four principal and several minor theories regarding the origin of maize: (1) the cultivated maize originated from pod corn, a form in which the individual kernels are enclosed in floral brackets as they are in other cereals and in the majority of grasses; (2) that maize originated from its closest relative, teosinte, by direct selection, by mutations, or by hybridization of teosinte with an unknown grass now extinct; (3) that maize teosinte, *Tripsaaum* have descended along independent lines directly from a common ancestor; (4) the tripartite theory of Mangelsdorf and Reeves (1945) that (a) cultivated maize originated from pod corn (b) teosinte a derivative of a hybrid of maize and *Tripsacum*, (c) the majority of modern maize varieties are the product of admixture with teosinte or *Pripsaaum* or both.

Other hypotheses called “minor" in the sense that they have had little effect upon the thinking and experimentation concerned with the origin of maize are: (1) that cultivated maize originated from papyrescent corn, a type superficially resembling a weak form of pod corn; (2) that maize is an allopolyploid hybrid originating in South-East Asia by the hybridization of two ten-chromosome species such as *Coix* and Sorghum. Despite these theories the origin of maize remains speculative and controversial as none of the theories is entirely satisfactory (Olasehinde et al, 2023).

2.1.4 **Sweet potato**

The Sweet potato (*Ipomoea batatas* (L.) Lam.) (Batatas an Arawak name) was originally domesticated at least 5000 years ago in tropical America (Tai-Hua and Peng-Gao, 2019).

Based on the analysis of key morphological characters of sweet potato and the wild Ipomoea species, Hongnan (2014) postulated that sweet potato originated in the region between the Yucatan Peninsula of Mexico and the Orinoco River in Venezuela. Using molecular markers, the highest diversity was found in Central America, supporting the hypothesis that Central America is the primary centre of diversity and most likely the centre of origin of sweet potato (Huang & Sun, 2000; Zhang et al. 2003). Columbus in 1492 brought it to Europe and Portuguese explorers of the sixteenth century took it to Africa, India, Southeast Asia and the East Indies. Spanish ships brought sweet potatoes from Mexico to the Philippines in the 16th century.

2.2 **Climatic and Soil Requirements of Moringa, Cassava, Maize and Sweet Potato**

2.2.1 **Moringa**

Rainfall**:** Moringa requires a minimum annual rainfall of about 250mm and with maximum at about 3000mm. However, for optimum leaf and pod production. Heuze et al, (2019) reported that well distributed rainfall of 1000-2000mm with high solar radiation is required. It is drought resistant, though in drought conditions it may lose its leaves. This does not mean it is dead and it recovers when the rains arrive (Zaku et al, 2015).

Altitude: Moringa is found between 30^0N and 20^0S of the equator. It grows best at altitudes up to 600m above sea level, although it can grow at altitude of 1000m-2000m above sea level (Nouman et al, 2014).

Temperature**:** Moringa is adapted to the tropical and sub-tropical regions, where leaves and pods production are enhanced. It will survive in a temperature range of 25ºC to 40ºC but has been known to tolerate temperatures of 48ºC and light frosts (Godino et al, 2013, Fuglie, 2005).

Soil**:** Moringa tolerate a wide range of soil types and pH range of 4.5-9.0 (Agoyi *et al*, 2015). According to Agoyi et al (2014), moringa prefers neutral to slightly acidic soils and grows best in well-drained loam to clay-loam soils. It tolerates heavy clay soils but does not grow well if waterlogged, and moringa preferred sandy soils for rooting cuttings (Trigo et al, 2020, Adebayo et al, 2017).

2.2.2 **Cassava**

Rainfall: Cassava can grow best when rainfall is fairly abundant, but it can be grown where the annual rainfall is as low as 500 mm but well-distributed and where it is as high as 5000 mm. The plant can stand prolonged periods of drought in which most other food crops would perish. This makes it valuable in regions where the annual rainfall is low or where seasonal distribution is irregular. In tropical climates, the dry season has about the same effect on cassava that a low temperature has on deciduous perennials in other parts of the world. The period of dormancy lasts two to three months and growth resumes when the rains begin again. It is a valuable crop where rainfall is uncertain. If moisture availability becomes low, the plant will cease to grow and shed some older leaves, reducing the transpiration surface. When moisture is available again, growth is resumed and the plant produces new leaves (Hauser et al, 2014).

Altitude: Cassava can grow well on higher altitude. The highest tuber production can be expected in the tropical lowlands, below an altitude of 150 m above sea level, but some varieties grow at altitudes of up to 1500 m above sea level (Akinwumiju et al, 2020) Cassava is a plant of tropical lowlands. Its cultivation is restricted to regions between the latitudes of 30° north and 30° south. It is most widespread near the equator between 15° north and south since cassava is a short-day plant, the highest yield of roots is in this region.

Temperature: Cassava is a typical tropical plant. For this reason, it is most productive between 15 degrees North and 15 degrees South latitudes. In general, the crop requires a warm, humid climate. Temperature is important, as all growth stops at about 10°C. The crop is typically grown in areas that are frost-free all year round. The highest tuber production can be expected in the tropical lowlands, below an altitude of 150 m, where temperatures average 25°C and 29°C, but some varieties grow at altitudes of up to 1500 m. More than 12 hours of daylight can cause delays in tubering (starch storage) and eventually low yields, while short light periods enhance flowering (Baguma et al, 2023, Daryanto et al, 2016). Cassava finds the most favourable growing conditions in humid-warm climates at temperatures of between 25 - 29°C and precipitations of between 1000 - 1500 mm which ideally should be evenly distributed (Akinwumiju et al, 2020).

Soil: Cassava grows best on light, sandy loams or on loamy soils which are moist, fertile and deep, but it also does well on soils ranging in texture from sands to clays and on soils of relatively low fertility. In practice, it is grown on a wide range of soils, provided the soil texture is friable enough to allow the development of the tubers. Cassava can produce an economic crop on soils depleted by repeated cultivation to the extent that they have become unsuitable for other crops. On very rich soils the plant may produce stems and leaves at the expense of tubers. In some parts of Africa, freshly cleared forest soils are regarded as highly suitable after they have produced a cereal crop (Hauser et al, 2014).

2.2.3 **Maize**

Rainfall: Maize requires a rainfall of 600-1000mm per annum, and cannot withstand drought when fully developed (Kamara et al, 2020). Approximately 10 to 16 kg of grain are produced for every millimetre of water used. A yield of 3152 kg/ha requires between 350 and 450 mm of rain per annum. At maturity, each plant will have used 250L of water in the absence of moisture stress (Sowunmi and Akintola, 2010).

Altitude: Maize has a remarkable adaptability to a wide range of environmental conditions and a wide range of climate. Maize is grown from 48^0N to 40^0S of 400m above sea level (Kamara et al, 2020).

Temperature: Maize is a warm weather crop and is not grown in areas where the mean daily temperature is less than 19^0C or where the mean of the summer months is less than 23^0C. Although the minimum temperature for germination is 10^0C, germination will be faster and less variable at soil temperatures of 16 to 18^0C. At 20 ^{0}C, maize should emerge within five to six days. The critical temperature detrimentally affecting yield is approximately 32^0C. Frost can damage maize at all growth stages and a frost-free period of 120 to 140 days is required to prevent damage. While the growth point is below the soil surface, new leaves will form and frost damage will not be too serious. Leaves of mature plants are easily damaged by frost and grain filling can be adversely affected (Sowunmi & Akintola, 2010).

Soil: The most suitable soil for maize is one with a good effective depth, favourable morphological properties, good internal drainage, and an optimal moisture regime, sufficient and balanced quantities of plant nutrients and chemical properties that are favourable specifically for maize production. Although large-scale maize production takes place on soils with a clay content of less than 10 % (sandy soils) or in excess of 30 % (clay and clay-loam soils), the texture classes between 10 and 30 % have air and moisture regimes that are optimal for healthy maize production (Plessis, 2003).

2.2.4 **Sweet potato**

Rainfall: Sweet potatoes need adequate water at the time of planting and for several weeks thereafter. They can tolerate light drought in the second and third month of growth, and often fairly severe drought in the fourth or fifth month. Temperate zone sweet potatoes are especially sensitive to flooding but many tropical varieties can tolerate short periods (a few days) of flooding. The sweet potato does not withstand drought, rather grows well in region with 750 - 1,250mm of rainfall and long sunny conditions without shade (Chakraborty et al, 2017).

Altitude: The sweet potato is adapted to a wide range of altitude ranging from sea level to 22,500m above sea level (Ikeokwu and Orji, 2022).

Temperature: Sweet potato is a hot weather crop. It is difficult to imagine an earthly environment that is too hot for sweet potato. In general, hot temperatures only speed up the activity and growth of sweet potato. On the other hand, sweet potatoes will survive at any temperature above freezing, and are very productive at temperatures that are comfortable for humans as well. Sweet potato is often said to be a tropical vegetable. Cool conditions such as found in tropical highlands can extend the needed growth period of normal varieties to 8-9 months. Sweet potatoes bloom more freely when days are short and nights long. There is some suggestion that they form tubers more freely at this time as well. However, if temperature and water is adequate, they can produce at any season (FAO, 2014).

Because sweet potatoes are of tropical origin, they adapt well to warm climates and grow best during summer. Sweet potatoes are cold sensitive and should not be planted until all danger of frost is past. The optimum temperature to achieve the best growth of sweet potatoes is between 21^0C and 29^0C, although they can tolerate temperatures as low as 18^0C and as high as 35^0C. Storage roots are sensitive to changes in soil temperature, depending on the stage of root development (FAO, 2014).

Soil: Sweet potatoes require a moist but well drained soil for best growth. Sweet potato prefer sandy loam soils and soils that are not prone to waterlogging. Sweet potatoes produce best in a well-aerated soil with medium texture. In such soils, they need not be planted on ridges. They can be produced in heavy soils formed into ridges for drainage and increased aeration. Sweet potatoes are often grown in sandy soils. The requirements for soil fertility are fairly low, moderate nitrogen, low phosphorous, and high potassium. Too much nitrogen results in abundant foliage and low and /or late yields (FAO, 2020).

A well-drained sandy loam is preferred and heavy clay soils should be avoided as they can retard root development, resulting in root cracks and poor root shape. Lighter soils are more easily washed from the roots at harvest time. Wet season green manure cropping with sterile forage sorghum is recommended and should be thoroughly incorporated and decomposed by planting time. Soil pH should be adjusted to about 6.0 by applying lime or dolomite. Rates of 240 kg and 400 kg/ha respectively will raise the pH by 0.1 of a unit. The soil should be deep ripped and then disk cultivated to break up any large clods and provide enough loose soil for hilling of beds. A yearly soil test is recommended to assess soil properties, pH and nutrient levels before ground preparation (FAO, 2014).

2.3 **Botany/Morphological Description of Moringa**

Moringa *(Moringa oleifera)* is the only genus in the family of *Moringaceae*. Moringa is one of the most widely cultivated species of the tropical flowering plant family Moringaceae, containing 13 known diverse species (Shahzad et al., 2013), of which 8 are endemic to the Horn of Africa. *Moringa oleifera* is most closely related to *Moringa concanensis* (also from India) and *Moringa perigrina* (from the region around the Red sea, the Horn of Africa, Yemen & Oman) (Sharma et al., 2011). The most important moringa species include; *Moringa oleifera, M. longituba, M. concancensis, M. arborea, M. drouhardi, M. hildebrandti, M. ovalifolia, M. peregrine, M. stenopetala, M. pygmaea, M. rivae and M. ruspoliana* (Sharma et al, 2011).

Moringa oleifera is a fast-growing perennial softwood tree with timber of low quality (Fahey, 2005), that can grow to a height between 7m to 15m, when grown in a good environmental conditions. However, moringa growing in a marginal conditions grow much slower and can have a stunted and shrubby habit, sometimes only reaching 5m in height. It is generally considered a small-to-medium sized tree (Sabin, 2023). It is a slender soft and spongy wood tree with many wide-spreading, drooping fragile branches. The bark of the tree is smooth, dark-grey, splash thin and yellowish in colour (Zaku et al, 2015).

The leaves of *Moringa oleifera* are tripinnate compound in nature. They are feathery with green to dark green in colour which may be 3 to 6cm long, with 2 to 6 pairs of pinnules. Each pinnule has 3 to 5 elliptical leaflets that are 1 to 2 cm long and 0.3 to 0.6 cm wide. The terminal leaflet is oval and often slightly larger (Anwer et al, 2007). The tree is often mistaken for a legume because of its leaves and it loses its leaves from December to January; during the dry period. New leaves and growth begins to appear in February to March and flowering often precedes or coincides with the appearance of the new leaves (Sachan et al, 2010). Moringa is a fast-growing tree which also has fast regrowth potentials after pruning as well as the capacity to produce high quantities of fresh biomass per square meter, even at high planting densities (Sabin, 2023).

The flower of moringa are very conspicuous and lightly fragrant. The flowers are borne profusely in axillary, drooping panicles 10 to 25 cm long. They are fragrant, white or creamy-white with yellow stamens and 2.5 cm in diameter (Adegun & Ayodele, 2015). The flower season typically continues through March, while its fruits ripen from April to June (Sharma et al, 2011). It flowering is not influenced by day length (Palada, 2020). In Southeastern Nigeria, leaf flushing and flowering take place even during the dry season. The bisexual flowers are highly cross-pollinated and insects such as bees (*Xylocopa spp*.) and sunbirds (*Nectara spp*.) have been found to be active and reliable pollinators in some parts of the world (Trigo et al, 2020). *Moringa oleifera* does not seem to require any specific pollinators, as it readily produces viable seeds in all parts of the world where it has been introduced.

The fruits of moringa are tri-lobed capsules that are commonly referred to as “pods”. The pods are borne singly or in pairs, are pendulous, turns from green to brown (when dry at maturity), and triangular, tapering at both ends, 25 to 45 cm long and 1.8 cm wide, and contain about 15 to 20 seeds embedded in the pith (Palada, 2020). The pods split lengthwise into three parts when dry. The immature pods are green and in some varieties reddish in colour.

The seeds of moringa are large with 3 papery wings. The seeds are round with a brownish semi-permeable seed hull with three white papery wings, embedded in dry, white, tissue-like pith (Anwer et al, 2007). Seed hulls are generally brown to black, but can be white if kernels are of low quality. Viable seeds germinate within 2 weeks (Palada, 2020).

Moringa oleifera tree produces tuberous taproot which explains its observed tolerance to drought conditions. Moringa root is a swollen, tuberous white tap root which has a characteristics pungent odour, and very sparse lateral roots that developed from the seedlings. However, if the trees are planted through seed a deep stout tap root with a wide-spreading system of thick, tuberous lateral roots will develop. According to FAO, (2014) tap roots do not develop from trees propagated from cuttings.

2. 4. **Utilization of Moringa, Cassava, Maize and Sweet potato**

2.4.1 **Moringa oleifera**

Moringa is considered one of the World's most useful trees, as almost every part of the Moringa tree can be used for food or has some other beneficial property. As a traditional food plant in Africa, this little-known vegetable has potential to improve nutrition, boost food security, foster rural development, and support sustainable land care. According to Motis (2021), other uses in which moringa can be put into include:

Agriculture

Alley cropping: Moringa is a fast growing plant. With their rapid growth, long tap root, few lateral root, few lateral branches with minimal shade and large production of high-protein biomass, moringa trees are well suited for use in alley cropping systems.

Honey production: Flowers of *Moringa oleifera* are good source of nectar for honey producing bees. Dried seeds can be used to clarify honey without boiling, seed powder can also be used to clarify sugar cane juice.

Foliar nutrient/Growth enhancer: Juice extracted from the leaves can be used to make a foliar nutrient capable for increasing crop yield by up to 30%. It is used as natural plant growth enhancer. Indeed, leaves are rich in zeatin (a plant hormone belonging to the cytokinin group). The leaf extracts can stimulate plant growth and increase crop yield (Ashfaq et al, 2010).

Organic fertilizer/bio-pesticide: The seed cake remaining after oil extraction can be used as manure. Interestingly, leaf extracts and also seed extracts show bio-pesticide activity, effective against larvae and adults of *Trigoderma granarium;* and can reduce the incidence of fungi on groundnut seeds (Ashfaq et al, 2012). *Moringa oleifera* leaves have been reported a valuable sources of macro and micro nutrients as well as being a significant sources of beta-carotene, vitamin C, protein, calcium, iron and potassium (Motis, 2021). Research on moringa application as fertilizer has been reported to increase the growth, yield and quality crops. Several researchers have indicated that moringa is highly valued with multi-purpose effects (Ojiako et al, 2011).

Industrial use

Gum**:** The gum produced from a cut tree trunk has been used in Calico printing, in making medicine and as bland-tasting condiment.

Water purification**:** Powered seed kernel act as natural flocculants, able to clarify even the most turbid water. Moringa seed powder use can therefore replace dangerous and expensive chemicals such as aluminium sulphate (Popoola & Obembe, 2013).

Bio-fuel: One of the interesting applications of Moringa seeds is their utilization as biomass for biodiesel production. Due to the increasing energy demand and environmental problems associated with fossil fuels, the improvement of alternative fuels and renewable sources of energy is required. Biodiesel can replace petroleum-derived oil (petro-diesel), without any Sulphur or aromatic compound and with lower emission of monoxides, hydrocarbons and particulates. Furthermore, biodiesel can reduce dependence on imported fuels: a crucial problem in developing countries (Karmakar et al, 2010).

Moringa seeds have an oil content of 30%–40%, with a high-quality fatty acid composition *i.e.*, high oleic acid (>70%) (Sharma et al, 2011). In addition, they possess significant resistance to oxidative degradation. These proprieties make moringa oil a good source to producing biodiesel after trans-esterification (Da Silva et al, 2010, Ofor & Nwufo, 2011). Biswas and John (2008), in a study conducted in Australia, report that approximately 3030 kg of oil are required to produce 1000 litres of biodiesel. Furthermore, an equivalent of 3.03 tons/ha of oil seeds can be harvested from dry land, and 6.06 tons/ha can be harvested from irrigated land. Since biodiesel production with moringa seed oil is a second generation production (*i.e.*, not in direct competition with existing farmland and with food crops) and as moringa can grow on degraded land, studies suggest that moringa biodiesel is an acceptable substitute to fossil fuels, even when compared against biodiesel derived from vegetable oil of other species (Sharma et al, 2011).

Pulp: The soft, spongy wood makes a poor firewood but the wood pulp is highly suitable for making newsprint and writing papers.

Domestic Cleansing agent: Crushed leaves are used in some parts of Nigeria to scrub cooking utensils or to clean walls.

Medicinal use

All plant parts of *Moringa oleifera* are traditionally used for different purposes, but leaves are generally the most used (Popoola & Obembe, 2013). In traditional medicine, these leaves are used to treat several ailments including malaria, typhoid fever, parasitic diseases, arthritis, swellings, and cuts, diseases of the skin, genital-urinary ailments, hypertension and diabetes. They are also used to elicit lactation and boost the immune system (to treat HIV/AIDS related symptoms) (Sivasankari et al, 2014; Yabesh et al, 2014; Kasolo et al, 2010), as well as cardiac stimulants and contraceptive remedy. One can directly consume either raw and dried leaves or the extract of an aqueous infusion.

Similarly, the use of seeds concerns both human nutrition and traditional medicine. Barks are boiled in water and/or soaked in alcohol to obtained drinks and infusions that can be used to treat stomach ailments (ease stomach pain, ulcer and aiding digestion), poor vision, joint pain, diabetes, anaemia and hypertension (Abe & Ohtani, 2013), toothache, haemorrhoids, uterine disorder (Yabesh *et al*, 2014). Roots are soaked in water or alcohol and boiled with other herbs to obtained drinks and infusions as remedies for toothache, as anthelmintic and anti-paralytic (Popoola & Obembe, 2013; Sivasankari et al, 2014), drugs and as sex enhancers. Finally, flowers are used to produce aphrodisiac substances and to treat inflammations, muscle diseases, hysteria, tumors and enlargement of the spleen (Yabesh et al, 2014).

2.4.2 **Cassava**

As Food for Human Consumption: Cassava is consumed in all its forms at nearly all income levels. Cassava as the principal source of carbohydrates occupies much the same position in the diet as potatoes. Leaves and tender shoots are used in many tropical areas as a cooked vegetable or in sauces, as they are rich in vitamins and have a high protein count (Heuser et al, 2014).

As Animal Feed: Cassava is widely used in most tropical areas for feeding pigs, cattle, sheep and poultry. Dried peels of cassava roots are fed to sheep and goats, and raw or boiled roots are mixed into a mash with protein concentrates such as maize, sorghum, groundnut or oil-palm kernel meals and mineral salts for livestock feeding. Cassava, similar to feed-grains, consists almost entirely of starch and is easy to digest. The roots are, therefore, especially suited to feeding young animals and fattening pigs (Hauser et al, 2014).

Non-food Uses

Natural Adhesives: Starch makes a good natural adhesive. There are two types of adhesives made of starches, modified starches and dextrin, roll-dried adhesives and liquid adhesives. The application of cassava in adhesives continues to be one of the most important end uses of the product (IITA, 2014).

Corrugated cardboard manufacture: One of the large users of dextrin is the corrugated cardboard industry for the manufacture of cartons, boxes and other packing materials.

Remoistening gums: These adhesives are coated and dried on surfaces, such as postage stamps and envelope flaps, for moistening by the user before application to another surface. Cassava dextrin in aqueous solution are well suited for this purpose as they give a high solids solution with clean machining properties

Wallpaper and other home uses: Various types of starch-based products are used as adhesives for wallpaper and other domestic uses.

Foundry: Starch is used as an adhesive for coating the sand grains and binding them together in making cores which are placed in moulds in the manufacture of castings for metals

Well drilling: Starches and modified starches mixed with clay are used to give the correct viscosity and water-holding capacity in bores for the exploratory drilling of oil wells or water wells. These starch products are replacing other commercial products for making the muddy materials which are indispensable for drilling wells. For this purpose, a cold-water-soluble pre-gelatinized starch which can be made up to a paste of the required concentration on the spot is desired (IITA, 2014).

Paper industry: In the paper and board industries, starch is used in large quantities for production of papers. Cassava starch has been widely used as a tub size and beater size in the manufacture of paper.

Textile industry: In the textile industry, starches occupy an important place in such operations as warp sizing, cloth finishing and printing.

Wood furniture: Before the Second World War the manufacture of plywood and veneer relied mainly on cassava as a glue. However, the use of cassava as a glue has declined to second place owing to the increasing success of water-resistant plastics.

Production of Alcohol: Cassava is one of the richest fermentable substances for the production of alcohol. The fresh roots contain about 30 percent starch and 5 percent sugars, and the dried roots contain about 80 percent fermentable substances which are equivalent to rice as a source of alcohol.

Production of Yeast: Cassava starch and cassava roots are being used in Malaysia and some other countries for the production of yeasts for animal feed, human diet and for bakery yeast (Ikuemonisan et al, 2020).

2.4.3 **Maize**

Maize has assumed considerable importance in Nigeria as part of the diet of the people and source of cash income to predominant small holder farmers (Onyishi et al, 2010). As a major food as well as a major constituent of livestock feeds, it contains on the average

68% carbohydrate, 13.5% water, 10% protein, 4% oil, 1.4% mineral matter and 3.1% fibre (Adeniyan, 2014). Maize is a popular grain used for food either fresh or processed into various forms for human consumption. It can be processed for oil, starch and alcohol used in industry for making adhesives, explosives, paint, ceramics, shoe polish, dyes, rubber substitutes (Adeniyan, 2014). Maize stalk serves as silage and can be used for feeding livestock and paper making.

Large scale/Industrial utilization of Maize

Maize is a major cereal crop. It is consumed in diversified forms to meet taste, preference and environment. Maize utilization pattern as human food is changing tending more toward the fast foods. The demand for convenience foods that meet nutritional and health requirements has put the Nigerians in the use of corn for human foods and industrial products.

Large Scale: Industrial utilization of maize is largely determined by the quality characteristics of the grains in terms of its physical and chemical attributes of the kernel (Amjadian et al, 2013).

i. ***Feed uses*****:** Animal feed accounts for 70 percent or more of total maize utilization. Maize is the feed ingredient of choices in formula feeds because of its low cost and high degree of consistency.

ii. ***Crop residue: utilization (Forage uses)*****:** Crop residue are basically high energy concentrates and natural supplements to protein-rich feeds. These residues are used mainly during the month of November – April. The use of maize as forage introduces another critical actor- herdsmen/livestock sector into it value chain.

iii. ***Alkaline utilization of maize***: Maize has been the traditional cereal for the preparation of tortillas. Tortillas are flat circular dough pieces that are baked on a griddle. The maize can be treated with spices, condiments and other ingredients to produce a large variety of products.

iv. ***Maize in the baking, soft drinks and confectionery industries***: In many African countries, maize is one of the local sources of flour for the baking industries. It is used in the production of composite bread, muffins, fibres, pancakes, biscuits, and doughnut. Maize formulas often include wheat flour (composite flour) in production (Adeniyan, 2014).

v. ***Pop-corn Production***: Popcorn is a popular snack. Consumers' wants popcorn that is tender, good tasting, free from hulls (Adeniyan, 2014).

2.4.4 **Sweet Potato**

Leaves: The sweet potato plant can be harvested for leaves during the 2nd and 3rd months of production. Only the tender stem and young (not fully developed) leaves, which constitute the distal 2-4 inches of the growing stem, should be taken. The leaves and stems are boiled for 15-20 minutes, washed, seasoned, and served (Hongnan, et al, 2014).

Boiled sweet potato: The sweet potato is washed, peeled and trimmed, cut into 1-inch thick slices or cubes, and boiled 18-20 minutes. The boiling water is then discarded. The sweet potato can then be served as is, mashed, or combined in many dishes (casseroles). The mashed pulp can be used as a partial substitute for wheat flour in baked products such as pancakes, cakes, flat breads, cookies, fritters, or even bread (Hongnan, et al, 2014).

Baked sweet potato: The entire sweet potato is wrapped and then baked in a modern or primitive oven until soft (one hour at 350 degrees). During baking of most sweet potatoes, part of the starch is converted to the reducing sugar, maltose, thus increasing sweetness (Chao-Chen et al, 2021).

Osmotically modified boiled sweet potato: The peeled and trimmed sweet potatoes can be cut into thin (1/8") slices, placed in water for 2 hours (moved once in a while) and then boiled. The products will be clearer, less sweet, and milder than those made from untreated sweet potatoes. (What is happening chemically is that the enzymes and substrates responsible for polyphenolic oxidation are partially lost, as well as some of the sugars).

Sweet potato flour: The flour of sweet potato is much more difficult to make than that of potato because the reducing sugars readily released from the starch combine with free amino acids to produce disagreeable colours, odours, and flavours. To avoid this, the peeled sweet potato can be shredded, and the shreds immersed in water for 2 hours. This process works better if the water is changed 2-3 times. The shreds are drained and then dried, first in the shade (with air movement or wind) and later in the sun (in some cases, drying over the stove or in an oven will be necessary). The brittle shreds are easily crushed to flour, or this can be done rapidly in a household blender. The flour can be stored for 6 months or more in sealed containers. It can be used as a substitute for wheat flour in the following amounts: 100% in white sauces, 25-50% in cookies, cakes and flat breads, and 15-20% in breads. From the water, starch can be recovered (Chao-Chen et al, 2021).

Starch production: The peeled sweet potato is ground in a mill or blender as finely as possible, and mixed with 5-10 times its weight in water. The starch settles out, and the water is carefully poured away (can be used as pig feed). The starch is then mixed with water 1-3 times more and the process is repeated. After the last settling the water is carefully drained and the starch is dried on a metal surface in the sun. It can be used, as is any starch, such as corn or potato starch, and can be stored in sealed containers for a year or more (IPC, 1987).

Breakfast cereal: A breakfast food similar to "cereal" can be made from any sweet potato. The sweet potato is grated (not as finely ground as for starch), suspended in water, and filtered through a cloth. The liquid is saved for starch, the residue is suspended 1-3 times more in water, and filtering is repeated. The portion of the sweet potato that does not pass through the filter is then dried and lightly toasted on a hot plate (over the fire). The toasting is very delicate. The product must be stirred and turned almost continuously, and should not become sticky and jellified. The toasted product can be stored in sealed containers and eaten with milk without further cooking, or can be used much like starch or flour, imparting its characteristic flavour (McGuire, 2020).

Feed: All parts of the plant can be used as feed. The storage roots should be cooked before feeding them to pigs. Rabbits love sweet potatoes (Hongnan et al, 2014; Bouwkamp, 1985).

2.5 **Concept of Good Agronomic Practices (GAPs) in a Sustainable Crop Production System**

Traditional agricultural practices are widespread in Nigeria with resultant low yields. The farmers generally do not perform any soil analysis or land levelling and there is little or no knowledge of the importance of crop diversification. Water use association and inefficient irrigation practices are generally lacking or inactive and so are agricultural innovations and this therefore, results in low yields. In addition to the difficulties small holder farmers face in obtaining fertilizers, the access to quality seeds is also limited. Most farmers purchase seeds from private suppliers who mix different qualities of seeds together to maximize their profits, resulting in low yield. Crop diversification is also generally lacking. Farmers tend to grow the crops they are traditionally used to plant. This could lead to decreased land fertility, increased risk of being attack by pest, increased vulnerability to climate changes etc. (FAO, 2019; Izquierdo et al, 2007).

In crop production, the ultimate goal of any farmer is to get maximum yield per unit area. The production potential of a particular crop depends on the environment and the skills of the farmers in identifying and eliminating those factors that reduce the production potential. To obtain high yield, effective crop management practices, which are otherwise known as cultural practices and a good cropping systems appeared to be of paramount value. Cultural practices simply refer to all the operations carried out in the farm, right from the beginning of the farming season to the end (Karaye et al, 2017; Reddy, 2017).

In Nigeria however, crop production is lagging behind in terms of yield per hectare compared to International standard, perhaps due to the problems associated with poor crop management practices (Nyako, 2008) as well as poor cropping system management. This is quite justifiable, considering the report by (OLAM, 2007) on sesame production in Jigawa State in which the average seed yield of sesame on farmer's field was put at 0.6t/ha as opposed to 1.25t/ha that is practically obtainable on well-managed farms. The low seed yield of sesame observed on farmer's field could be ascribed to failure of the farmers to adopt and practice the recommended agronomic practices that govern the production of the said crop.

In fact, each crop has an established cultural practice that guides its production, which were developed by crop scientists through a series of experimentations. And for the inherent yield potential of that crop to be fully expressed, such management practices must be properly adopted and carried out accordingly.

Crop production in Nigeria is faced with many challenges among which are: untimely planting, incorrect plant spacing, wrong method of planting, poor sowing depth, delayed weeding, ineffective pests and diseases control, inappropriate use of fertilizers, untimely harvesting and above all usage of low yielding varieties of seeds/ planting materials. More often than not, such poor crop management practices become reflected in reduced crop growth and yield which invariably make farming to be physically strenuous and economically unrewarding in nature.

2.5.1 **Meaning of Good Agronomic Practices (GAPs) in Agriculture**

Agronomic practices are a vital plan as part of farming systems. These are practices that farmers incorporate to improve soil quality, enhance water usage, manage crops and improve the environment. Agronomic practices focus on better fertilizer management as a way of improving agricultural practices. GAP, as defined by FAO, are a collection of principles to apply for on-farm production and post-production processes, resulting in safe and healthy food and non-food agricultural products, while taking into account economic, social and environmental sustainability (FAO, 2019).

A good agronomic practice (GAP) is however, steps farmers incorporate into their farm management systems to improve soil quality, enhance water use, manage crop and crop residues and improve crop environment (TNAU, 2014). Agronomic practices incorporate many areas of conservation in farming. Such operation includes sanitation and use of clean and healthy seeds for planting, tillage and mulching, time of planting, multiple and intensive cropping, crop rotation, spacing, intercropping, use of fertilizers (manuring), irrigation, pest and disease management, timely harvesting and storage (Bankina et al, 2015;Karaye et al, 2017).

Agriculture has moved from the traditional means of planting and harvesting to sustainable agricultural production through efficient use of productive resources in order to ensure food security and to eradicate poverty. Proper usage of agronomic practices decreases cost of production of farm product and consequently, the quality and quantity of the yields with significant increase. The operation also helps the farmer in taking care of the environment by reducing pollutions. Decreasing water usage and proper use of fertilizer also contribute to maintaining the quality of land (Anil et al, 2012; FAO, 2008). In farming, any practice that entails conservation is an agronomic practice. Practices such as tillage management, managing plant population and controlling the usage of water are some of the major agronomic practices that every farmer has tried. The changes in agronomy might be small, but the results of the practices are massive. The routine nonetheless have yielded major dividend that farmers have enjoyed (Bankina et al, 2015).

Agronomic practices are efficient and very useful to a farmer. For a commercial farmer, the practice will enable the farmer target profits while taking care of the environment. To a domestic farmer, the practices are a cheap method of maintaining the farm (Nilda & Erkan, 2007). Agronomic practices are also used to maximize the farm produce in different ways and quality production. It also includes efficient uses of chemicals (pesticides), weed management, timing of farming operations and farm mechanization. Good Agricultural Practices (GAPs) are ways that growers' produce can prevent on-farm contamination of fruits and vegetables and it is a new way of thinking about food safety.

According to Katan (1996), GAP can be classified into three categories:

- Practices, which are usually applied for agricultural purposes not connected with crop protection, such as fertilization and irrigation. They may or may not have a positive or a negative side-effect on disease incidence.
- Practices that are used solely for disease management, such as sanitation and flooding and
- Practices, which are used for both agricultural purpose and for disease management, such as crop rotation and grafting.

In agricultural sense, cultural practices refer to all the operations carried out in the farm, right from the beginning of the farming season to the end and these agronomic or cultural practices could further be classified into pre-planting, planting and post planting operations:

a. Pre-planting operations*:* - These are the operations carried out in the farm before planting is done which include the following:

i. Site Selection: - This is very important in crop production as soil type determines not only the kind of crop to be grown in an area but also the performance of the crop. For example, maize thrives well in sandy loam soil while cassava performs better in loamy soil.

ii. Land clearing: - It is the method of removing vegetation from the field and the clearing of existing vegetation so as to make cultivation and other farm operations easy. It can be done manually or mechanically.

iii. Stumping: - removal of stumps or the under-ground portion of the plants; right from the base of their roots. It is done with the use of tractor-coupled implements like disc plough etc. during ploughing, harrowing and ridging.

iv. Ploughing: - It is the breaking of soil to loosen it for easy penetration of roots, soil aeration, and water percolation and to create a suitable medium for microbial activities within the soil.

v. Harrowing: - it is the act of breaking up the large clods or particles of soil resulting from ploughing into fine particles. Harrowing mixes the soil together and destroys weed seeds as well as exposing harmful pests for easy destruction.

vi. Ridging: - this is the process of making ridges. Ridges increase crop yield by promoting moisture retention and easy root penetration into the soil (Lado, 2004)

vii. Seed Selection: - in crop production, the first step in attaining good harvest is the use of good quality seeds (Okosun 2002). Certified seeds from a reliable seed company should be selected for planting as seeds of poor quality result in poor harvest.

viii. Organic Manuring:- as opposed to inorganic fertilizers, organic manures are usually incorporated into the soil prior to planting as they decompose gradually and release nutrients into the soil (OCIA, 2007).

b. Planting Operations*: -* these are the operations carried out in the farm during planting which include plant spacing, seed rate and planting itself.

i. Planting Spacing: - this is the distance between two plants. The distance between one plant and another along the same ridge or row is called intra or within row spacing, while the distance between one plant and another on different ridges or row is known as inter or between row spacing. The spacing at which crop is planted determines plant population per unit area, seed rate, plant competition for limited environmental resources, interception of solar radiation, weed suppression and the yield per unit area (Karaye & Yakubu, 2006). Okosun (2002) reported that, each crop has an optimum plant density at which it produces maximum yield, below or above this point yield becomes negatively affected.

ii. Seed Rate: - this refers to the quantity of seeds or planting materials required to cover the planting of an area. To determine seed rate of a given area, the area of the land, the actual spacing and the number of seeds per hole must be known.

iii. Planting methods/Time: - this is the placement of seeds into the soil for germination. Different crops have different planting methods and as such different planting methods (dibbling, drilling and broadcasting) are employed in crop production and the method to be adopted depends on crop and resources available. Time and method of planting as well as sowing depth are very crucial in crop production as each of these influence seed germination, seedling establishment, crop growth and yield (Alhassan et al, 2007). For good germination, sesame for example requires shallow planting depth due to the smaller nature of the seeds. Karaye (2004) also reported that, early sown garlic plants tend to grow more vegetative and produce high yield compared to lately planted garlic plants.

c. Post Planting Operations

These are operations carried out after planting which include the following:-

i. Weeding: - this is the removal of unwanted plants found growing among the cultivated crops. Weeds compete with crops for limited environmental resources and harbour pests and diseases that are harmful to crops (Lado, 2004). Such competition usually becomes manifested in reduced crop growth and yield. Timely weeding is very necessary if crop yield is to be increased

ii. Thinning: - this is the removal of weak or extra seedlings from a stand when the seeds per stand germinate more than required. Thinning is preferably done after rain or watering when the soil is wet and care must be taken not to damage the roots of other plants.

iii. Supplying: - this is the practice of replanting the vacant positions created by poor seed germination. It is done when all the seeds have germinated.

iv. Fertilizer Application: - cropping depletes plant nutrients from the soil and fertilizers are added to the soil to supplement or replenish the lost nutrients. By following fertilizer recommendations in terms of method, dosage, time and number of application, farmers may get back, more than double of their investment (FAO, 2007).

v. Mulching: - this is the placement of materials such as dry grasses, saw dust, leaves, wood shavings etc. over the soil surface. Mulching conserve soil moisture, regulates soil temperature, provides erosion control, suppresses weed growth, serves as vegetative cover, improves soil condition and increases soil fertility.

vi. Control of Pests and Diseases: - when crops are attacked by pests and diseases, the result is low yield or sometimes total crop failure. It is therefore necessary to control pests and diseases to avoid crop failure. This can be achieved through the use of resistant varieties, good farm management practices, crop rotation, use of natural enemies of the pests and spraying with insecticides.

vii. Harvesting: - when crops are fully matured, the useful parts are removed or detached from the parent plants for consumption or for sale. This practice is called harvesting. Timely harvesting is very important in crop production as delay in harvesting leads to reduction in crop yield and quality.

viii. Processing: - this is the process of transforming the farm produce into consumable form or into forms acceptable to the consumers. Wheat, for example, requires drying, threshing, winnowing and grinding to make bread. Well processed goods fetched more income to the farmer

ix. Storage*:* - this involves the safe keeping of farm produce that will not be sent to market or consumed immediately. The storage facilities should be dry and free from insect pests and diseases. Good storage fetches more money to the farmer as most of stored goods are sold during off-season when price is relatively high (Katan, 1996).

x. Marketing: - this is the last stage of farm operations in which the farms produce to be sold are sent to the market. Marketing is very important in agriculture as it ensures the movement of goods and services from where they are produced to where they are not produced. Effective marketing strategy yields more profit to the farmer (FAO, 2019 and 2007; Nilda et al. 2007).

2.5.2 **Types of Good Agronomic Practices (GAPs) in Intercropping Systems**

i. Soil tillage

The soil is the most vital thing on a farm. Taking good care of it means that the crops will do well and the soil won't lose fertility. In a farm, one needs to practice minimum methods of soil tillage. Minimum soil tillage will increase the water retention capability of the soil as well as maintain its fertility. Maintaining the soil also entails the good use of fertilizer. This will not only take care of the soil but the environment as well.

ii. Sowing/Planting Time and Plant Density Management

Each farmer wants to ensure that they get a bumper harvest. Nevertheless, it is also vital that they ensure their harvest is of quality and not just quantity. Controlling plant population is, therefore, the best way of ensuring that crops do well. Managing the population ensures that they are not over crowded such that they compete for nutrients or under crowded such that the input is under-utilized. The plants have to grow in prime growing conditions.

In other words, this indicates the periods during which the crops would perform best for maximum yields. It is important that the time of planting should be so adjusted that the crops attains vegetative growth rapidly and the foliage does not allow for wastage of solar energy at longer period during seedling growth. This will have a favourable impact on the reproduction growth phase of the crops and in turn ultimately, the grain yields per hectare. Variations in growth due to seasonal drift influence leaf area expansion and active period, photosynthetic efficiency, relative growth rate resulting in variation in dry matter production, its distribution and translocation to grain considerably and therefore the final grain yield. High temperature and light intensity favour early emergence of leaves, faster crop growth, dry matter production and translocation to grains. As such, performance of a dry season crops comparatively better as compared to rainy season crops due to low temperature as high in relative humidity favours the incidence of pests and diseases of crops. Thus, it is better to choose a proper time for planting in tune with the season (Okosun, 2002).

Basically, the seed rate depends on the plant stature and structure, leaf disposition, the growth habit of the crop, its duration, size of the seeds, type of cropping (irrigated or dry land), purpose for which crops are grown, spacing between crop rows etc. Seeding rate is also determined by the germination and emergence potential of the seeds. Factors like season, soil moisture and soil fertility status are equally important in deciding proper density of plant. Optimum plant population generally provide conditions for better utilization of land space, soil moisture, nutrients and for maximum light interception right from the early periods of crop growth. Variation in plant population influences greatly the performance of the individual plant. More than required, population in a given area creates more competition among plants and plants become lanky. Sometimes leads to barrenness of crops due to mutual shading and competition (Karaye et al, 2004; Watts, 2012).

iii. Fertilizer Application and Management

Each crop has its own nutrient requirement. Soil type as well as response need of variety and balanced fertilizer application of Nitrogen, Phosphorus and Potassium are required. Micro nutrients in conjunction with the organic manure certainly has great impact on plant growth and yield. For each crop, the way fertilizers are applied depends on its rooting pattern, planting and cultivation requirements. The nutrients supplied thus influences better root growth, early emergence and expansion of leaf canopy as well as increase photosynthetic efficiency which results in greater dry-matter-production (DMP). These eventually lead to the formation and development of large sink where the food materials accumulate like the grain; tubers etc. and ultimately provide higher yields. The knowledge of the crucial stages of floral initiation and floret differentiation (for example grain crops) lead to beneficial adjustment to be followed in nutrient supply and management for better production in crops such as cereal crops. The period of top dressing of nitrogen nutrition for the crops should be at most active and vital stages of floral initiation and floret differentiation so as to aid the development of large sink to accumulate carbohydrates produced at later stages. However, proper nutrients management leads to increase in photosynthetic efficiency as the plant advance in age (Morris et al, 2017; Chapman, 2015).

iv. Proper Use and Management of Herbicide, Plant Pests and Diseases

Practicing good agronomic practices and paying attention to habitat management, including conserving and encouraging the spread of natural enemies can suppress and mitigate the damage created by pests (Akkaya & Yalcin 2015). The Food and Agriculture Organization (FAO) also recommends avoiding late and staggered planting to enable the maize crop to escape fall armyworm attacks. This is to ensure that farms will not continually provide the favoured food of the fall armyworm (Gailis et al, 2017; FAO, 2014).

v. Reducing Water Usage

Every farm needs water for the survival of crops and every other use on the farm. Nevertheless, too much usage of water leads to wastage and can sometimes affect the soil. The farm, therefore, needs not too much water such that it’s wasted or not too little water such that the soil lacks (FAO, 2008; Tilman, 2008).

vi. Good Crop Rotation (Cropping Systems)

The good thing about crop rotation is that it allows crops field to recover and manage the soil naturally. It is known that planting the same crop two years in a row drastically reduced the yield and can damage the nutrient balance of the soil. Crop rotation practices have been a key part of farming in the past, and have continued to be of advantage in the farming practices. For a better and productive yield of crop in a year after year cropping, intensive soil fertility practice to support crop growth and yield needs to carefully and scientifically manage to maintain nutrient consistency as well as moisture content and soil pH (Izquierdo et al, 2007).

2.5.3 **Benefits of Good Agronomic Practices (GAPs) in Agriculture**

In crop production, the ultimate goal of any farmer is to obtain maximum yield per unit area at harvest. To obtain high yield, effective crop management practices which are otherwise known as cultural practice, appeared to be of paramount value. However, proper usage of agronomic practices, decreases input costs in producing farm products. Consequently, the quality and quantity of the yield will increase significantly. The exercises also help the farmer in taking good care of the environment by reducing pollution. Decreasing water usage and proper use of fertilizer also contribute to maintaining the quality of land (Eaton, 2007; Ellis, 2004; Earnest, 1995).

2.6 **Intercropping Principles and Production for Sustainable Agriculture**

Sustainable agriculture seeks, at least in principle, to use nature as the model for designing agriculture systems. Since nature consistently integrates her plants and animals into a diverse landscape, a major tenet of sustainable agriculture is to create and maintain diversity. Nature is also efficient and there are no waste products in nature. Outputs from one organism become inputs for another. The death of one organism becomes food for other organisms (Grossman & Quarles, 1993; Sullivan, 2003).

Self - sustaining, low-input, and energy-efficient agricultural systems in the context of sustainable agriculture have always been in the centre of attention of many farmers, researchers, and policy makers' worldwide (Mahtab-Naza & Tess Astatkle, 2023). However, most practices of modern agriculture, e.g. mechanization, monocultures, improved crop varieties, and heavy use of agrochemicals for fertilization and pest management, led to a simplification of the components of agricultural systems and to a loss of biodiversity. Restoring on-farm biodiversity through diversified farming systems that mimic nature is considered to be a key strategy for sustainable agriculture (Jackson et al., 2007; Jones et al, 2021, Jonesa et al, 2022). On-farm biodiversity, if correctly assembled in time and space, can lead to agro-ecosystems capable of maintaining their own soil fertility, regulating natural protection against pests, and sustaining productivity (Thrupp, 2002).

Biodiversity in agro-ecosystems can be enhanced in time through crop rotations and sequences in space through cover crops, intercropping, and agroforestry (Kremen et al, 2012, Malézieux et al., 2009). While modern agriculture has brought vast increases in productivity to the world's farming systems, it is widely recognized that much of this may have come at the price of sustainability (Tilman et al., 2002; Lichtfouse et al., 2009). This is because modern farming systems imply the simplification of the structure of the environment over vast areas, replacing natural plant diversity with only a limited number of cultivated plants in extensive areas of arable monocultures (Nicholls et al, 2016; Vandermeer et al., 1998). By contrast, on- farm biodiversity is familiar to traditional farmers mainly in developing countries, where traditional farming systems are characterized by their great degree of genetic diversity in the form of mixed cropping and agroforestry patterns, based on numerous varieties of domesticated crop species as well as their wild relatives (Altieri, 1999). These farming systems offer a means of promoting diversity of diet and income, stability of production, reduced insect and disease incidence, efficient use of labour, intensification of production with limited resources, and also maximization of returns under low levels of technology (Malézieux et al, 2012; Anil et al., 1998; Malézieux et al., 2009).

Intercropping however, is the practice of growing two or more crops simultaneously to promote interaction between crops grown on the same area (Andrews & Kassam, 1976). Intercropping, also referred to as mixed cropping or polyculture, is the agricultural practice of cultivating two or more crops in the same space at the same time (Ofori & Stern, 1987; Anil et al., 1998). The component crops of an intercropping system do not necessarily have to be sown at the same time nor do they have to be harvested at the same time, but they should be grown simultaneously for a great part of their growth periods. In intercropping, there is normally one main crop and one or more added crop(s), with the main crop being of primary importance for economic or food production reasons. The two or more crops in an intercrop normally are from different species and different plant families, or less commonly they may be simply different varieties or cultivars of the same crop, such as mixing two or more kinds of wheat seed in the same field. The most common advantage of intercropping is to produce a greater yield on a given piece of land by achieving more efficient use of the available growth resources that would otherwise not be utilized by each single crop grown alone. There are many different kinds of species that can be used for intercropping such as annuals, e.g. cereals and legumes, tuber crops and vegetables, tuber crops and cereals or legumes, perennials, including shrubs and trees, or a mixture of the two (annuals and perennials) (Andrews & Kassam, 1976).

Intercropping offers farmers the opportunity to engage nature's principle of diversity and sustainability on their farm and is regarded as a type of crop rotation practice in a piece of land which is characterized by intensive integration of numerous food crops in the same land which promote interaction between crops grown in the same area (Andrews & Kassam, 1976).

The important reason to grow two or more crops together is the increase in productivity per unit of land. In intercropping system, all the environmental resources are utilized to maximize crop production per unit area per unit time, while risk may be minimized (Woolley & Davis, 1991). Intercropping however, increase crop productivity, achieve more returns per unit land area. Other benefit of intercropping are risk reduction due to a total crop failure, restriction of spread of pest and disease in epidemic proportion (Ikeh, 2010), generation of early monetary returns, soil erosion control, conservation of soil moisture and reduction in soil temperature (Javanmard et al, 2009).

Intercropping requires careful planning, taking into account the soil, climate, crops and crop varieties. The crop cultivated under intercropped management system can be grown in rations designed by the grower, to increase crop yield as a multiple cropping systems. This type of cropping system leads to an improvement in the soil fertility and hence, increase in crop yields because two or more crops are properly chosen, the products and the refuse from one plant help in the growth of the other plant and vice versa (Yahaya et al, 2010). It is particularly important not to have crops competing with each other for physical space, nutrients, water or sunlight. Example of intercropping strategies are planting a deep rooted crop with a shallow rooted crops or planting a tall crop with a shorter crops that requires partial shade (Yahaya et al, 2010; Bowen & Bernard, 1986). When crops are carefully selected, other agronomic benefits are also achieved.

However, since we are modelling nature, let us first look at some of the principles by which nature functions. By understanding these principles we can utilize them to reduce costs and increase profitability, while at the same time sustaining our land resource base:

I. **Principle:** ***Diversity is nature's design***

When early humans replaced hunting and gathering food with growing crops and animals, the landscape changed accordingly. By producing a limited selection of crop plants and animals, human kind has reduced the level of biological diversity over much of the earth to much simpler levels. Annual crop monocultures represent a classic example. In response to this biological simplification, nature has struggled to restore diversity to these landscapes – that is her tendency. Our "war" with nature over the tendency to diversity is what we call "weed control" and "pest management." Of course we could hardly produce any crops if we simply allowed our fields to return to a higher level of succession and high diversity, but we can realize some of the benefits of diversity by planting mixtures of different crops.

II. **Principle:** ***Cooperation is more apparent than competition***

There is far more cooperation in nature than competition. Cooperation is typified by mutually beneficial relationships that occur between species within communities. In the Redesigned Forest, ecologist offers a glimpse of the cooperation inherent in a northern temperate forest when he describes a relationship that exists among squirrels, fungi, and trees (Andrews & Kassam, 1976). The squirrels feed on the fungi, then assist in its reproduction by dropping faecal pellets containing viable fungal spores onto the forest floor then, new fungal colonies establish. Tree feeder roots search out the fungi and form a symbiotic association that enables the tree roots to increase their nutrient uptake. The fungi, in turn, derive food from the tree roots. Each benefits from the other's presence or actions. If we view competition as the driving force in nature, we fail to see the complex relationships and feel compelled to take actions that may have unforeseen impacts. The rancher, who views the coyote as a competitor (for calves and lambs) and kills them out, may later find the predator helped keep rodent populations in check. With the predator gone, rodent numbers explode and cause more problems than ever before. The same is true with many insect pests of crops, when the only food for insects is crops that is what they will eat. With no predator or parasite habitat present in a pure stand of crop, the pest insect could not possibly have it better. If we can shift our view of nature from a theme of competition to one of collaboration, we can act in ways that yield fewer negative consequences (Yahaya et al, 2010).

III. Principle: *Stability tends to increase with increasing diversity*

If left undisturbed and unplanted, an abandoned crop field will first be colonized by just a few species of plants, insects, bacteria, and fungi. After several years, a complex community made up of many wild species develops. Once a wild plant and animal community has reached a high level of diversity, it appears to remain stable for many years. When wild communities are in the early stages of development, or when they have lost diversity due to natural catastrophe or human actions, they are prone to major fluctuations, both in type of species present and in their numbers. Disease outbreaks in plants and animals occur more frequently – as do outbreaks of weed, insect, bird or rodent pests. One good example is the grasshopper plagues that follow regional weather shifts. Another is the shift in weed species dominance following a change in soil disturbance (Sullivan, 2003).

The more complex and diverse communities become, the fewer the fluctuations in numbers of a given species, and the more stable communities tend to be. As the number of species increases, so does the web of interdependencies. In both higher and lower rainfall years, there are fewer increases in any one species and fewer fluctuations in the community as a whole (Bowen & Bernard, 1986).

2.7 **Pursuing Diversity on the Farm**

Farmers can model his agricultural pursuits after some of these natural principles as well as model pattern to imitate nature. Some pioneering farmers have been able to utilize nature's principle of diversity to their advantage. Results of their efforts include lower cost of production and higher profits. Among the practices that promote diversity and stability are:

Enterprise diversification – Stability of income and yield are two of the reasons people diversify their crop and livestock systems. Increasing diversity on-farm also reduces costs in pest control and fertilizer needs because these costs can be spread out over several crops or animal enterprises.

Crop Rotation – Moving from simple monoculture to a higher level of diversity begins with viable crop rotations, which break weed and pest life cycles, and provide complementary fertilization to crops in sequence with each other.

Farmscaping – Diversity can be increased again by providing more habitat for beneficial organisms with borders, windbreaks, and special plantings for natural enemies of pests.

Intercropping – Intercropping is the growing of two or more crops in proximity to promote interaction between them.

Integration – On-farm diversity can be carried to an even higher level by integrating animals with intercrops as harvesters. With each increase in the level of diversity comes an increase in stability.

2.8 **Concepts of Intercropping**

The idea behind intercropping is that when two or more crops are grown together, each must have adequate space to maximize cooperation and minimize competition between them (Sullivan, 2003). Most grain-crop mixtures with similar ripening times cannot be machine-harvested to produce a marketable commodity – since few buyers purchase mixed grains. Because of limited harvest options with that type of intercropping, farmers are left with the options of hand harvesting, utilizing crops in the field with animals, or harvesting the mixture for on-farm animal feed. However, some intercropping schemes allow for staggered harvest dates that keep crop species separated. To accomplish this, four things need to be considered:

2.8.1 **Spatial Arrangement**: An ideal spatial arrangement is one which maximizes the complementary between the component crops, and enhances physiological efficiency of the intercropping system in a given environment. This refers to the way that crop plants are distributed in a field. For example, they are randomly distributed, when seeds or propagules are randomly broadcast, or they may be sown in rows, in a regular pattern when drillers are used (Grossman & Quarles, 1993).

2.8.2 **Plant Density**: To optimize plant density, the seeding rate of each crop in the mixture is adjusted below its full rate. If full rates of each crop were planted, neither would it yield well because of intense overcrowding. By reducing the seeding rates of each, the crops have a chance to yield well within the mixture. According to Grossman and Quarles (1993), Sullivan (2003), the challenge comes in knowing how much to reduce the seeding rates. For example, if planning to grow corn and cowpeas and you want mostly peas and only a little corn, it would be easy to achieve this. The corn-seeding rate would be drastically cut (by 80% or more) and the pea rate would be near normal. The field should produce near top yields of peas even from the lower planting rate and offer the advantage of corn plants for the pea vines to run on. If you want equal yields from both peas and corn, then the seeding rates would be adjusted to produce those equal yields.

2.8.3 **Maturity Dates of Crop**: Planning intercrops that feature staggered maturity dates or development periods takes advantage of variations in peak resource demands for nutrients, water, and sunlight. Having one crop mature before its companion crop lessens the competition between the two crops. An aggressive climbing bean may pull down corn or sorghum growing with it and lower the grain yield. Timing the planting of the aggressive bean may fix the problem if the corn can be harvested before the bean begins to climb. Selecting crops or varieties with different maturity dates can also assist staggered harvesting and separation of grain commodities. In the traditional sorghum/pigeon pea intercrop, common in India, the sorghum dominates the early stages of growth and matures in about four months. Following harvest of the sorghum, the pigeon pea flowers and ripens. The slow-growing pigeon pea has virtually no effect on the sorghum yield (Willey, 1983).

According to Seran and Brintha (2010), when two or more crops are grown together, the peak of period of growth of component crops do not coincide. The biggest complementary effects and thus biggest yield advantages seem to occur when the component crops have different growing times. Crops of varying maturity duration should be chosen so that a rapidly maturing crop completes its life cycle before the major growth period of other crop commence. However, crops which mature at different times thereby separating their periods of maximum demand to nutrient and moisture, aerial space and light could be suitably intercropped (Enyi, 1977, Reddy & Reddi, 2007). Mongi et al (1976) found out that planting of cowpea simultaneously with maize gave better yield. Amede and Nigatu (2001) stated that simultaneous planting of maize and sweet potato do not influence maize yields, whereas late planting of sweet potato negatively affects maize yield.

2.8.4 **Plant Architecture**: Plant architecture is a commonly used strategy to allow one member of the mix to capture sunlight that would not otherwise be available to the others (Sullivan 2003). Widely spaced corn plants growing above an understory of beans and pumpkins is a classic example. The tropical multi-tier system where coconut occupies the upper tier, banana the middle tier, and the pineapple, ginger or leguminous fodder, medicinal or aromatic plants occupy the lowest tier is another example (Anonymous, 2010).

2.8.5 **Compatible Crops**: Choosing of a good crop combination plays a vital role in intercropping. Plant density, shading and nutrition competition between plants reduce the yield. Plant competition could be minimized not only by spatial arrangement, but also by choosing those crops best able to exploit soil nutrients (Fisher, 1977a & b). Kassam (1976), reported that, groundnut is usually intercropped with maize in South East Asia and Africa. Agboola and Fayemi (1971) reported that beans (*Phaseolus lunatus*) and Mucuna (*Mucuna utilis)* lowered maize yield, while Calopo (*Calopogonium mucunoides*), Cowpea (*Vigna sinensis*) and Greengram (*Phaseolus aureus*) had much less effect on maize and were themselves tolerant to maize shade. Baker and Norman (1975) stated that increased yield from better use of space in mixtures are complimentary to utilizing time with crops in sequences. Therefore, maximum cropping should be obtained with sequences of high yielding crops in compatible mixtures. Cereal-legume intercropping is commonly practiced in Asia, Africa and South America (Vandermeer, 1992; Maluleke et al, 2005), and in the tropics, maize-cowpea intercropping is often practiced (Mpanane et al, 2004).

2.9 **Intercropping Systems Worldwide**

Traditional agriculture, as practiced through the centuries all around the world, has always included different forms of intercropping. In fact, many crops have been grown in association with one another for hundred years and crop mixtures probably represent some of the first farming systems practiced (Plucknett & Smith, 1986). Various types of intercropping were known and presumably employed in ancient Greece about 300 B.C. Theophrastus, among the greatest early Greek philosophers and natural scientists, notes that wheat, barley, and certain pulses could be planted at various times during the growing season often integrated with vines and olives, indicating knowledge of the use of intercropping (Papanastasis et al., 2004). Today, intercropping is commonly used in many tropical parts of the world particularly by small-scale traditional farmers (Altieri, 1991). Traditional multiple cropping systems are estimated to still provide as much as 15-20% of the world's food supply (Altieri, 1999). In Latin America, farmers grow 70-90% of their beans with maize, potatoes, and other crops, whereas maize is intercropped on 60% of the maize-growing areas of the region (Francis, 1986). Other quantitative evaluations suggest that 89% of cowpeas in Africa are intercropped, 90% of beans in Colombia are intercropped, and the total percentage of cropped land actually devoted to intercropping varies from a low 17% for India to a high of 94% in Malawi (Vandermeer, 1989). In the tropical regions, intercropping is mostly associated with food grain production, whereas in the temperate regions it is receiving much attention as a means of efficient forage production (Anil et al., 1998; Lithourgidis et al., 2006).

Although intensive mono-cropping is much easier for large-scale farmers who plant and harvest one crop on the same piece of land using machinery and inorganic fertilizers, small-scale farmers, who often do not have readily access to markets and grow enough food only to sustain themselves and their families, recognize that intercropping is one good way of ensuring their livelihood. Intercropping is a common practice in many areas of Africa as a part of traditional farming systems commonly implemented in the area due to declining land sizes and food security needs (Dakora, 1996). It is mostly practiced on small farms with limited production capacity due to lack of capital to acquire inputs. Features of an intercropping system can differ largely with soil conditions, local climate, economic situation, and preferences of the local community. Several crop species have been identified as suitable or unsuitable for intercropping, and local varieties, which have been selected over the years for this purpose, are used for intercropping. However, in the mechanized agricultural sector of Europe, North America, and some parts of Asia, intercropping is far less widespread. This is because modern agriculture has shifted the emphasis to a more market-related economy and this has tended to favour intensive mono-cropping systems

(Horwith, 1985). Although agricultural research originally focused on sole cropping and ignored the potential of intercropping, there has been a gradual recognition of the value of this kind of cropping system.

In fact, despite its advantages, the agricultural intensification in terms of plant breeding, mechanization, fertilizer and pesticide use experienced during the last 50 years has led to elimination of intercropping from many farming systems. However, intercropping has been shown to produce higher and more stable yields in a wide range of crop combinations, while the system is characterized by minimal use of inputs such as fertilizers and pesticides, emphasizing the production of healthy, safe, and high quality food in the context of environmentally sound production. For organic sector, intercropping is considered an effective means of self-regulation and resilience of the organic agro-ecosystems to meet environmental perturbations in the organic culture practice (Lammerts van Bueren et al., 2002). Organic farmers have practically no chemical tools to confront environmental fluctuations since according to the principles of organic agriculture and the European Union regulation 1990/91 agrochemicals are not allowed. Nowadays, organic farmers still depend mainly on modern varieties developed from conventional breeding programs (Murphy et al., 2007; Vlachostergios & Roupakias, 2008; Vlachostergios et al., 2010), but the majority of these varieties cannot face up efficiently problems as pest and fungus pathogens, weed competitiveness, or resource exploitation under organic farming systems (Wolfe et al., 2008; Lammerts van Bueren et al., 2003). On the contrary, intercropping offers effective weed suppression, pest and disease control, and use of soil resources under organic farming systems (Bulson et al., 1997; Theunissen, 1997; Jensen et al., 2005). The last decades, several organic farmers are experimenting and gradually adapt intercropping systems in order to benefit from the advantages of intercropping (Entz et al., 2001).

2.9.1 **Types of Intercropping**

The degree of spatial and temporal overlap in the two companion crops cab vary somewhat, but both requirements must be met for a cropping system to be an intercrop. Thus, there are several different types of intercropping, ranging from regular arrangements of the companion crops to cases where the different companion crops are intermingled. All of which have been identified (Andrews & Kassam, 1976). Some of the more significant type include:

i. Mixed Intercropping: - the plants are totally mixed in the available space without arrangement in distinct rows. It is the most basic form of intercropping.

ii. Row Intercropping: - this involves the components crops arranged in alternate rows. This means that two or more plant species are cultivated in separate alternate rows. This may also be called alley cropping. Another option is that of within-row intercropping, where the component crops are planted simultaneously within the same row in varying seeding ratios.

iii. Strip Intercropping: - With strip intercropping, several rows of a plant species are alternated with several rows of another plant species.

iv. Relay Intercropping: - this is the planting of the second crop into the standing crop at a time when the standing crop is at its reproductive stage but before harvesting. Intercropping also uses the practice of sowing a fast-growing crop with a slow-growing crop, so that the first crop is harvested before the second crop starts to mature. This practice requires some kind of temporal separation, e.g. different planting dates of the component crops so that the differential influence of weather and in particular temperature on component crop growth can be modified (Midmore, 1993). Further temporal separation is found in relay intercropping, where the second crop is sown during the growth, often near the onset of reproductive development or fruiting of the first crop, so that the first crop is harvested to make room for the full development of the second crop (Andrews & Kassam, 1976, Willey, 1979).

2.10 **Importance / Benefits of Intercropping**

2.10.1 **Efficient Resource Utilization and Yield Advantage**

The main advantage of intercropping is the more efficient utilization of the available resources and the increased productivity compared with each sole crop of the mixture (Hauggaard-Nielsen & Jensen, 2001; Hauggaard-Nielsen et al., 2001b; Zhang & Li, 2003; Szumigalski & Van Acker, 2006; Dhima *et al.*, 2007; Ofosu-Anim and Limbani, 2007; Muoneke et al., 2007; Agegnehu et al., 2008; Carrubba et al., 2008; Launay et al., 2009; Mucheru- Muna et al., 2010). An alternative to yield for assessing the advantages of intercropping is to use units such as monetary units or nutritional values which may be equally applied to component crops (Jannasch & Martin, 1999; Li et al., 1999). Yield advantage occurs because growth resources such as light, water, and nutrients are more completely absorbed and converted to crop biomass by the intercrop over time and space as a result of differences in competitive ability for growth resources between the component crops, which exploit the variation of the mixed crops in characteristics such as rates of canopy development, final canopy size (width and height), photosynthetic adaptation of canopies to irradiance conditions, and rooting depth (Midmore, 1993; Morris and Garrity, 1993; Tsubo et al., 2001). Regularly intercropped pigeon pea or cowpea can help to maintain maize yield to some extent when maize is grown without mineral fertilizer on sandy soils in sub-humid zones of Zimbabwe (Waddington et al., 2007). Intercropping maize with cowpea has been reported to increase light interception in the intercrops, reduce water evaporation, and improve conservation of the soil moisture compared with maize alone (Ghanbari et al., 2010, Andersen et al., 2007). This yield advantage occurs when the component crops do not compete for the same ecological niches and the interspecific competition for a given resource is weaker than the intraspecific competition (Willey, 1985; Jannasch & Martin, 1999).

Normally, complementary use of resources occurs when the component species of an intercrop use qualitatively different resources (Hauggaard-Nielsen & Jensen, 2001), or they use the same resources at different places or at different times (Tofinga et al., 1993). In ecological terms, resource complementarity minimizes the niche overlap and the competition between crop species, and permits crops to capture a greater range and quantity of resources than the sole crops (Hauggaard-Nielsen et al, 2001b). Improved resource use gives (in most cases) a significant yield advantage, increases the uptake of other nutrients such as P, K, and micronutrients, and provides better rooting ability and better ground cover as well as higher water use efficiency (Mucheru-Muna et al, 2010; Carrubba et al, 2008). Thus, selection of crops that differ in competitive ability in time or space is essential for an efficient intercropping system as well as decisions on when to plant, at what density, and in what arrangement. Although in this way cropping management decisions specify the design of intercropping systems, and intercrop performance is governed largely by the availability and the competition for the environmental resources (Li et al, 1999).

Research has shown that intercrops are most productive when component crops differ greatly in growth duration (Wien & Smithson, 1981; Smith & Francis, 1986; Fukai & Trenbath, 1993; Keating & Carberry, 1993). For example, when a long-duration pigeon-pea cultivar was grown in mixture with three cereal crops of different growth durations (i.e. setaria, pearl millet, and sorghum), the Land Equivalent Ratio was highest with the quick-maturing setaria and lowest with the slow-maturing sorghum (Rao & Willey, 1980). It must be noted here that Land Equivalent Ratio shows the efficiency of intercropping for using the environmental resources compared with mono-cropping with the value of unity to be the critical value. When the Land Equivalent Ratio is greater than one (unity) the intercropping favours the growth and yield of the species, whereas when the Land Equivalent Ratio is lower than one the intercropping negatively affects the growth and yield of the plants grown in mixtures (Willey & Rao, 1980). Asynchrony in resource demand ensures that the late maturing crop can recover from possible damage caused by a quick-maturing crop component and the available resources, e.g. radiation capture over time, are used thoroughly until the end of the growing season (Keating & Carberry, 1993). By contrast, when the component crops have similar growth durations their peak requirements for growth resources normally occur about the same time and the competition for the limiting growth resources is intense (Fukai & Trenbath, 1993). Intercropping advantages are not as large or as obvious as those with crops of differing growth cycles and may vary from substantial (Rao & Willey, 1980) to low (Rao, 1986), or to negative (Cenpukdee and Fukai, 1992a, 1992b).

The efficient use of basic resources in the intercropping system depends partly on the inherent efficiency of the individual crops that make up the system and partly on complimentary effects between the crops (Willey & Reddy, 1981a). Biological basis for intercropping involves complementarity of resources used by the two crops (Barhom, 2001). One of the main yield advantages in intercropping those crops sown as intercrop combination may be able to make better overall use of resources than when growing separately (Willey & Osiru, 1972). The partitioning of limiting resources among crop plants occur whenever plants are grown in association (Blade et al, 1997).

Soil fertility problems are not only an agronomic issue, but also strongly related to economic and social issues. Poor farmers are typically risk adverse and cannot afford to make large investments in relation to fertility management. Integrated nutrient management adopts a holistic approach to plant nutrient management by considering the totality of the farm resources that can be used as plant nutrients. Vesterager et al (2008) found out that maize and cowpea intercropping is beneficial on nitrogen poor soils. Maize – cowpea intercropping increases the amount of nitrogen, phosphorus and potassium contents compared to mono-crop of maize (Dahmardeh *et al*, 2010). Suryanta and Harwood (1976) reported that nutrient uptake and utilization is more efficient in corn-rice and corn-soybean intercrops than in those crops as monocrop.

Different leaf and root in intercropping systems attract more light and make use of more water and nutrients than when the leaves and roots of only one species are present. When only one species is grown, all the roots tend to compete with each other since they are all similar in their orientation and below surface depth. Similarly, the leaves of plants of the same species are directly opposite and growing at the same rate as each other, whereas the leaves of a plant of another species do not compete directly for sunlight in space and time (Seran & Brintha, 2010). In the tropics, multi-storey plants harvested in sequence can utilize the sun's energy on a year round basis. A combined leaf canopy might make better special use of light (Waddington & Edward, 1989). Intercropping between high and low canopy crops is a common practice in tropical agriculture and to improve light interception and hence yields of the shorter crops requires that they be planted between sufficiently wider rows of the taller ones. Intercropping create micro-climate that favours the lower plant growth (Azam-Ali et al., 1990).

According to Jiao *et al* (2008), maize-groundnut intercropping enhanced the efficient utilization of strong light by maize and weak light by groundnut leading to yield advantages. Soybean and maize intercropping has been attributed to better use of solar radiation (Keating and Carberry, 1993), nutrients (Willey, 1990) and water (Morris and Garrity, 1993) over monocrop. When two morphologically dissimilar crops with different periods of maturity are intercropped, light is the vital factor that determines the yields (Willey, 1979).

Availability of water in cropping system is vital to determine the growth of plant. Improvement of water use efficiency in intercropping leads to increases in the use of other resources (Hook and Gascho, 1988). Intercrops have been identified to conserve water largely because of early high leaf area index and higher leaf area (Ogindo and Walker, 2005). Under normal conditions, cereal-legume intercropping uses water equally (Ofori and Stern, 1987). Various root systems in the soil reduces water loss, increases water uptake and increases transpiration leading to creating microclimate cooler condition than the surrounding (Innis, 1997). Barhom (2001) reported that water use efficiency was the highest under soybean-maize intercropping compared with monocropping maize and monocropping soybean. Soybean – maize intercropping was the best combination system during water scarcity period (Tsubo *et al*, 2005).

2.10.2 **Insurance against Crop Failure**

One important reason for which intercropping is popular in the developing world is that it is more stable than monocropping (Horwith, 1985). Data from 94 experiments on mixed cropping sorghum/pigeon pea showed that for a particular 'disaster' level quoted, sole pigeon-pea crop would fail one year in five, sole sorghum crop would fail one year in eight, but intercropping would fail only one year in thirty six years (Rao and Willey, 1980). The stability under intercropping can be attributed to the partial restoration of diversity that is lost under monocropping. From this point of view, intercropping provides high insurance against crop failure, especially in areas subject to extreme weather conditions such as frost, drought, flood, and above all provides greater financial stability for farmers, making the system particularly suitable for labour intensive small farms. Thus, if a single crop may often fail because of adverse conditions such as frost, drought, flood, or even pest attack, farmers reduce their risk for total crop failure by growing more than one crop in their field (Clawson, 1985). Consequently, intercropping is much less risky than monocropping considering that if one crop of a mixture fails, the component crop(s) may still be harvested. Moreover, farmers may be better able to cope with seasonal price variability of commodities which often can destabilize their income. For example, if the market price may be more favourable for one crop than for others, farmers may be able to benefit from good prices and may suffer less due to poor prices for particular crops, if they grow several crops.

Intercropping maize with beans reduced nutrient decline and raised household incomes compared with monocropping of either of the two crops (Onduru and Du Preez, 2007). During the past two decades, yield increases from intercropping have been reported in several studies in semi-arid environments. On the basis of these studies, intercropping has been advocated to increase crop yield and improve yield stability in environments where water stress occurs. Combinations involving crops with slightly differing growth duration, e.g. millet and sorghum or mixtures of early- and late-maturing cultivars of the same species are used in areas with growing seasons of variable-length to exploit the occasional favourable season yet insure against total failure in unfavourable seasons (Rao, 1986). On average, late-maturing cultivars of groundnut and sorghum gave higher dry pod and grain yield, respectively, when intercropped with early maturing cultivars of the associated crops (Tefera and Tana, 2002). If the growing season is long, the late-maturing type takes advantage of the abundant resources, whereas if the growing season is short, the early-maturing type can provide a reasonable yield. Differing growing seasons may thus lead to reversals of success in such intercrops, giving more stable yield in intercropping when measured over a run of seasons (i.e. as the growing season increases).

2.10.3 **Soil Conservation**

Intercropping with legumes is an excellent practice for controlling soil erosion and sustaining crop production (El- Swaify *et al*., 1988). Where rainfall amount is excessive, cropping management systems that leave the soil bare for great part of the season may permit excessive soil erosion and runoff, eventually resulting in infertile soils with poor characteristics for crop production. Moreover, deep roots penetrate far into the soil breaking up hardpans and use moisture and nutrients from deeper down in the soil. Shallow roots bind the soil at the surface and thereby help to reduce erosion. Also, shallow roots help to aerate the soil. Reduced runoff and soil loss were observed in intercrops of legumes with cassava (El-Swaify *et al*., 1988).

In another experiment, it was observed that although soil erosion was greater with forage legume intercropping than with cassava sole cropping in the first cropping period, once they were well established and uniformly distributed, the under-sown legumes controlled soil erosion effectively (Leihner *et al*., 1996). Similarly, sorghum-cowpea intercropping reduced runoff by 20-30% compared with sorghum sole crop and by 45-55% compared with cowpea monoculture (Zougmore *et al*, 2000). Moreover, soil loss was reduced with intercropping by more than 50% compared with sorghum and cowpea monocultures.

Intercropping controls soil erosion by preventing rain drops from hitting the soil where they tend to seal surface pores, prevent water from entering the soil and increase surface erosion. In Maize-cowpea intercropping, cowpea act as best cover crop and reduced soil erosion (Kariaga, 2004). Reddy and Reddi (2007) mentioned that taller crops act as wind barrier for short crops. In brinjal-groundnut intercropping, pod weight of brinjal in monocropping was low due to absence of intercrop which leads to high water evaporation in soil surface (Prashaanth *et al*, 2009). Row of maize in a field with a shorter crops will reduce the wind speed above the shorter crops and thus reduce desiccation (Beets, 1990). Siddoway and Barnett (1976) suggested that multiple cropping systems increases soil protection by increased vegetative growth during critical erosion periods.

2.10.4 **Weed Control**

Intercropping have better weeds control. Evidence of better weed control is reasonably clear where intercropping provides a more competitive effect against weeds either in time or space than does monocropping (Seran *et al*, 2010). Weed population was reduced in brinjal-groundnut intercropping (Srikishnah *et al*, 2008). The nature and magnitude of crop-weed competition differs considerably between mono and inter crop combinations. The crop species, population density, sowing geometry, duration, growth rhythm of the component crop, the moisture and fertility status and tillage influence weed flora in cropping system.

Crop-weed competition is determined by growth habit of crop. Increased leaf cover in intercropping systems helps to reduce weed population once the crops are established (Beets, 1990). Shading showed considerable potential as a means of reducing the spread of *Cyperus rotundata* (Patterson, 1982). This re-emphasizes the possible importance of growing more than two crops in the same land at the same time. Mixed cropping reduces weed incidence (Zuofa *et al*, 1992). Makinde *et al* (2009) found out that leafy greens can be intercropped with maize to control weeds in the tropics and increase productivity. Weed suppression in maize-groundnut intercropping was reported by Steiner (1984). Intercropping maize and legumes considerably reduced the weed density compared with the monocropping maize by decrease in available light for weeds compared to monocrops (Dimitrios *et al*, 2010).

Maize-cowpea intercropping suppresses weeds and insures against total crop failure when one crop fails (Mongi *et al*, 1976). Maize –pumpkin and maize-bean intercropping reduced weed biomass by 50-66% when established at a density of 12,300 and 222,000 plants/ha for beans (Mashingaidze, 2004). Mugabe *et al* (1982) noted intercropping controlled weed effectively and reduce the harvestable biomass. Advantages from intercropping in weed control under low input conditions and increase in components crop yields leads to improved weed control (Leihner, 1979).

Weed control is an important aspect in intercropping because chemical control is difficult once the crops have emerged. This is also because normally in intercropping a dicotyledonous crop species is combined with a monocotyledonous crop species and therefore the use of herbicides is problematic. In general, intercrops may show weed control advantages over sole crops in two ways. First, greater crop yield and less weed growth may be achieved if intercrops are more effective than sole crops in usurping resources from weeds (Olorunmaiye, 2010) or suppressing the growth of weeds through allelopathy.

Alternatively, intercrops may provide yield advantages without suppressing the growth of weeds below levels observed in sole crops if intercrops use resources that are not exploitable by weeds or convert resources into harvestable materials more efficiently than sole crops. Intercropping may often result in reduced weed density and growth compared with sole crops (Liebman and Dyck, 1993). Intercrops that are effective at suppressing weeds capture a greater share of available resources than sole crops and can be more effective in pre-empting resources by weeds and suppressing weed growth. Intercrops of sorghum with fodder cowpea intercepted more light, captured greater quantities of macronutrients N, P, and K, produced higher crop yields, and contained lower weed densities and less weed dry matter compared with sole-cropped sorghum (Abraham and Singh, 1984).

Similarly, intercropping cassava with maize with nitrogen-fertilizer application gave the highest leaf area index and light interception and hence the best weed control, highest N, P and K uptake, total yields and Land Equivalent Ratio, whereas intercropping with no nitrogen application made a slight improvement in leaf area index, light interception, and weed control over cassava sole crop (Olasantan *et al*., 1994). Intercropping leek and celery in a row-by-row replacement design considerably shortened the critical period for weed control in the intercrop compared with the leek pure stand. Also, the relative soil cover of weeds that emerged at the end of the critical period in the intercrop was reduced by 41% (Baumann *et al*., 2000). Pea intercrops with barley instead of sole crop had greater competitive ability towards weeds and appeared as a promising practice of protein production in cropping systems with high weed pressures (Hauggaard-Nielsen *et al*., 2001a).

Similarly, intercrop treatments such as wheat-canola and wheat-canola-pea tended to provide greater weed suppression compared with each component crop grown alone, indicating some kind of synergism among crops within intercrops with regard to weed suppression (Szumigalski and Van Acker, 2005). Deferred seeding of blackgram (*Phaseolus mungo*) in rice after one weeding was the most remunerative intercropping combination and also it was very effective for weed smothering among non-weeded intercrops (Midya *et al*., 2005). A significant reduction in weed density and biomass for the wheat/chickpea intercrops over both monocrops of wheat or chickpea was found (Banik *et al*., 2006). Mixed cropping peas with false flax in additive arrangements had a great suppressive effect on weed coverage, i.e. 63% in 2003 and 52% in 2004, compared with sole pea (Saucke and Ackermann, 2006). Intercropping single and double rows of sorghum, soybean, and sesame with cotton was effective in inhibiting purple nutsedge density (70-96%) and dry matter production (71-97%) (Iqbal *et al*., 2007). However, intercropping of four winter cereals with common vetch did not show any significant competitive advantage against sterile oat (Vasilakoglou *et al*., 2008). On conventionally managed land, mixtures of wheat and oats and mixtures of wheat and barley at a seeding ratio 25:75 showed high yield potential than the monocrops, whereas barley mixtures also exhibited weed suppressive capabilities (Kaut *et al*., 2008).

Farmers reported that intercropping maize with improved varieties of horsegram (*Macrotyloma uniflorum*) reduced labour since less weeding was required and, in most cases, did not have a yield-reducing impact on their maize crop or on the availability of fodder (Witcombe *et al*., 2008). Recently, it was reported that intercropping maize with legumes considerably reduced weed density in the intercrop compared with maize pure stand due to decrease in the available light for weeds in the maize-legume intercrops, which led to a reduction of weed density and weed dry matter compared with sole crops (Bilalis *et al*., 2010). Similarly, finger millet (*Eleusine coracana*) intercropped with Greenleaf desmodium (*Desmodium intortum*) reduced *Striga hermonthica* counts in the intercrops than in the monocrops (Midega *et al.,* 2010).

2.10.5 **Reduction of Pest and Disease Incidence**

An important aspect of intercropping systems is their ability to reduce the incidence of pests and diseases. However, this is a very complex aspect and both beneficial and detrimental effects have been observed. Indeed, components of intercrops are often less damaged by various pest and disease organisms than when grown as sole crops, but the effectiveness of this escape from attack often varies unpredictably (Trenbath, 1993). A review of 150 published field studies in which 198 herbivore species were studied showed that 53% of the pest species were less abundant in the intercrop, 18% were more abundant in the intercrop, 9% showed no significant difference, and 20% showed a variable response (Risch, 1983). Crops grown simultaneously enhance the abundance of predators and parasites, which in turn prevent the build-up of pests, thus minimizing the need of using expensive and dangerous chemical insecticides. Mixed crop species can also delay the onset of diseases by reducing the spread of disease carrying spores and by modifying environmental conditions so that they are less favourable to the spread of certain pathogens. The worsening of most insect problems has been associated with the expansion of monocultures at the expense of the natural vegetation, thereby decreasing local habitat diversity. Results from 209 studies involving 287 pest species were analysed (Andow, 1991). Compared with monocultures, the population of pest insects was lower in 52% of the studies, i.e. 149 species and higher in 15% of the studies, i.e. 44 species. Of the 149 pest species with lower populations in intercrops, 60% were monophagous and 28% polyphagous. The population of natural enemies of pests was higher in the intercrop in 53% of the studies and lower in 9% of the monocrp. Thus, the simplification of cropping systems can affect the abundance and efficiency of the natural enemies, which depend on habitat complexity for resources. Compared with a monoculture, adding more plant species to a cropping system can affect herbivores in two ways. Firstly, the environment of the host plants, e.g. neighbouring plants and microclimatic conditions, is altered and secondly, the host plant quality, e.g. morphology and chemical content, is altered (Langer *et al*., 2007).

However, the simultaneous effect on both the environment and the quality may complicate comparisons between systems as several mechanisms can affect herbivorous insects (Bukovinszky *et al*., 2004). Changes in environment and host plant quality lead to direct effects on the host plant searching behaviour of herbivorous insects as well as indirect effects on their developmental rates and on interactions with natural enemies. Mixed cropping of cowpeas with maize reduced significantly the population density and activity of legume flower bud thrips (*Megalurothrips sjostedti*) compared with sole cowpea crop (Kyamanywa and Ampofo, 1988). Similar results were also reported with intercrops of beans, cowpea, and maize, where the reduced pest incidence was attributed to the increased populations of natural enemies favoured by intercropping. Black aphid (*Aphis fabae*) infestation of beans was greatly reduced when beans intercropped with older and taller maize plants which interfered with aphid colonization and only small proportions of beans were infested by the aphid (Ogenga-Latigo *et al*., 1993). There was significantly lower population of insects on the cowpea crop when grown in mixture with maize at specific ratios than in monoculture (Olufemi *et al*., 2001).

Intercropping maize with soybean, groundnut, and common beans reduced significantly termite attack and the consequent loss in grain yield of maize compared with maize monoculture, whereas it increased the nesting of predatory ants in maize fields. Also, soybean and groundnut were more effective in suppressing termite attack than common beans, suggesting the necessity to identify suitable legumes for each intercropping situation (Sekamatte *et al.,* 2003). *Orobanche crenata* infection on faba bean and pea was reduced when these host crops were intercropped with oat than when grown alone. Moreover, the number of *O. crenata* plants per host plant decreased as the proportion of oats increased in the intercrops (Fernandez-Aparicio *et al*., 2007). Intercropping upland rice with groundnut at low and medium populations of groundnut resulted in lower green stink bug (*Nezara viridula*) and stem borer (*Chilo zacconius*) infestations in rice compared with rice monoculture (Epidi *et al*., 2008). This demonstrates that careful selection of crop combination and plant population could lead to reduced pest incidence in upland rice. Also, intercropping cowpea with cotton proved the best in suppressing the population of thrips and whiteflies, produced high yield, and was at par with the intercrops of cotton with marigold and cotton with sorghum (Chikte *et al*., 2008). Intercropping sugar beet between the sugarcane rows reduced nematode infestation when compared with a standard aldicarb (nematicide) monocrop treatment and an untreated control (Berry *et al.*, 2009). Turnip root fly (*Delia floralis*) oviposition was found to be lower in a clover-cabbage intercrop compared with the monocultures and the reduction in the number of *D. floralis* pupae in intercropping could be explained by a disruption in the oviposition behaviour caused by the presence of clover because predation or parasitization rates did not differ between cultivation systems (Björkman *et al*., 2010).

Intercropping has been shown to be an effective disease management tool. Also, variety mixtures provides functional diversity that limits pathogen and pest expansion due to differential adaptation, i.e. adaptation within races to specific host genotypic backgrounds, which may prevent the rapid evolution of complex pathotypes in mixtures (Finckh *et al*., 2000). According to Trenbath (1993) three principles are proposed to explain yield of intercrops. The productivity of an attacked crop component may be increased several-fold through intercropping. The influence of attack on the Land Equivalent Ratio is positive where escape occurs, especially if two or more components each escape from their own specific attacker. Use of symptomless carriers of disease can lead to low Land Equivalent Ratio values. Several examples have demonstrated that intercropping can reduce considerably the incidence of various diseases by reducing the spread of carrying spores through modification of environmental conditions so that they become less favourable for the spread of certain pathogens. For example, intercropping potato with maize or haricot beans has been reported to reduce the incidence and the rate of bacterial wilt (*Pseudomonas solanacearum*) development in potato crop (Autrique and Potts, 1987).

A mixture of wheat and black medic (*Medicago lupulina*) reduced the incidence of take-all disease (*Gaeumannomyces graminis*) of wheat, a soil borne pathogen (Lennartsson, 1988). Mixtures of winter rye with winter wheat and spring barley with oats reduced the incidence of leaf fungal diseases (Vilich-Meller, 1992). Both mixed intercropping and row intercropping bean with maize significantly decreased incidence and severity levels of bacterial blight and rust compared with sole cropping (Fininsa, 1996). In the same study, common bacterial blight incidence levels were reduced in mixed cropping by an average of 23% and 5% than with sole cropping and row intercropping, respectively, whereas intercropping reduced rust incidence levels by an average of 51% and 25% relative to sole cropping and row intercropping, respectively. It was also observed that when pea was intercropped with barley, the level of ascochyta blight (*Ascochyta pisi*) was reduced and also net blotch (*Pyrenophora teres*), brown rust (*Puccinia recondita*), and powdery mildew (*Blumeria graminis*), in order of incidence, on barley during the period between flag leaf emergence and heading were reduced in every intercrop treatment compared with barley monocrop (Kinane and Lyngkjær, 2002).

Dual mixtures of grain legumes such as pea, faba bean, and lupin with barley reduced the disease incidence compared with the corresponding sole crops, with a general disease reduction in the range of 20–40% (Hauggaard-Nielsen *et al.*, 2008). It was also observed that for one disease in particular, i.e. brown spot on lupin, the disease reduction was almost 80% in the intercrops. By contrast, there was no stable effect of intercropping on bacterial blight (caused by *Xanthomonas axonopodis* pv. *vignicola*) reduction on cowpea, though intercropping cowpea with maize or cassava in alternate rows reduced bacterial blight in some cases (Sikirou and Wydra, 2008). Climbing genotypes of common beans most susceptible to angular leaf spot (*Phaeoisariopsis griseola*) had less diseased pods in the bean intercrop with maize than in the monocrop and also anthracnose (*Colletotrichum lindemuthianum*) on pods of a susceptible bean cultivar was less intense in the intercrop with maize than in the sole crop (Vieira *et al.*, 2009). Ascochyta blight (*Mycosphaerella pinodes*) severity on pea was substantially reduced in pea-cereal intercrop compared to the pea monocrop when the epidemic was moderate to severe and the disease reduction was partially explained by a modification of the microclimate within the canopy of the intercrop, in particular, a reduction in leaf wetness duration during and after flowering (Schoeny *et al*., 2010).

2.10.6 **Improvement of Soil Fertility**

Legumes enrich soil by fixing the atmospheric nitrogen changing it from an inorganic form to forms that are available for uptake by plants. Biological fixation of atmospheric nitrogen can replace nitrogen fertilization wholly or in part. When nitrogen fertilizer is limited, biological nitrogen fixation is the major source of nitrogen in legume-cereal mixed cropping systems (Fujita *et al*., 1992). Moreover, because inorganic fertilizers have contributed to environmental damage such as nitrate pollution, legumes grown in intercropping are regarded as an alternative and sustainable way of introducing N into lower input agro-ecosystems (Fustec *et al*., 2010). In addition, the green parts and roots of the legume component can decompose and release nitrogen into the soil where it may be made available to subsequent crops. In particular, under low soil N conditions the advantages of legumes in an intercrop are greater (Lunnan, 1989). The benefits of a legume intercrop with respect to nitrogen are direct transfer of nitrogen from the legume to the cereal during the current intercrop and residual effects when the fixed nitrogen becomes available on the sequential crops after the senescence of the legume and the decomposition of residues.

The direct transfer of nitrogen to companion crops occurs mainly by excretion of nitrogen from the legume nodules, representing an immediate source of nitrogen to the cereal. Thus, the use of legumes in mixtures contributes some nitrogen to the cereal component and some residual nitrogen to the following crops (Adu- Gyamfi *et al*., 2007). The main pathway of conservation of other nutrients is through the return and decomposition of crop residues (Rahman *et al*., 2009). Crop residues represent a major resource of fertilization for the small-scale farmer and manipulation of the fate of the nutrient released by the decomposition of crop residue is thus a main target for improving nutrient use efficiency of cropping systems. This is because minerals from the soil become available for development of aboveground biomass through the roots of legumes in intercropping. Transfer of other nutrients, such as P, might occur through mycorrhizal bridges (Newman, 1988).

2.10.7 **Improvement of Forage Quality**

Combining the growth of cereal forages with other crops capable of increasing the protein content of the ration has great nutritional and financial value. Combinations of cereals with legumes are seen as one way of achieving this goal. Intercropping cereals with legumes and other fodder crops to provide forage for ensiling offers one method for increasing home-grown protein sources. Most patterns of intercropping corn with soybean produced more forage than sole crops compared at the same yield ratio of corn-soybean as in the intercrop harvested mixture (Putnam *et al*., 1986). Moreover, increases in crude protein content by 11-51% were recorded for the various intercrop treatments over corn sole crop.

Intercropping field beans with wheat improved forage dry matter and percentage of dry matter compared with bean sole crop and also enhanced crude protein, neutral detergent fibre content, and water-soluble carbohydrates compared with beans and wheat sole crops (Ghanbari-Bonjar and Lee, 2002; Lithourgidis and Dordas, 2010). Forage yield and quality can be enhanced by intercropping barley or oat with pea (Carr *et al*., 2004). Also, barley intercrops with Austrian winter pea (*Pisum sativum* ssp. *arvense*) resulted in values of Land Equivalent Ratio ranging from 1.05 to 1.24 on a biomass basis and from 1.05 to 1.26 on a protein basis indicating a production advantage of intercropping (Chen *et al*., 2004).

Intercropping corn with legumes was far more effective than corn monocrop to produce higher dry matter yield and roughage for silage with better quality (Geren *et al*., 2008). Common vetch intercrops with barley or winter wheat produced higher dry matter than sole common vetch and the intercrop of common vetch with barley at a seeding ratio 65:35 gave higher forage quality than other intercrops tested (Lithourgidis *et al*., 2007). Also, intercropping common bean with corn in two row-replacements improved silage yield and protein content of forage compared with sole crops (Lithourgidis *et al*., 2008). The crude protein yield, dry matter yield, and ash content of maize forage increased by intercropping with legumes compared with maize monoculture (Javanmard *et al*., 2009).

Furthermore, intercropping legumes with maize significantly reduced neutral detergent fibre and acid detergent fibre content, increasing digestibility of the forage. It is evident from the above that intercrops of maize with legumes can substantially increase forage quantity and quality and decrease the requirements for protein supplements compared with maize sole crops (Javanmard *et al*., 2009). Maize and cowpea intercrops gave higher total forage dry matter digestibility than maize or cowpea sole crops and led to increased forage quality (crude protein and dry matter digestibility concentration) than maize monoculture and higher water -soluble carbohydrate concentrations than sole cowpea (Dahmardeh *et al*., 2009).

2.10.8 **Lodging Resistance / Protection to Prone Crops**

Intercropping can provide better lodging resistance for some crops highly susceptible to lodging (Assefa and Ledin, 2001). Lodging, which is commonly observed in some crops, frequently can reduce plant growth severely. Some of the damage is often attributable to subsequent disease infections and mechanical damage, whereas loss of plant height reduces efficiency of light interception. The ability of forage crops to remain standing is particularly important because lodged forage crops may not be able to photosynthesize and translocate nutrients and water efficiently, which can result in loss of yield. In addition, lodged crops may slow harvest operations or may cause harvest loss. Improved standard ability commonly results in increased harvestable yield, improved crop quality, and increased efficiency of harvest.

Lodging-prone plants, e.g. those that are prone to tip over in the wind or heavy rain, may be given structural support by their companion crop (Trenbath, 1976). Delicate or light sensitive plants may be given shade or protection and thus wasted space can be utilized. The introduction of legumes intercropped with non-legumes has drawn considerable interest because not only is there the ability to improve cash returns by increasing land use efficiency, but the inclusion of component crops such as canola or mustard as an intercrop will also greatly improve lodging resistance of grain legumes, thereby increasing yield, product quality, and harvest efficiency (Waterer *et al*., 1994). This is because legumes are sensitive to shading, resulting in thinner stems and easier to lodging. Lodging of pea in mixed stands with oat was prevented to some extent because oat provided support to pea and also acted as a wind barrier (Rauber *et al*., 2001). Similarly, Cowell *et al*. (1989) observed advantageous impacts like this in mixed stands of lentil (*Lens culinaris*) and flax (*Linum usitatissimum*).

2.10.9 **Promotion of Biodiversity**

Intercropping is one way of introducing more biodiversity into agro-ecosystems and results from intercropping studies indicate that increased crop diversity may increase the number of ecosystem services provided. Intercropping or crop mixtures mimic natural ecosystem and are more dynamic biologically than sole crops. Crops grown in mixtures have been found to utilize resources better than sole crops (Chinaka and Obiefuna, 2000). Higher species richness may be associated with nutrient cycling characteristics that often can regulate soil fertility (Russell, 2002), limit nutrient leaching losses (Hauggaard-Nielsen *et al*., 2003), and significantly reduce the negative impacts of pests (Bannon and Cooke, 1998), and also including that of weeds (Hauggaard- Nielsen *et al*., 2001a).

Intercropping of compatible plants promotes biodiversity by providing a habitat for a variety of insects and soil organisms that would not be present in a single crop environment. Stable natural systems are typically diverse, containing numerous different kinds of plant species, arthropods, mammals, birds, and microorganisms. As a result, in stable systems, serious pest outbreaks are rare because natural pest control can automatically bring populations back into balance (Altieri, 1994). Therefore, on-farm biodiversity can lead to agroecosystems capable of maintaining their own soil fertility, regulating natural protection against pests, and sustaining productivity (Thrupp, 2002; Scherr and McNeely, 2008). From this point of view, crop mixtures which increase farmscape biodiversity can make crop ecosystems more stable and thereby reduce pest problems. Increasing the complexity of the crop environment through intercropping also limits the places where pests can find optimal foraging or reproductive conditions.

2.10.10 **Economic Benefits**

Intercropping often provides higher cash returns than growing one crop alone (Kolawole *et al*, 2011). Intercropping occupies greater land use and thereby provides higher net returns (Seran and Brintha, 2009a). Kalra and Gangwar (1980) reported that intercropping helps in increasing farm income on sustained basis. Intercropping commonly gave greater combined yields and monetary returns than obtained from either crop grown alone (Ahmad and Rao, 1982). Intercropping capsicum and vegetable cowpea gave high net return compared to monocropping (Seran and Brintha 2009b).

2.11 **Limitations of Intercropping**

Depending on crops mixed, competition for light, water and nutrients, or allelopathic effects that may occur between mixed crops may reduce yields (Cenpukdee and Fukai, 1992a, 1992b; Carruthers *et al*., 2000; Santalla *et al*., 2001; Yadav and Yadav, 2001; Olowe and Adeyemo, 2009). Selection of appropriate crops, planting rates, and changes in the spatial arrangement of the crops can reduce competition. A serious disadvantage in intercropping is thought to be difficult with practical management, especially where there is a high degree of mechanization or when the component crops have different requirements for fertilizers, herbicides, and pesticides. Additional cost for separation of mixed grains and lack of marketing of mixed grains, problems at harvest due to lodging, and grain loss at harvest also can be serious drawbacks of intercropping.

Mechanization is a major problem in intercropping. Machinery used for sowing, weeding, fertilizing, and harvesting are made for big uniform fields. Harvesting remains a great problem, but it may be more easily overcome where the intercrops are harvested for forage or grazed. In the developing countries, the work needed in the field is mainly done by hand with simple tools because intercropping is very labour intensive. In these countries however, where manual labour is plentiful and cheap, it is not necessary to invest in expensive machinery especially for intercropping. From this point of view intercropping has no disadvantages, but for intercropping on a large scale basis, mechanization is generally believed to be impossible or inefficient (Vandermeer, 1989).

2.12 **Crop Combinations in Intercropping**

Careful planning is required when selecting the component crops of a mixture, taking into account the environmental conditions of an area and the available crops or varieties. For example, faba bean yielded more in a maize/faba bean intercrop, but not in a wheat/faba bean intercrop (Fan *et al*., 2006). Moreover, total biomass, grain yield, and N acquisition of faba bean increased considerably when intercropped with maize, but the values decreased when faba bean intercropped with wheat, irrespective of nitrogen fertilizer application, indicating that the legume could gain or lose productivity in an intercrop situation depending on the companion crop. Similarly, significant yield and monetary advantage was found in the case of intercrops of groundnut with maize than intercrops of groundnuts with sorghum or pearl millet (*Pennisetum glaucum*) (Ghosh, 2004).

It is particularly important not to have crops competing with each other for physical space, nutrients, water, or sunlight. Examples of intercropping strategies are planting a deep-rooted crop with a shallow-rooted crop, or planting a tall crop with a short crop that requires only partial shade. Component crops differ with geographical location and are determined by the length of growing season and the adaptation of crops to particular environments. Maize seems to dominate as one of the cereal component of intercrops, often combined with various legumes. The combination of cereals with legumes in mixed cropping offers particular scope for developing energy-efficient and sustainable agriculture due to the nitrogen fixation capability of the legume and the provision of protein in the form of either grain or forage. There are many different types of species that can be used for intercropping: annuals, e.g. cereals and legumes, perennials including trees, or a mixture of the two. In the latter case the term that is used mostly is agroforestry.

In areas with annual rainfall of less than 600 mm and rather short growing seasons such as northern Nigeria, early-maturing and drought-tolerant crops such as millet and sorghum often dominate. In areas with annual rainfall greater than 600 mm cereals such as wheat, barley, oat, and rye, and legumes such as pea, lupins, and common vetch of ranged maturity are often used. In tropical and subtropical regions, the cereals primarily used are maize, sorghum, millet, but less rice, whereas the legume crop is normally cowpea, groundnut, soybean, chickpea, bean, and pigeon-pea. In these systems, early- and slow-maturing crops are used that are combined to ensure efficient utilization of the growing season length.

In temperate regions such as Southern Europe with warm climates, intercrop combinations consist of wheat, oats, rye, or barley as the cereal component and field bean, vetch, lupin, or soybean as the legume component (Malézieux *et al*., 2009; Lithourgidis and Dordas, 2010). In areas with high rainfall in the West Africa, maize and cowpea are used, whereas in South and Central America, maize with different types of beans are mainly used. In India, short-duration sorghum and millet are grown with pigeon-pea that matures 90 days later than the cereal. In Asia, rice and other cereals with legumes are grown in high rainfall areas. It is not clear which species are the best for intercropping since there are conflicting reports depending on the environment. Some of the most common crop mixtures are those of winter cereals with a legume. One of the most common cereals that are used in temperate regions is barley (*Hordeum vulgare* L.) which was found to produce higher quality forage than oat, triticale, and wheat (Thompson *et al*., 1992; Qamar *et al*., 1999). On the other hand, another study showed the most suitable cereal for intercropping with common vetch is oat (*Avena sativa* L.) (Thomson *et al*., 1990). However, it was also proposed that wheat (*Triticum aestivum* L.) is the most suitable cereal for intercropping (Roberts *et al*., 1989).

Legumes are mostly preferable to non-legumes because they supply their own N and have higher protein content, but in production agriculture where N is not limited or where legumes do not perform well, non-legumes or mixtures of legumes and non-legumes may be more advantageous. When choosing the appropriate forage to be grown, farmers should consider the need for roughage and protein, the costs of N fertilizer for crops, protein for animal feed stuff, and the rotational role of the crop (Papastylianou, 1990). Also, crop morphology and the duration of life cycle have been used to distinguish crop combinations, crops of similar height and growth duration such as barley and oats of similar morphology and different growth duration e.g. 6-month sorghum and 3-month millet annual or biennial crop with those of longer growth duration such as millet and cassava or soybean and sugarcane, annual crops of cereals and legumes such as sorghum and pigeon-pea and cowpea.

2.12.1 **Sequence of Intercropping Systems**

The traditional practice of intercropping major food crops under the shifting cultivation system has persisted in Nigeria. In northern Nigeria, cereals dominate the farming system with one or several crops in a mixture or rotation (Weber *et. al,* 1996). The mixtures mostly found are: sorghum/millet/cowpea, sorghum/millet, sorghum/groundnut, sorghum/millet/groundnuts and sorghum/cowpea. Others are cassava/maize/cowpea, cassava/maize/yam, yam/maize/cowpea, cassava/melon/vegetables and sorghum/millet/cowpea/okra/maize/benniseed/roselle (Muhamman and Gungula, 2006). In southeastern Nigeria, the cropping system is yam or cassava based (Ibeawuchi and Ofoh, 2000) in mixtures with maize and cocoyams and interspersed with tree crops such as oil palm, orange and mango (Ugwu, 2006). According to Okigbo (1978) and Nwosu (1973), cropping combinations that involve cassava under various ecological conditions in West Africa include; yam/cassava or pineapple/cassava, yam/maize/cassava, cocoyam/plantain/yam/cassava, yam/cocoyam/pigeon-pea/cassava and yam/cocoyam/maize/cassava. Other identified crop combinations practiced in Nigeria include; yam/maize/melon/cassava, yam/maize/melon/groundnut/vegetables/cassava. Production of *Moringa oleifera* under these cropping systems will demand adjustment by farmers. The implication is a reduction in the area of land used for the cultivation of staple crops in order to accommodate Moringa (Ojiako *et al*, 2011).

2.12.2 **Interactions in Crop Combinations**

i. Cassava/maize interaction:

Maize is the principal cereal associated with cassava in the derived savanna (Okigbo, 1981). Both cassava and maize are planted either at the same time in the beginning of rains or cassava is relay planted in maize from 4 weeks after planting to as late as after physiological maturity, stage with maximum dry weight (Murreno and Hart, 1978). In the humid tropics, cassava is known to be mixed with a wide variety of crops. Some principal staple food crops and subsidiary crops can be identified as grown in intercropping systems. Okigbo (1978) and Ezeilo *et al* (1975) reported cassava-maize, cassava-yam and cassava-yam-maize as dominant mixed cropping system on acid ultisol in the forest zone of Southern Nigeria, while Wilson and Agboola (1979) claim that maize-cassava mixed cropping systems are the most popular and wide spread in West Africa. They attributed this popularity to high compatibility and complementarity of the crops, the fast-growing maize exploiting the environment early and the slow-growing cassava exploiting it later. During plant interactions, many indirect effects on the environment can also affect neighbouring species not by addition or removal of some factor but by affecting conditions such as temperature, soil and sun insulation or wind movement.

ii. Corn/bean/squash interactions:

Farmers throughout tropical area traditionally grow an intercrop of corn, beans, and squash and these crops optimize available resources (Sullivan, 2003). The corn towers high over the other two crops, and the beans climb up the corn stalks. The squash plants sprawl along the ground, capturing light that filters down through the canopy and shading the ground. The shading discourages weeds from growing (Sullivan, 2003).

2.12.3 **Soil – Plant Interaction in Intercropping System**

In cropping system where crops are grown in close association to each other, the activity and response of one crop affect another crop. This is soil-plant interaction. The interaction may be competitive or complementary. If one crop affect the growth of another crop, it is termed as competitive and if one crop helps the growth and production of another crop, it is termed as complementary. Different types of interaction are governed by light, water, nutrient, oxygen and carbon dioxide required for growth of the plant (Singh, 2002).

Light is the foremost component for the growth of plant. It is the photosynthesis through which the plants transform light energy into chemical energy to produce food, feed and other materials. When crops of different height combinations are grown together, maximum light interception takes place by top storey crop. Of course, it is largely governed by growth and canopy spread of the plant. For instance, coconut plant transmits only 20% of light to the ground when it is 8-10 years old and when plants becomes 40 years old, light transmission increases to about 50%. Light transmission through top storey component hastens as it grows taller and taller from the ground (Singh, 2002). Accordingly, while selecting component crop for a particular type of cropping system, spacing is taken into account. Nutrient and moisture are another component of soil-plant interaction. Plants which are of aggressive in nature, absorbed more nutrients and deprives another plant of nutrient. In such circumstances, roots grow less towards aggressive component and more towards non-aggressive ones. Under moisture-nutrient competitive conditions, plants may have increased root/shoot ratio (Singh, 2002).

2.12.4 **Plant Interactions and its Types**:

In intensive cropping, when crops are grown in association (intercropping) or sequence (sequential cropping), interaction between different component crop species occurs, which is essentially a response of one species to the environment as modified by the presence of another species (commonly referred to as interference or interaction). Interaction can be divided into two, namely: Removal Reactions of one Plant on its Environment and Additive Reactions when something is added.

When some factor is removed from the environment, the resulting response of neighboring species can be negative, positive or neutral. Competition among plants is one example for removal interactions. Some such additive interactions are allelopathic and symbiosis. When crops are grown in sequence, residual effect of the preceding crop influences the succeeding crop. However, this may be harmful or helpful. The toxic chemicals (allelopathic chemicals) left in the soil by the roots of sunflower crop inhabit germination of the succeeding crop. The stubbles of sorghum with high C: N ratio cause immobility of nitrogen, thus causing nitrogen deficiency in early stages of the succeeding crops. The roots of legume crops and their residues add nitrogen to soil. The plant interaction may be:

1. **Competitive Interaction**: - One species may have greater ability to use the limiting factor(s) available and gain at the expense of the other and this is called as competitive interaction or interference. Or when one or more growth factors are limiting, the species that is better equipped to use the limiting factor(s) will gain at the expense of the other and this is called as competitive interaction. In mixed crop communities, if the associated species are to share their growth from a limited pool of resources such as light, water or nutrients, then it is non-competitive interaction or interference.

2. **Non-competitive Interaction**: - If the crops are grown in association and the growth of either of the concerned species is not affected, such type of interaction is called non-competitive interaction or interference. Or if these resources (growth factors) are present in adequate quantities, as a result of which, the growth of either of the concerned species is not affected, then it is non-competitive interaction or interference.

3. **Complementary Interaction**: If one species is able to help the other, it is known as complementary interaction. Or if the component species are able to exploit to supply of growth factors in different ways (temporal or spatial) or if one species is able to help the other in supply of factor (like legumes supplying part of N fixed by symbiosis to non-legumes), it is complementary interaction or interference. This also referred to as Annidations. Complementary interaction in plant (annidation) augments yield and performance of both crops. In multi-tier cropping system, annidative effect is utilized. In coconut-black pepper-turmeric, coconut has high evaporative demand and it is grown under open sunny situation. However, it has requirements for high humidity which is provided by another storey crop by further intensifying shade and thus favour coconut yield. On the other hand, black pepper requires partial shade and support for growth and production which is provided by coconut. Thus, all components benefited mutually. This is annidation in space dimension. Annidation in time dimension is also achieved when crops with nutrients requirement at different periods are grown together (Singh, 2002).

2.12.5 **Plant – Environmental Interaction in Intercropping Systems**

Natural ecosystems inhibits the capacity for both competition and cooperation, although there is far more cooperation in nature than competition (Sullivan, 2003). Cooperation is typified by mutually beneficial relationships that occur between species within communities. The ability of different plant species to cooperate to mutual advantage is often the result of physical changes in plant structures or manipulation of the surrounding environment. This principle of mutualism can be applied to plant interactions in an agricultural systems in the form of intercropping system involving relay cropping. One major concern regarding intercropping system on infertile soil is the accelerated depletion of mineral nutrients when both crops are harvested.

Intercropping often result in accelerated harvesting of soil resources as a short-term gain for farmers with limited resources. The concern is reduced if nurse crops are not harvested from the system but instead their capacity to capture and recycle nutrients for use by the primary crop is used to the farmers advantage. Multi-species systems may maximize beneficial interactions while minimizing competition. In comparison with homogeneous pure cropping systems, different species that are sharing a common space interact together and with the environment in an information feedback loop, where the environment affects the plants and the plants reciprocally affect the environment. These types of interactions give them a set of properties including competition for space, competition for light between canopies, and competition for water and nutrients between root systems. The agronomic advantages of multi-species systems are the result of differences in the competitive ability for growth factors between plant components. In terms of competition, this means that the components are not competing for the same ecological niches and that interspecific competition is weaker than intraspecific competition for a given factor. According to Vandermeers (1989), the ecological niche concept underlies the fact that the different species involved may have different resource requirements at different times, as well as different sources of nutrition, e.g. root exploitation of superficial soil layers by one species versus deeper exploitation by the other, different growth patterns, or different affinities for the same nutrient, e.g. nitrogen in NO^-_3 form versus NH^+_4 form. Plant interaction in an ecosystem can be viewed as:

i. ***Below-ground interactions***:

Little or none is known about root interaction in intercropping system (Trenbath, 1974). Study have shown that yield advantages in mixtures of oat varieties to be the result of differential root growth. Another view is that, differences in rooting patterns are the result of mutual cooperation of root systems and differences in root system particularly rooting depth. Lateral root spread and root density have been found to affect competition for water and proper management of root systems can minimize root competition for water (Haynes, 1980). According to Willey (1979), root avoidance also occur in monoculture and increased exploration of the soil matrix by roots in intercropping systems which does not have a direct advantage over monoculture. However, below-ground competition occurs when plants decrease the growth, survival or fecundity of neighbours by reducing available soil resources.

Contrary to above-ground competition, which primarily involves a single resource, light, plants compete for a broad range of soil resources including water and at least 20 mineral nutrients that differ in molecular size, valence, oxidation state and mobility within the soil (Casper and Jackson, 1997). The components of the mixture may be complementary in a spatial sense by exploiting different layers of the soil with their root systems. Components of a mixture may complement each other nutritionally (different needs in quantities, preferential use of different chemical forms). Mixtures of leguminous and non-leguminous species are well known in that regard, and provide repeatable examples of over yielding due to nutritional complementation. To evaluate those interactions, three aspects have to be taken into account that address the resource supply to the roots, the characteristics of the root system, and the demand for water and carbon allocation, respectively:

(i) Resource supply to the roots involves four main processes: the distribution of resources in the soil and their availability, which depends on soil biophysical and chemical properties, interception by the roots (<10%), mass flow, which affects water and mobile nutrients such as NO^{-}_{3} , and diffusion, which affects nutrients such as P and K.

(ii) Root system characteristics include morphological plasticity – root location in time (Caldwell and Richards, 1986) and space (de Willigen and Van Noordwijk, 1987), investment in root biomass, root length or surface – and physiological plasticity – rate of resource uptake in relation to enzyme functioning.

(iii) The demand for water: Water distribution depends on the partitioning of evaporative demand between the species' components, and on soil evaporation (Ozier-Lafontaine *et al.*, 1997, 1998).

An analysis of the belowground processes and resource use by plants presents tremendous challenges as there are still general methodological difficulties despite the advances made in techniques and equipment design. For example, roots of the component plants can intermingle (Gregory and Reddy, 1982), making the task of separating the respective root systems very cumbersome. Staining techniques generally fail to distinguish one root system from another. Other possibilities, such as isotopic discrimination of 13C between C3 legumes and C4 cereals are efficient but require special equipment (Wong and Osmond, 1991; Lichtfouse, 1997).

ii. ***Above-ground interactions***:

This is viewed on the management of light, water, mineral nutrients, oxygen and carbon dioxide are all managed for plant growth. Competition occurs when two plants vie for the same nutrition and water requirement in the same space and time. The growth of two or more crops often results in competition for limited essential resources. One of the plants usually receives less than it requires. Overlapping in space and time, the growth of two or more crops often results in decreased yields of both crops due to competition for limited essential resources (Haynes, 1980).

Of all the major environmental factors that contribute to reported multispecies system merits, the capture and use of solar radiation is the one that has received the most attention (Keating and Carberry, 1993). Over yielding by mixtures has often been attributed to a more efficient use of light by their canopies. Trenbath (1974) reported that an "ideal" leaf arrangement could be approached by a mixture of a tall erect-leaved genotype and a short, prostrate-leaved genotype. Among the above-ground factors, the factors that affect the light regime of plant canopies are the amount of light and quality of incident radiation, the canopy architecture and the optical properties of the leaves and the soil (Sinoquet and Caldwell, 1995). In comparison with pure, uniform stands, light capture depends on:

(i) The fraction of incident photosynthetically active radiation (PAR) that is partitioned by heterogeneous canopies and intercepted by each species, and

(ii) The efficiency with which intercepted radiation is converted by photosynthesis. While direct measurement techniques have been slow to develop, light modelling within multispecies systems has quickly matured (Sinoquet and Caldwell, 1995).

A number of models are now available with different levels of complexity for multispecies systems, but field applications face some practical limitations. Compared with pure stands, multispecies systems contain significant spatial variations in leaf area density and leaf angle distribution that are difficult to simulate.

2.13 **Assessing Intercrop Productivity and Competitiveness**

One of the most important reasons to grow two or more crops together is the increase in productivity per unit area of land. Researchers have designed a method for assessing intercrop performance as compared to pure stand yields. In research trials, they grow mixtures and pure stands in separate plots. Yields from the pure stands, and from each separate crop from within the mixture, are measured. From these yields, an assessment of the land requirements per unit of yield can be determined. This information tells them the yield advantage the intercrop has over the pure stand, if any. They then know how much additional yield is required in the pure stand to equal the amount of yield achieved in the intercrop. The calculated figure is called the Land Equivalency Ratio (LER). To calculate an LER, the intercrop yields are divided by the pure stand yields for each component crop in the intercrop. Then, these two figures are added together. Here's the equation for a corn/pea intercrop where the yields from pure corn, pure peas, and the yields from both corn and peas growing together in an intercrop are measured.

(Intercrop corn/pure corn) + (Intercrop pea/pure pea) = LER

When an LER measures 1.0, it tells us that the amount of land required for peas and corn grown together is the same as that for peas and corn grown in pure stand (i.e., there was no advantage to intercropping over pure stands). LERs above 1.0 show an advantage to intercropping, while numbers below 1.0 show a disadvantage to intercropping. For example, an LER of 1.25 tells us that the yield produced in the total intercrop would have required 25% more land if planted in pure stands. If the LER was 0.75, we know the intercrop yield was only 75% of that of the same amount of land that grew pure stands (Francis and Decoteau, 1993).

The assessment of crop mixture productivity is a useful tool for evaluating yield advantages in intercropping systems. Various competition functions which are based on relative yields were introduced by ecologists. The various yields assessments are Relative Yield Total (RYT), Land Equivalent Ratio (LER), Area x Time Equivalent Ratio (ATER), Monetary Equivalent Ratio (MER), Energy Equivalent Ratio (EER) and Relative Crowding Co-efficient and Aggressivity (RCCA). Current methods of comparing intercrops with monocrops generally fits into one or two types viz:

a) Those in which absolute yields of monoculture and intercrops are compared, and
b) Those in which a relative value is calculated among other indices used in evaluating crop performances under intercropping.

The evaluation of yield from intercropping situation is much more complex than sole cropping. The harvested yield of one crop make very little sense if added arithmetically to the harvested yield of another crop. In order to solve this problem, the concept of relative yield have been evolved. The relative yield of each component crop in an intercropping situation is the yield of each component in the intercropping situation divided by what the crop would have yielded as a sole crop, covering the same area as the intercrop and managed at the same level (Onwueme and Sinha, 1991).

The sum of the relative yields of the various component crops in the intercrop is sometimes called the relative yield total. A little reflection will show that this sum is also an indication of how many times the land area used for the intercrop would be required to produce the same yields of the component crops when they are grown as sole crops. The relative yield total is therefore more conventionally referred to as the Land equivalent Ratio (LER).

The biological productivity of the intercrops per unit of ground area could also assessed as a ratio of intercrop to sole crop using the land equivalent ratio (LER) defined by Willey (1979). For an intercrop comprising of three species ‘a’, ‘b’ and ‘c’, $LER_{abc} = LER_a + LER_b + LER_c$.

2.13.1 **Yield advantage in intercropping**

Yield is taken as primary consideration in the assessment of the potential of intercropping practices. In legumes and non-legume intercropping, yield of non-legume increased in intercropping as compared with mono-cropping. It is found that by inter-cropping, land was effectively utilized and yield was improved. The crops are grown together because of higher yields and greater biological and economic stability in the system. Land equivalent ration (LER) is the most common index adopted in intercropping to measure the land productivity. It is often used as an indicator to determine the efficacy of intercropping. LER>1 indicates greater efficiency of land utilization in the intercropping system. It is due to greater efficiency of resources utilization in intercropping or by increased plant density. LER shows advantage of cereal legume intercropping. Tsubo *et al* (2005) stated legume-cereal intercropping generally more productive than monocrop. When two crops are grown together, yield advantages occurs because of differences in their use of resources. Inter-cropping gives a greater stability of yield over monoculture and intercropping was more productive than the sole crop grown on the same area of land. LER value exceeding unity in radish vegetable + amaranth intercropping indicates yield advantages from inter-cropping compared to monocropping. Legume and non-legume intercropping increases total grain and nitrogen yield. In intercropping, higher yield and greater stability over mono-cropping was reported. Maize yield was affected by intercropping with soybeans. Maize + soybean intercropping gave LER of 1.18. Intercropping often provides higher cash returns than growing one crop alone.

Intercropping occupies greater land use and thereby provides higher net returns. Intercropping helps in increasing farm income on sustained basis. Intercropping commonly gave greater combined yields and monetary returns than obtained from either crop grown alone. Net return of radish and vegetable amaranth intercropping correlated with vegetable amaranths plant density. Intercropping capsicum and vegetable cowpea gave high net return compared to mono-cropping (Azam-Ali *et al*; 1990).

2.14 **Compatibility of Component Crops in Intercropping Systems**

When two or more plant species are grown in close proximity as intercropping, there is the tendency for them to compete for environmental resources of the air and the soil. Most reports of the study on this subject are in agreement that, apart from few instances, when some plant species secrete obnoxious chemical substances which have antagonistic influence on other (neighbouring) plant species, the major bone of contention for the competing plants are light (solar radiation), water and mineral nutrients (Trenbath, 1974; Pam, 2002).

Tall plants in a mixture always has an advantage over short plant in competition for solar radiation. Considering the fact that plant height is a factor in the struggle for light. The differences in few millimeters high can be very decisive, because the few extra lengths provide ample leverage for the foliage of the possessor plant to overlap and consequently create a disadvantage in the shorter component crop (Pam, 2002). However, some crops can tolerate some degree of shading. Midmore (1988) and Kurupuarachi (1990) have all reported some significant improvement in tuber yield with varying degrees of shading in intercropping with maize. The implication of this is that some amount of shading is even desirable for some crops especially in the warm tropical regions. This shade serves as some sort of cooling agent to the microclimate of some crops (Midmore 1983, 1988 and 1990).

The overall quality of solar radiation that is intercepted for photosynthetic processes in the complexity of the intercropping arrangement in an area that has not been studied thoroughly but some scientist have suggested that the higher yields obtained from mixed cropping as compared to sole crops can be attributed to better utilization of environmental resources mainly solar radiation quality (Ghaffarzadeh *et al*, 1997). Harris (1998) stretched the point to emphasize that between 700-800MJM^{-2} of radiation is wasted before full canopy is developed in potato fields but intercropping with fast growing crops like maize will reduce those losses to insignificant level.

In the case of essential mineral nutrients, the competition by component crops in a mixture, appears to be more critical for nitrogen because of its mobility in the soil compared to phosphorous and potassium (Trenbath, 1974). However, if a deficiency gradient is established in any soil for certain element (s), the affinity for them supersedes other factors assuming that other soil, plant and atmospheric considerations are known with distinct growth patterns and equally varied architectural disposition of the two crops that are biological potential for effective exploration of the rhizosphere. When the two crops are grown together, there is a more severe effect of the deficiency at nitrogen followed by phosphorous and potassium (Ifenkwe *et al*, 1990). The intensity of the competition for moisture increases when it coincide with the peak moisture requirement stages of the crops, either individually or collectively, such periods like germination, active growth, translocation of photosynthates etc. (Pam, 2002).

2.15 **Managing Intercrop Systems**

In intercropping system, crops are grown simultaneously. Management practices aim to provide favorable environment to all the components, exploit favorable interaction among the component crops and minimize competition among the component crops. Many combinations of crops have been grown or experimented with as mixed or relay intercrops. Some of these include sunflowers grown with black lentils, wheat with flax, and canola with flax. Other combinations include cucumbers, beans, celery, and chives in China; upland rice, corn, and cassava in Indonesia and in various parts of the tropics corn and cassava, corn and peanut, sorghum and millet, and sorghum and pigeon pea grown together. Frequently these cropping combinations involve a short and a tall crop both planted at the same time. In many cases the tall crop is harvested first. For example, corn grown with a shorter plant would be harvested first, then peanut or sweet potato would be harvested later. Another pattern would be planting two tall crops with different growth rates. In relay intercrops, different planting dates are used so that one crop might mature sooner. Corn or sorghum, requiring three months to mature, can be grown with pigeon pea, requiring 10 months to maturation.

There are five distinct aspects to successful multiple cropping. These are 1) detailed planning, 2) timely planting of each crop, 3) adequate fertilization at the optimal times, 4) effective weed and pest control, 5) efficient harvesting (Bowen and Bernard, 1986). Before any fieldwork is begun, adequate planning should be done.

Planning covers selection of crop species and appropriate cultivars, water availability, plant populations and spacing, labor requirements throughout the season, tillage requirements, and predicted profitability of the intercrop. These and other parameters need to be evaluated before spending money on inputs.

As with any crop, seed germination and seedling establishment is the most critical growth phase of the entire season. A good seedbed is needed to get a good stand. Delayed planting may reduce yield since crop development many not coincide with the optimal seasonal growth periods.

Planning fertilization for intercrops can be challenging, as the full needs of both crops must be met. Generally, there is little information available on how to go about this. One possibility would be to ask for soil test results for each crop separately, then formulate a recommendation that will cover the needs of both crops to be grown. Such recommendations are generally 10% to 30% higher than rates for individual crops.

As with any crop, also accounting for residual or carryover fertility from past crops saves money. Carryover fertility from intercrops may well be lower than that of pure stands because of the two crops having different root types and feeding habits.

Weed and pest control needs in intercrops will likely be different than in pure stands. Some disease incidence such as soybean or mung bean rusts may increase when aggravated with high corn populations and over-fertilization. Any disease or pest that prospers under shady conditions could increase when grown under a taller crop such as corn or sunflowers. In many cases insect pests are lower when two or more crops are grown together.

Harvesting mixed intercrops has been a major limitation to their adoption in mechanized farming. As mentioned earlier, if the crop cannot be harvested by animals, or all together as feed, you're left with hand harvest. Some crops such as flax and wheat have been harvested together and mechanically separated. Any other mechanized harvest efforts must get one crop without damaging the other. One example would be harvesting wheat over the top of a young stand of soybeans growing beneath the grain heads. All intercropping strategies –

especially mixed intercropping – require advanced planning and keen management. Success will likely be the reward for such efforts.

However, effective management of intercropping system could be achieved through the following practices:

a. **Seedbed Preparation:** The objective of land preparation is to establish an ideal zone for the seedling that minimizes the stress. Potential stress condition include inadequate or excess moisture, unfavorable temperature for a given species, soil crusting, weeds, residue of preceding crop and insect or pathogen attack. Important of seedbed is the same in both conventional (monoculture) and in multiple cropping. Seedbed preparation depends on the crop. Deep rooted crops responds to deep ploughing while for most of cereal shallow tillage is sufficient. The crops with small seed require fine seedbed, cotton, and maize, planted on ridges, certain crops on flat seedbed. Since more than one crop is planted in intercropping, the seedbed is generally prepared as per the needs of base crop. Sugarcane planted in furrow and intercrop sown on ridges. In Groundnut + red gram intercropping system, flat seedbed is prepared for sowing crops. However, ICRISAT is recommending broad bed and furrow for black soils. In rice + maize intercropping system, ridges and trenches are formed. Maize is planted on ridges and rice in trenches (ICRAF, 2001).

b. **Crop Varieties:** The varieties of component crop in intercropping system should be less competitive with the base crop and peak nutrient demand period should be different from the base crop. Minimum difference between the maturity periods of two components should be of 30 days. Hybrids varieties of sorghum like CSH - 6, CSH - 9 are suitable for intercropping with long duration variety of red gram like C11 and LRG 30 because of wider gap between maturity periods. The varieties selected for intercrop should have thin leaves, tolerant to shading and less branching. If the base crop is shorter than intercrop, the intercrop should be compact with erect branching and its early growth should be slow. The characteristics of the base crop should be as in sole crop.

c. **Sowing:** Practices of sowing are slightly altered to accommodate inter - crop in such a way that it cause less competition to the base crop. Widening inter row spacing of cereal component to accommodate more rows of component legume crop improves legume yield and efficiency of the intercrop system. Sowing of base crop is done either as paired row, paired – wider row or skip row of base crop are brought close by reducing inter row spacing. The spacing between two pairs of rows is increased to accommodate the inter crop. Such row arrangement of base crops within the rows improves the amount of light transmitted to the lower component crop, which can enhance legume yield in cereal + legume intercropping system. For example – the normal row spacing in Rainfed cultivation is 30 cm. The row spacing is reduced to 20 cm between paired rows and 50 cm spacing in two pairs. The spacing in paired row planting designed as 20/50 cm indicates that the spacing between two rows in pairs is 20 cm and among the pairs 50 cm. Similarly, pearl millet is planted with row spacing 30/60 cm in paired row planting. These changes in crop geometry do not alter the yield of base crop, but intercrops are benefited to some extent. When alternating pairs of sorghum rows 90cm with two rows of an associated legume, Onwueme and Sinha (1991) found that LER was greater compared at 60cm between rows with two rows of the legume in between. Planting in fixed ratio of intercrop is most common. The intercropping system of groundnut + red gram is either in 5:1 or 7:1 ratio and sorghum + red gram in 2:1 ratio. In these cases the normal three tined or four tined seed drill can be used without any modification. The hole(s) pertaining to intercrop row in the hopper is/are closed with a piece of cloth in that row, intercrop is sown with alkali or kera. For higher yields, base crop population is maintained at its sole crop population and intercrop population is kept at 80 percent of its sole crop population. Relative sowing time of component crop is important management variable manipulated in cereal + legume intercropping system but has not been extensively studied. Sowing may be staggered to increase the temporal difference, which might result in higher yield advantage (Tsubo *et al*, 2005).

d. **Fertilizer Application:** The nutrient uptake is generally more in intercropping system compared to pure crops. When the legume is associated with a cereal crop in intercropping system, legume supplement a portion of nitrogen required of cereal crop; the amount may be of 20 kg/ha by legumes. Application of higher dose of nitrogen to the cereal + legume intercropping system not only reduce the nitrogen fixation capacity of legumes, but also growth of the legume is suppressed by aggressive fast growth of cereals. Cereal + legume intercropping, therefore is mainly advantageous under low fertilizer application. Considering all the factors, it is suggested that the nitrogen dose recommended for base crop as pure crop is sufficient for intercropping system with cereal + legume or legume + legume. With regards to phosphorus and potassium, one eighth to one fourth of the recommended dose of intercrop is also added in addition to recommended dose of base crops to meet the extra demand. Basal dose of nitrogen is applied to rows of both components in cereal + legume inter crop. Top dressing of nitrogen is done only in cereal rows. P & K are applied as basal dose to both crops.

e. **Water Requirement:** The technique of water management is the same for sole cropping and intercropping or sequential cropping. However, the presence of an additional crop may have an important effect on evapo - transpiration. With proper water management, it is possible to grow two crops where normally only one crop is raised under rain fed condition. Intercropping system is generally recommended for rain fed situations to get the stable yields. The total water requirement of intercrop does not increase much compared to sole cropping. At ICRISAT, the water requirement of sole sorghum and intercropping with red gram was almost similar (584 and 585 mm, respectively). However, in a more competitive crop like onion as intercropped in groundnut increase the total water requirement by about 50 mm. The total water used in intercropping system is almost same as in sole crops, but yields are increased. Thus water use efficiency of intercropping is higher than sole crops.

Scheduling of water: If one of the crop is irrigated based on its requirement, the other crop may suffer due to excess water stress, sometimes leading to total failure of crop. In cotton + black gram intercropping system, cotton is irrigated once in 15-20 days. The intercrop black gram is often affected by excess water and gives poor yield. In such situations, skip furrow method of irrigation is advocated. Scheduling irrigation at IW/CPE ratio of 0.60 to 0.80 or irrigation at one bar soil moisture tension is suitable for most of the systems.

f. **Weed Management:** Generally, it is believed that intensive cropping reduces weed problems. Weed infestation depends on the crop, plant density and cultural operation done. Weed problems is less in intercropping system compared to the sole crops. This is due to complete crop cover because of high plant density in intercropping which cause severe competition with weeds and reduce weed growth Wistrom *et al,* 2018).

The weed suppressing ability of intercrop is dependent upon the component crops selected, genotype used, plant density adopted, proportion of component crops, their spatial arrangement, fertility and moisture status of the soil. Experiment carried out at ICRISAT, Hyderabad, indicated that there was 50 - 75 % reduction in weed infestation by intercropping. Pigeon pea + sorghum intercropping system, which is extensively practiced in Karnataka, M.S and A.P is known to reduce weed intensity. The higher plant population and complete covering of the soil earlier in intercropping system reduce weed infestation. In late maturing crops that are planted in wide rows, presence of early maturing crops helps to cover the maturing crops that are planted at wide rows. Presence of early maturing crops helps to cover the vacant inter-row space and keeps weed under check. Quick growing noncompetitive, compact legumes like green gram and black gram act as another crop due to their good canopy coverage (Jannoyera *et al*, 2011).

In certain situations, intercrops are used as biological agents to control weeds. Black gram, green gram, cow pea in sorghum and cowpea in banana reduce weed population. One hand weeding can be avoided by this method. However, in some intercropping systems like maize + groundnut, rice + cassava, maize + cassava, weed problem is similar to their sole crops. The growth habit of genotype used in intercropping has a great influence on weed growth. Weed infestation in intercropping is influenced by early growth and competitive additives of the component crops. If one or both the component crops are vigorous and cover the land area rapidly, weed infestation is greatly reduced. Early crop canopy to cover the soil is more important than rapid increase in plant height. It is well known that, different species of weeds are associated with different crops, but weeds present in sole crops are different than those present in intercropping system. At Hyderabad, in pearl millet as sole crop mixed weed flora was observed as *Celosia*, *Digitaria* and *Cupreous* in sole crop of groundnut. In pearl millet + groundnut intercropping system type of weeds changes with proportion of component crops. As more rows of groundnut are introduced in place of pearl millet of rows, there is a striking increase in both numbers and biomass of the tall and competitive Celosia, especially in groundnut rows (Geno and Geno, 2001). Weed problem is less; weed control is necessary in intercropping system. But labour required for weeding is less; second weeding is not necessary because of crop coverage and limited weed growth. Normally two hand weeding are required, but it may restrict to one hand weeding under intercropping in sorghum + red gram or sorghum + cowpea. Just one weeding is sufficient to get high yield as in weed- free check. The critical period of weed free condition may be extended a little longer in intercropping than in sole cropping. This is because the critical growth stages of the component crops vary temporally in intercropping. For example, critical weed free period has to be extended to first 7 weeks in sorghum + red gram intercropping while sole sorghum crop requires only 2- 4 weeks weed free period.

Chemical weed control is difficult in intercropping system because the herbicide may be selective to one crop but non- selective to another. Atrazine control weeds in sole sorghum, but it is not suitable for sorghum + red gram intercropping system, as it is toxic to red gram. Herbicides suitable for intercropping systems as-

* Maize + green gram and Maize + cowpea. Butachlor (pre - emergence) (Machete)

* Sorghum + pulse – fluchloralin (PPI) (Basalin) or Alachlor (pre - emergence) (Lasso)

* Sorghum + red gram – prometryne (pre- emergence)

* Sugarcane + groundnut – nitrofen (pre-emergence) (TOK E -25).

g. **Pest and Disease in Intercropping System:** Pest and diseases are believed to be less in intercropping system due to crop diversity than sole crops. Some plant combination may enhance soil fungicide and antibiotics through indirect effects on soil organic matter content. The spread of the diseases is altered by the presence of different crops. Little leaf of Brinjal is less when Brinjal is sheltered by maize or sorghum, as the insect- carrying virus first attacks maize or sorghum; virus infestation is less on Brinjal. Non – host plant in mixtures may emit chemicals or odor that affects the pests, thereby protecting host plants. The concept of crop diversification for the management of nematode population has been applied mainly in the form of decoy and trap crops. Decoy crops are non-host crops, which are planted to make nematode waste their infection potential. This is affected by activating larva of nematode in the absence of hosts by the decoy crops (Wistrom *et al*, 2018).

Crop	Nematode	Decoy crops
Brinjal	Meloidogyne incognita	Sesamum orientale
Tomatoe	Meloidogyne pratylenchus	Castor, groundnut

Soybean	Pratylenchus spp.	Crotolarias spectabillus

Trap crops are host crops sown to attract nematode but destined to be harvested or destroyed before the nematode manage to hatch. This is advocated for cyst nematode. The technique involves is sowing in pineapple plantations; tomatoes are planted and ploughed in to reduce root knot nematodes. There is also evidence that, some plants adversely affect nematode population through toxic action. Marigold reduces the population of *Pratylenchus* species (Jannyera *et al*, 2018).

Many combinations of crops have been grown or experimented with as mixed or relay intercrops. Some of these include sunflowers grown with black lentils, wheat with flax, and canola with flax. Other combinations include cucumbers, beans, celery, and chives in China; upland rice, corn, and cassava in Indonesia; and in various parts of the tropics corn and cassava, corn and peanuts, sorghum and millet, and sorghum and pigeon-peas. Frequently these cropping combinations involve a short and a tall crop both planted at the same time. In many cases the tall crop is harvested first. For example, corn grown with a shorter plant would be harvested first, then peanut or sweet potato would be harvested later (Altieri, 1992).

Sustainable farming is farming that is economically viable, highly productive, and environmentally sound and protects public health. Since four decades ago, crop yields in agricultural systems depended on internal resources and were modest, but stable. Production was safeguarded by growing more than one crop or variety in space and time in a field as insurance against severe weather. In orchards and trees ecosystems the use of cover crops promote soil fertility, soil structure, and water penetration, inhibit soil erosion, alter the microclimate and decrease weed competition as well as the use of herbicides (Altieri, 1992; Jannoyera *et al*, 2011; Wistrom *et al*, 2018). Intercropping is getting popularized in developing and developed countries for the best investment of land resources and reducing the risks of single crop failure (Geno and Geno, 2001). In some intercropping system like cotton and sorghum, intercropping was observed to significantly reduce the weed density and dry matter as observed by Sathishkumar *et al*, (2017).

2.16 **Overall Evaluation and Future of Intercropping**

There seems to be a prejudice among some researchers that intercropping is only for peasant farming and has no place in modern agriculture. However, in many areas of the world, traditional farmers developed or inherited complex farming systems in the form of poly-cultures that were well adapted to the local conditions and helped them to sustainably manage harsh environmental conditions and to meet their subsistence needs without depending on mechanization, chemical fertilizers, pesticides or other technologies of modern agricultural science (Denevan, 2005). In most multiple cropping systems by smallholders, productivity in terms of harvestable products per unit area is higher than under sole cropping with the same level of management and yield advantages which may range from 20% to 60% due to reduction of pest incidence and more efficient use of nutrients, water and solar radiation. These microcosms of traditional agriculture offer promising models for other areas as they promote biodiversity, thrive without agrochemicals, and sustain all year-round yields (Alteri, 2004).

2.17 **Role of Cover Crops in Crop Production**

According to Sullivan (2003), cover crops are crops grown to provide soil cover, regardless of whether it is later incorporated. They can be annual, biennial or perennial herbaceous plants grown in pure or mixed stand during all or part of the growing season (Muhamman and Gungula, 2006). Cover crop play the following functions:

i. ***Reduce soil erosion***:

Cover crops are used in covering and protecting the soil surface from wind and water erosion. The shoots cover the soil while the roots bind and stabilize the soil particles (Varhallen *et al*, 2003).

ii. ***Increase in Soil Organic Matter***:

Organic matter is important both in improving soil fertility and physical conditions. It acts as a store house of nitrogen and other nutrients such as phosphorus and Sulphur and it influence soil exchange capacity, improves water holding capacity and increase aeration, especially in clay soil (Janick, 1982; Sullivan, 2003 and Encarta, 2004).

iii. ***Reduce Loss of Nutrients from the Soil***:

Nutrients held in the plant tissues are returned to the soil when the plants are dead, allowed to decay on the soil or incorporated into the soil and subsequent plants make use of the nutrients. Cover crops takes in nitrogen from the soil thereby reducing nitrogen loss through leaching which may contaminate the ground water table (Varhallen et al, 2003; Muhamman and Gungula, 2006). Some cover crops help in making phosphorous available to crops that needs it by the action of their roots (Varhallen et al, 2003). Deep rooted cover crops such as alfalfa can bring nutrients up from lower depth in the soil profile and make them available to other plants.

iv. Cover Crops Suppress Weeds:

Light and space will be taken up by cover crops which help in covering the soil and reducing the opportunity of weeds to be established (Sullivan, 2003; Kolo et al, 2004; Asadu et al, 2004). In a cropping system where labour productivity is low and declining due to weeds inversion, cover crops can provide an effect alternative to chemical weed control and a net savings in labour cost (Stockwell and Fisher, 1996).

v. Reduce Pest Population:

Some species of cover crops may be a non-host for pest or may release toxic materials (allelopathic chemicals) that are harmful to the pest or other plants. Some crops attract beneficial insects which are detrimental to pests. This result forced them to leave the environment (Sullivan, 2003).

vi. Improve Soil Structure and Reduce Soil Compaction:

Plant residues help in improving water holding capacity, infiltration rate, soil compaction, consequently improving soil structure. According to Sullivan (2003), some cover crops with extensive root system are highly effective in loosing and aerating the soil. Erosion increases where there is no plant cover, but where permanent and undisturbed plant cover exist, erosion is more or less gradual (Janick, 1982).

vii. Promote Microbial Activities:

When cover crops in the form of green manure are incorporated into the soil, soil microbial activities are promoted. Soil microbes multiply to attack the freshly incorporated plant materials. Therefore, nutrients held in the plant tissues are released due to the microbial breakdown which are then made available to the crops (Sullivan, 2003).

viii. Cover Crops Provide Forage to Animals:

According to Varhallen et al (2003), under adverse conditions and / or dry season in Nigeria, there is a shortage of pasture, cover crops can make available to much needed pasture for animal and helps in settling the nomads who moves from the North to the South in search of pasture in the dry season. Cover crop in a mixed cropping increases farmer's income and insurance against any crop failure. Cover crops such as cowpea, groundnut, melon and sweet potato when integrated in a cropping system help in increasing farmer's income per unit area. Similarly, in case of the failure of one crop, the other will help in the protection from total crop failure. There are a lot of reasons why the use of cover crops in Nigeria is becoming pertinent. There is an increased pressure on land due to population growth leading to permanent intensive cultivation, the consequences of which are destruction of organic matter, loss of fertility and increased acidity (Stockwell & Fisher, 1996; Harris, 1998) as well as increased weed competition. Soil fertility and productivity has to be maintained by the use of cover crops which supply some nutrients to plants.

Cover crops have a lot of economic benefits such as improving soil fertility, reduction in the use of inorganic fertilizer, herbicides, weed and insect control cost, protection of ground water, scavenging residual nitrate and high economic return to the farmers (Okoh et al, 2001; Kolawole & Tian, 2004; Egbo et al, 2005).

2.18 **Effect of Intercropping Systems on Weed Management**

Weed management for any cropping system can involve the use of many kinds of biological, physical and chemical techniques to promote crop dominance over weeds. There is no question that herbicides, tillage and water management can be important components of weed management programme for intensive cropping systems (Reddy, 2012). Intercrop weed management combines two qualitatively different aspects of plant/plant interactions. To increase intercrop yields, complementarity in pattern of resource use by the component crops must be emphasized. The goal is to maximize the degree of overlap in resource use by inter sown crop such that more resources are exploited and more yield can be harvested per unit of ground area.

In contrast, to achieve weed control, the similarity of requirement of crop and weed species, the consequent competition for limited resources and the suppression of growth and yield of associated species are emphasized. Weed scientists and farmers work to create an environment that is detrimental to weeds and favourable to crops. Intercropping has potential as a means of weed control because it offers the possibility of a mixture of crops capturing a greater share of available resources than in sole cropping, pre-empting their use by weeds (Alteri and Liebman, 1986), provided that interference between crop components is weaker than that between crops and weeds. Intercropping can suppress the weed growth more than sole cropping. Sequential cropping systems have been found to minimize weed problems in area where weeds have assumed alarming proportions due to continuous adoption of certain cropping systems. Effective weed control in rainy season crop can reduce the weed problems in subsequent crops considerably. However, a variety of processes that include allelopathy and competition with weeds, along with pest and disease interactions with plants is known as biological interactions.

2.18.1 ***Interactions with weeds in intercropping systems***

Two types of action are identified to explain the reduction in weed biomass frequently observed: (i) competition for resources such as light, water, nitrogen or other nutrients, and (ii) allelopathy (Liebman & Dyck, 1993), though the distinction between those effects sometimes remains difficult. Allelopathy refers to inhibition of the growth of one plant by chemical compounds released into the soil from neighbouring plants. It may inhibit a mixture: tree species such as *Gliricidia sepium or Leucaena leucocephala* used in agroforestry are reported to have allelopathic effects on maize and rice seedlings (Nair, 1993). Conversely, the use of specific species may enable better control of weeds and thereby be a benefit of mixing. However, little is known about allelopathic mechanisms for weed control in a mixture. Beyond those allelopathic mechanisms, the suppressive effect on weeds is observed through competition when the cultivated species are complementary in resource uptake: nitrogen requirements (legumes versus other plants), photosynthesis metabolism (C3 versus C4 plants) and different soil exploration by roots depending on the species.

The complementarity between cultivated species often makes it possible to capture a greater quantity of resources in the case of intercrops versus pure stands, thereby reducing the resources available for weed growth (Liebman & Dyck, 1993; Bulson et al., 1997; Hauggaard-Nielsen & Jensen, 2001; Hauggaard-Nielsen & Jensen, 2005). In mixtures combining a cereal and a legume, the greater competitiveness of the mixture compared with monocultures is due to the fact that cereals are more competitive than legumes in taking up nitrogen from the soil due to faster root development and demand (Corre-Hellou et al., 2006). Mixing species may also reduce the specific diversity of the weed stand and lead to a change in biomass distribution between weed species (Poggio, 2005).

2.18.2 ***Interactions between crop mixtures and diseases and pests***

In order to explain interactions between mixtures and diseases and pests, a distinction is made between different processes:

(i) **The dilution effect**

The hypothesis of resource concentration put forward by Root (1973) reflects the fact that the mixture gives rise to a "dilution" of the host plant in the plant cover, making the parasite or pest less efficient at locating and colonizing its host plants. An increase in the proportion of nonhost plants in a mixture enhances that effect (Trenbath, 1993).

(ii) **The physical barrier effect**

The previous theory of Root (1973) is completed by the disruptive crop hypothesis (Vandermeer, 1989). By modifying the structure of the stand and the architecture and microclimate of the cover, the mixture modifies the location of the host plant, thereby affecting disease spread or disrupting the parasitic insect’s search for feeding or mating sites (Francis, 1990). Conventional cereal crops can disrupt insects in their visual search for smaller crops (Ogenga-Latigo et al., 1992), and the existence of a lower crop storey may, likewise, affect the visual search for a potential host.

(iii) **The habitat effect**

Introducing species with a contrasting plant architecture creates a new habitat which in turn modifies populations of predators. For instance, Jones and Sieving (2006) reported a change in the behaviour of insectivorous birds with the introduction of a single row of sunflowers in organically grown vegetables.

(iii) The chemical effect

A mixture may contain species that produce substances that have negative effects on diseases and pests, such as nematodes, that are parasites on another component in the mixture. That is the case for certain intercropping systems based on cover crops dedicated to controlling nematodes (Yeates, 1987; Rodriguez-Cabana & Kloepper, 1998). Those different effects can be combined in different ways: for example, cover crops used in mixtures may affect plant parasitic nematodes (a) as non-host plants affecting nematode reproduction, (b) by producing root exudates stimulating nematode reproduction in the absence of hosts and causing nematode death, (c) by producing root exudates with nematicide properties, and (d) by producing compounds in the foliage which, once incorporated into the soil, have nematicide properties. Functions (a) and (d) can be utilized in crop rotations, where they ensure a preventive function (cleansing), whilst functions (b) and (c) can be taken advantage of in mixtures, as those two control methods can be utilized in overlapping cycles.

2.19 **Factors Affecting Intercrop-Weed Balance**

Although intercropping appears to offer considerable potential as a means of increasing crop dominance over weeds, the effectiveness of weed control in intercrop systems differ among intercrop combinations due to several factors influencing intercrop/weed relationships (Reddy, 2012).

2.19.1 Crop density:

High plant population promoting crop dominance over weeds in sole cropping is an established fact. Highest yields for many intercrop combinations grown under weed free environment are obtained with increased crop population densities. Similarly, maximum intercrop yields and weed suppression are obtained under weedy conditions with total crop densities significantly higher than those used for sole crop (additive series) (Reddy, 2012).

Highest combined yields and the greatest degree of weed suppression were obtained from sorghum and pigeon pea intercropping with a normal density of pigeon pea sown with a twice normal population of sorghum (Shetty & Rao, 1981). Weed growth in flax and wheat intercropping was inversely proportional to crop density. As the seeding rate for either or both components of the mixture increased, weed weight decreased (Walker & Buchanan, 1982).

Smother intercrops and live mulch intercrops of high density, additive crop mixtures appear to offer great promise as means of weed control. In this systems, low growing weed suppressive species are sown between two rows of main crop. Two legume species, *Centrosema pubescence* and *Psophocarpus palustris* gave excellent control of weeds when inter sown between maize rows (Akobundu, 1980). Intercropping cowpea and mung beans in sorghum or pigeon pea minimized weed growth after first weeding (Reddy, 2012). Weed suppression due to the smother crops was about the same as that obtained with second weeding. However, smother crops were ineffective for weed control in sorghum and pigeon pea intercropping where yields of both components were decreased (Shetty & Rao, 1981). It should be noted that inter sown live mulch crops can greatly reduce the yields of main crop species if component for water and/or nutrients is strong.

2.19.2 Crop Species and Cultivars:

Large differences in weed suppression ability have been observed among different species in intercropping. These reflect differences in the timing and nature of resource capture, and are manifest in differences in growth form between species. In maize based cropping systems, mung beans was more weed suppressive than groundnut due to more rapid early growth and more uniform canopy structure (Banitilan et al, 1974).

2.20 **Effect of Moringa on Crop Production in Intercropping Systems**

Moringa has been reported to provide human, livestock and crop nutritional benefits such as nitrogen fixation through litter falls (Foidl et al, 2001), while increasing the soil fertilization. According to CTA (2001), other uses in which moringa perform in both growth and yield of other crops include; the provision of minimal shade and large production of high nutritive biomass well suited for alley cropping systems. *Moringa oleifera* tree is a medicinal plant and is one of the potent sources of several active ingredients like flavonoids, tannins, saponins, terpenoids, pro-anthocyanidins and cardiac glycosides which have tremendous therapeutic properties (Vinoth et al, 2012; Bhattacharya et al, 2018), which is normally intercropped with other plants, but its effect on the associated plants is unknown. However, the potentials of moringa in intercropping systems must be sustained for better productivity. Studies also revealed significant ($P \geq 0.05$) increase on plant growth parameters, yield and yield components when *moringa oleifera* was intercropped with maize + sweet potato, and also showed that plant height and pod yields of okra was significantly ($P \geq 0.05$) greater under intercropping systems than in sole cropping with *moringa oleifera* (Ozobia, 2014).

Moringa *(Moringa oleifera)* can be used as a shade tree in cropping system since it exhibits an open crown that allows radiation to penetrate under-storey crops (Nair, 1993). This claim is supported by Chundawat and Gautam (1993), who hypothesized that a shade tree should have a sparse, small crown to allow sunlight into cropping system.

2.21 **Effects of Intercropping Systems on Soil Microbial Populations**

Soils are the naturally occurring physical covering of the earth's surface, and represent the interface of the three material status; solids (geological and dead biological materials), liquids (water), and gases (air in the soil pores). Earth soil is a unique product of the combination of geological parent material, glacial and geo-morphological history. Soils are the foundation of terrestrial ecosystems and are home to a vast diversity of bacteria, archaea, fungi, insects, annelids and other invertebrates as well as plants and algae. Soil also plays critical roles in buffering and filtering freshwater ecosystems (Dominati et al, 2010).

Soil microbes (bacterial, fungi, archaea, nematodes) play diverse and often critical roles in ecosystem services. The vast metabolic diversity of soil microbes' means their activities drives or contributes to the cycling of all major elements (e.g. C, N, P) and this cycling affects the structure and the functions of soil ecosystems as well as the ability of the soil to provide services to people and plants. Soil microbes contribute to soil formation through nutrient cycling and organic matter production (Davis et al, 2011; Bergmann et al, 2011).

Microbial products are critical to soil aggregation, improved soil structure, making soil more habitable for plants. Soil microbes produce antimicrobial agents and enzymes used for biotechnological purposes. Soil microbes mobilizes nutrients from insoluble minerals to support plant growth, soil macro pores formed by plant roots, earthworms and other soil biota, which may depend on soil microbes as food or for nutrients (Nemerght et al, 2011; Jones et al, 2009).

Soil microorganisms are very important part of soil health which is concerned as almost every chemical transformation taking place in soil involves active contributions from soil microorganisms (Dominati et al, 2010). In particular, they play an active role in soil fertility as a result of their involvement in the cycle of nutrients like carbon and nitrogen, which are required for plant growth. The crop management practices like source of nutrient, selection of crop and growing inter crops will decide the extent of microbial population. Rather than growing cereals as sole crop, it is better to include legumes as an intercrop as legumes have beneficial role of adding nitrogen to soil and enhancing microbial load in the soil. The application of chemical fertilizer may assist in obtaining maximum production of baby corn but it may lead to hazardous effect on environmental health and have negative effect on soil microbial population. Judicious use of fertilizers from different sources for a crop or baby corn production will maintain the environmental sustainability for generations, without affecting the environmental health and enhances microbial population (Rekha et al, 2017).

Increasing the sustainability of cropping systems involves the reduction of agrochemical and fertilizer inputs through the reliance in soil ecosystem processes and biological interactions for the provision of plant nutrients. Of particular importance are soil microbial processes as they are crucial for plant nutrient supply given their central role in soil organic matter decomposition and nutrient dynamics. Mineral fertilization can provide readily available nutrients to the plant growth but it does not contribute to the soil physical condition. Management of soil fertility through organic fertilizers has always been a pivotal principle of sustainable agriculture (Srinivas et al, 2011).

Intercropping, the historical practice of growing two or more crops together in the same field is one of the main planting methods of ecological and sustainable agriculture. Intercropping is a strategy for growing more crops in limited land, taking advantage of the crops' natural growth pattern to effectively match crops that can grow together so as to maximize the cultivation space. Intercropping is an essential practice to obtain high production while maintaining the quality of growing crops (Sullivan, 2003; Seran & Brintha, 2010; Alemayehu et al, 2017). In Nigeria, farmers have adopted intercropping systems for several years to increase production and decrease erosion.

Different cropping patterns can affect soil environmental conditions and soil microbes. Soil microorganisms are very important part of soil health, which is concerned with almost every chemical transformation taking place in soil involving active contributions from soil microorganisms. In particular, they play an active role in soil fertility as a result of their involvement in the cycle of nutrients like carbon and nitrogen, which are required for plant growth. The crop management practices like source of nutrient, selection of crop and growing inter crops will decide the extent of microbial population. The practice of integrated nutrient management (INM) on the field are important and are beneficial. The adoption of INM practices on the field will reduce the production cost, thereby increasing the economic returns to the farmers and also increases the supply and availability of soil nutrients to the crop as well as increasing the activity of beneficial soil microorganism due to availability of more organic matter content (Auwal, 2014).

The introduction of plants to soil affects the physical-chemical properties and the biological parameters of the soil environment close to the growing roots (Hinsinger et al, 2006). The rhizodeposition of nutrients by plant roots supports increased microbial growth in comparism with that of the bulk soil communities and results from enrichment of microorganisms from the bulk of soil, a phenomenon often referred to as the 'rhizosphere effect'(Smalla et al, 2001; Dunfield & Germida, 2003; Mougel et al, 2006). Sugarcane-soybean intercropping has been widely used to stabilize yields and reduce nitrogen leaching (Rowe et al., 2005; Xu et al, 2008; Li et al., 2013). N fixation associated with soybeans can improve soil fertility and field ecological conditions that favor sugarcane in the intercropping system (He et al., 2006). Intercropping of sugarcane with soybean, may also stimulate N fixation by the legume's micro-biome (Li et al., 2013).

In an intercropping system, the roots of different plant species interact directly with each other and subsequently affect root exudation, which undoubtedly alters the microbial diversity, structure, and activity (Broeckling et al., 2008; Gomes et al., 2003). The changed microbial community and activity by intercropping could affect C and N dynamics (Kaur et al, 2000; Rowe et al., 2005; Sun et al., 2009), and this may be attributed to the ability of microbial communities to regulate carbon and nitrogen-use efficiency (Mooshammer et al., 2014). The influence of intercropping on the soil microbial communities have been studied in several intercropping systems, including mulberry–soybean, Eucalyptus–Acacia magnum and apple tree-crown vetch intercropping (Li et al., 2013, 2016; Rachid et al., 2015; Zheng et al., 2018). For example, Li et al. (2016) investigated the effects of mulberry–soybean intercropping on the diversity and composition of the soil bacterial community in salt–alkali soil and found that intercropping increased the abundance of some phosphate solubilizing species. Moreover, Rachid et al. (2015) reported that Eucalyptus intercropped with Acacia magnum increased soil fungal community diversity.

The effect of modern agriculture on soil microbial communities are very complex, yet understanding them is important for effective and sustainable management of agricultural ecosystems. Both no-till and crop rotations have been widely adopted in many agricultural settings, and although it is generally accepted that these practices have the potential to increase microbial biomass and activity (Franzluebbers, Hons & Saladino. 1995; Feng et al. 2003). Frey et al, (1999) reported no consistent effects on bacterial abundance or biomass in a 30-year tillage plot. Other studies have indicated that tilled soil may or may not contain grater bacterial diversity than non-tilled soil (Ovreds & Tossurk, 1998; Ferreira et al, 2000. Upchurh et al, 2008). Similarly. Varying outcomes have been reported with respect to the effects of monoculture production versus crop rotation on soil microbial communities. Some studies suggest that monocultures select for less diverse microbial communities of wheat (*Triticum aestivum* L.), maize (*Zea mays* L), or soybean (*Glycine max* L.) may lead to reduced levels of metabolic activity (Lupwayi *et al*, 1998); the dominance of certain genotypes of rhizobium (Depret *et al*, 2004), or the decline of fungal species (Meriles *et al* 2009). In addition, it has been reported that potato (*Solanum tuberosum* L) monocultures results in increase, abundance of plant pathogens, leading to a decline in both crop yield and quality (Hide and Read, 1991); unless crop rotation is practiced which may alter diversity by specifically decreasing the abundance of fluorescent Pseudomonas species (Govaerts *et al*, 2008, Hungria *et al*, 2009).

According to Acosta-Martinez *et al*, (2010), Carney *et al*, (2004), soil microbial diversity, soil enzyme activities and crop yield could be affected by land management practices. Soil enzyme is one of the major soil components present in a very nominal quantity in soil, but its role in improving soil quality can never be ignored (Huang, 1981; Li, 1981). It is believed that enhanced nutritional uptake is not the only reason for yield increase under intercropping system, but many other unknown causes also affect it (Dessougi *et al*, 2003). Soil has a complex and unique environment, in which the biological activity is mostly controlled by microorganisms. Soil microorganisms play a critical role in nitrogen, sulphur and phosphorous cycle as well as ecosystem functioning by changing soil structure formation, organic matter decomposition, nitrogen fixation and toxin removal (Acosta-Martinez *et al*, 2010; Karlen et al, 1997; Gomes et al, 2003).

Research also showed that the extent of soil microbial diversity is important for maintaining good quality of agricultural soil (Acosta-Martinez *et al*, 2010; Garbeva *et al*, 2004; Jauvier *et al*, 2007). On the other hand, microbial diversity of soil is affected by land management practices (Acosta-Martinez, 2010; Garbeva *et al*, 2004). Composition of microbial communities in soil can be affected either directly by changing physiology of host plant or indirectly by altering pattern of root exudation (Marschner *et al*, 2001; Van der Heijden, 1998). Soil enzymes derived primarily from soil microbial populations, plant root system and organic wastes indicate the potential to support biochemical processes involving decomposition of organic residues and nutrient cycling in soil (Lalande et al, 2000; Casucci et al, 2003).

2.22 **Cropping Systems Defined**

Cropping systems is an important component of a farming system, represents a cropping pattern used on a farm and their interaction with farm resources, other farm enterprises and available technology, which determine their makeup. It is defined, as the order in which the crops are cultivated on a piece of land over a fixed period or cropping system is the way in which different crops are grown. In the cropping systems, sometimes a number of crops are grown together or they are grown separately at short intervals in the same field.

Cropping systems is based on climate, soil and water availability; have to be evolved for realizing the potential production levels through efficient use of available resources. The cropping system should provide enough food for the family, fodder for cattle and generate sufficient cash income for domestic and cultivation expenses. This objective could be achieved by adopting intensive cropping. Methods of intensive cropping include multiple cropping and intercropping. Intensive cropping may pose some practical difficulties such as shorter turn- around time lapse for land preparation before the succeeding crop and labour shortage at peak of agricultural activities. These problems can be overcome by making modification in the cropping techniques. Alteration in crop geometry may help to accommodate intercrops without losing the base crop production (Arshad et al, 2002; Rana & Rana, 2011).

2.22.1 **Efficiency in Cropping Systems**

Efficient cropping systems for a particular farm depend on farm resources, farm enterprises and farm technology because farm is an organized economical unit. The farm resources include land, labour, water, capital and infrastructure. When land is limited intensive cropping is adapted to fully utilize available water and labour. When sufficient and cheap labour is available, vegetable crops are also included in the cropping systems as they require more labour. Capital intensive crop like sugarcane, banana, turmeric etc. find a space in the cropping system when capital is not a constraint. In low rainfall regions (750 mm/annum) mono cropping is followed and when rainfall is more than 750 mm, intercropping is practiced. With sufficient irrigation water, triple and quadruple cropping is adopted. When other climatic factors are not limiting farm enterprise like dairy, poultry etc. also influence the type of cropping system. When the farm enterprises include dairy, cropping system should contain fodder crops. Components change in cropping system also takes place with the developments of technology. The feasibility of growing for crop sequences in Genetic alluvial plains inputs to multiple cropping (Rana and Rana, 2011).

2.22.2 **Management of Sequential Cropping Systems**

Unlike intercropping, crops are grown one after another in sequential cropping and hence, management practices are different.

a. **Seedbed Preparation**: Suitable seedbed can be prepared as per crops. Puddling for rice, ridges and furrows for vegetables, maize and cotton and flat seedbed for several other crops. However, two problems are encountered in seedbed preparation in sequential cropping system;

1) The time available for seedbed preparation is less in high intensity cropping system. Frequent rain interfere with the land preparation.

2) Due to the presence of crop in the field, land preparation may be difficult. For example, field preparation after rice is difficult, it is mainly because soil structure is destroyed during puddling.

The turn – around time, the time between harvesting to sowing of next crop is more if rice is the preceding crop. To avoid this problem minimum tillage or zero tillage is adopted. It is the common practices to sow pulse crop just before or immediately after harvesting rice crop. In rice- wheat system, the stubbles are killed by spraying paraquat and wheat is sown in plough furrows between stubble of rice.

In irrigated agriculture, the time available for tillage between two successive crops is minimal leading to minimum tillage. Minimum tillage is applicable for soils with;

1. A course texture surface soil,

2. Good drainage

3. High biological activity of soil fauna.

4. An adequate quantity of soil residue mulch and

5. Favourable initial soil moisture and friable soil consistency over a wide range of soil moisture.

It is not possible to practice zero or minimum tillage in all sequence cropping systems. If sunflower is the preceding crop, ploughing is essential to oxidize the allelo-chemicals of sunflower. The stubbles of pearl millet and sorghum, which contain high C: N ratio immobilizes nitrogen. It is therefore, necessary to remove them. Stubble also interfere with the field operations (Rana and Rana, 2011).

In rice-rice-green gram system, firstly summer ploughing is done. Later in the rainy season when water is available, puddling is done and first crop is sown. Second rice crop is sown after minimum tillage. Green gram is sown as a relay crop in the second rice crop. In Cotton-Sorghum-finger millet cropping system in garden lands, thorough field preparation is done and field is laid out into check basins to transplant finger millet. In next season, cotton is planted among the stubbles of finger millet without field preparation. Weeds are controlled by inter-cultivation operation in Nigeria. No till planting of sorghum into residues of the previous crop maintained the seed at 10^0C lower temperature in the seeding zone when it reaches 41^0C (Gan *et al*, 2003).

b. **Crop Varieties:** Short duration of crops are selected to fit well in the multiple cropping systems. Photo-insensitive varieties are essential for successful sequence cropping system.

c. **Sowing:** Sowing is not a problem as there is sufficient time for seedbed preparation. If seedbed is not prepared well, the establishment of crop is difficult. For example- cotton establishment is difficult in black soil after rice. Due to hard pans in the shallow layer, root penetration is difficult. If field is allowed to dry for land preparation, sowing is delayed by one month. Hence seedlings are raised either on twisted paddy straw or leaf cups before harvesting of rice crop. After harvesting a cow bar hole is made up to 30 cm. It is partly filled with sand and soil mixture and cotton seedlings are planted. The establishment of pulse crop is difficult after rice and broadcasting of seeds in standing rice crop results in uneven germination, therefore, high seed rate is necessary. Crops planted in stubbles are subject to competition from regenerated stubbles. It can be overcome by spraying, preparation or digging of stubbles. Delay in sowing is a common problem in intensive cropping systems. To reduce yields loss due to transpiration of overage seedlings, higher level of nitrogen is applied to induce tillering. In rice – wheat system, wheat yields are reduced considerably when the sowing of wheat is delayed beyond November. In such situation, planting of 40 to 50 days old seedlings of wheat is done. Farm yard manure (FYM) is broadcasted over the field to maintain soil temperature (Miller *et al*, 2002).

d. **Soil fertility management:** Soil fertility management become more complex in intensive cropping because of residual effect of nutrients applied to the previous crops, possible effect of legume in the system, complementary and competitive interaction from the component crops and influence of crop residues left in the soil. The modern or chemical agriculture, which includes higher cropping intensity involving improved varieties, heavier inputs of fertilizer and water, increasing yields and accelerated removal of plant nutrients has added newer dimensions to the fertility management (Rana and Rana, 2011; Gan *et al*, 2003; Miller *et al*, 2002). Studies have shown that:

System productivity increased with the application of P along with N, and further increased with use of N, P and K. Application of N at recommended dose is advocated to each of the crop in cropping system.

Phosphorus management in cropping system needs careful adjustment of P fertilizer dose taking into the account type of fertilizer, soil characteristics and their yield level, extent of P removal and growing environment. In cropping system – involving wheat, fertilizer P dose to kenaf crop can be reduced if preceding wheat has received P in adequate amounts (Miller *et al*, 2002).

Removal of K in proportion to N is very high in cropping systems particularly those involving cereal and fodder crops. It is important to apply K fertilizer at recommended dose to maintain soil fertility. In K rich soils of Coimbatore, K application at 50% recommended dose to each crops in the sequence rice-rice-soybean was optimum.

Among the secondary nutrients, sulphur application is benefited particularly to sesame - mustard, soybean - safflower and groundnut - mustard cropping sequence (Miller *et al*, 2002).

Among micronutrients, Zn deficiency is the most common as nearly 50% soils of intensive cultivated areas suffers from Zn deficiency. Rainy season crops like rice, maize and sorghum respond more to applied Zn than winter crops like wheat and chickpea. Use of organics prevents Zn deficiency in intensive cropping system under normal soils (Miller *et al*, 2002).

e. **Water management:** There is no carry over effect of irrigation as in case of fertilizer. Rice – rice is efficient cropping system for total yield, but it consume large amount of water especially in dry season. If water is scare in dry period instead of rice, groundnut is used in cropping system.

Method of irrigation: The layout should be so planned that most of the crops can be suitable. In rice – rice - groundnut system; rice is irrigated by flood method, while groundnut by boarder strips. In cotton – sorghum- finger millet system, cotton, sorghum by furrow method while finger millet checks – basin method is adopted (Rana and Rana, 2011).

f. **Weed management:** Weed problems are observed in individual crops, weed shifts and carry over effect of weed control method on the succeeding crops is usual. Weeds are dynamic in nature, generally broad- leaved weeds occur in wheat at later stages and 2,4 D is applied as post emergence herbicide to control them. In rice- wheat system, canary grass (*Phallaris minor*) is a menace for wheat crop. Seed of other species decompose and loss viability, but *Phalaris minor* seed do not loss viability. When sown in rice stubble, wheat is heavily infested with *Phalaris minor*. In zero till cotton- sorghum-finger millet, weeds are controlled by herbicide. Herbicide applied to the previous crop may be toxic to the succeeding crop. Higher dose of Atrazine applied to sorghum crop affect germination of succeeding pulse crops. Herbicide recommendation should be depends on succeeding crops, ploughing before the planting helps to kill most of the weeds.

g. **Pest and Diseases:** Pest and diseases infestation more in sequence cropping due to continuous cropping. Carry over effect of insecticides is not observed.

h. **Harvesting:** In sequences cropping crop can be harvested at physiological maturity stage instead of harvest maturity. The field can be vacated one week earlier. Because of continuous cropping the harvesting time may coincide with heavy rains and special post harvest operations, like artificial drying, treating the crop with common salt etc. are practices to save the produce (Rana and Rana, 2011).

2.22.3 **Cropping System and Integrated Nutrient Management (INM)**

The concept of integrated nutrients management (INM) involves use of various inorganic, organic, biological sources of nutrient for improvement and maintenance of soil fertility leading to sustained crop production. Crop responses to organic and biological sources of nutrients for improvement and maintenance of soil fertility leading to sustained crop production. Crop responses to organic and biological sources of nutrients are not spectacular as to fertilizers, but the supplementary and complementary use of these resources is known to enhance the use efficiency of applied fertilizer besides improving soil physicochemical properties and preventing emergence of micro – nutrient deficiencies. The major components of the INM are fertilizer, organic manures, green manures, crop residues and Bio-fertilizers. In cereal- based cropping systems, about 25-50% fertilizer NPK dose of rainy season crops could be curtailed with the use of organics such as FYM, green manure and crop residues. In sugarcane based system, integrated use of sulphitation press- mud, cane trash and Bio-fertilizers each with inorganic fertilizers and green leaf manuring showed 20-25% economy of fertilizers N applied to sugarcane by improving the use efficiency of N, P and other nutrient (Gan *et al*, 2003).

2.23 **Cropping Systems of Eastern Nigeria**

The agricultural situation in South Eastern Nigeria is one of very heavy population and offers a challenging opportunity to study the problems encountered by the subsistence farmer in such regions of the humid tropics. As one moves from the more sparsely populated to the more densely populated parts of the Eastern Region of Nigeria, one witnesses a transition from the so-called 'shifting cultivation' to a more settled cropping system, employing bush fallow to maintain or regenerate soil fertility. Travelling along the major highways during the early part of the growing season, which extends from March to June, one observes also different soil management practices and an amazing combination of crops in mixed cultivation, with dominance of root crops, notably cassava, yams and cocoyams, in that order of importance. Several writers have described the system of farming in South Eastern Nigeria, a good deal of which lies within what is generally known as the 'oil palm belt.' (Nwosu, 1973).

In the past, considerable attention has been devoted in Nigeria to the study of the fallow phase of arable crop rotations with a view to better understanding its role, and as a basis for devising an alternative based on green manures or planted fallows which could be as efficient as, or better than natural bush in maintaining soil fertility. Unfortunately, much less effort has been spent on the study of the cropping phase in the rotation which exploits soil fertility and converts it into crop products required by man. Consequently our knowledge about this equally important part of the cropping system in Eastern Nigeria is scanty.

However, the cropping systems practiced in the region are dominated *by* three basic food crops, yams, cassava and maize, though maize is of less significance than either of the tuberous crops. In the long past, before any population pressure developed, this rotation was probably the only one in use around the villages, i.e. there was no differentiation into compound land and distant farmland rotations as occurs now (Nwosu, 1973).

As population pressure develops, a distinction cropping system begins to occur between the rotations practiced on land nearer to settlements ('compound' rotations) and land remote from habitation ('distant' farmland). The further away the farmland is from the village, the less the extent of intercropping in the first course of the rotation, and generally, vegetables are omitted from the rotation. Also, even though the fallow period continues to be long, because of pressure of population on the land, the length of the regenerative part of the 'compound' rotation becomes reduced in some places to four or five years, whereas in the 'distant farmland' the basic rotation survives. Distant farmland rotations can still be found in use in most of the agricultural zones of the region.

In the Eastern Nigeria, basic rotation has undergone a series of fundamental and far-reaching changes and evolved into a variety of different crop rotations. In areas of dense settlement, all land is cropped with short cycle rotations, the curtailment in the length of the rotation having been achieved by a reduction in the number of years the land is rested under bush fallow. In the high forest zone of eastern Nigeria where smaller high forest exists as well as fresh water occur, land is therefore plentiful for agricultural development and exploitation, and for the practice of long cycle rotations. It is in this zone also that plantation agriculture has great scope. Most of the large commercial oil palm and rubber plant are located in this zone. The major food crops, plantain and cassava, continue to grow admixed with the invading bush fallow at the end of the cropping phase, the farmer harvesting both crops for food as and when required. There is hardly any differentiation of the rotation into compound and distant farmland rotations. The range of food crops grown is narrow and the intensity of cropping is light. Plantain replaces yams as a major food crop (Obi and Tuley, 1973).

In the riverine zone of eastern Nigeria, continuous cropping is practiced, apparently with no – till- effect on the soil and its fertility. Soil fertility is generally replaced annually through silt deposited by floods and the organic matter added by grasses and herbs which colonies the soil as soon as the flood recedes. However, the 'dry zone' of South Eastern Nigeria is part of the 'derived savannah' zone of Nigerian vegetation (Enyi, 1973).

2.24 **Characteristics of Major Farming Systems in South Eastern Nigeria Agro-ecosystem**

Farming system may be defines as a system that comprises the resources and characteristics in terms of the environment, crops, livestock, labour and materials of a farm unit that is managed by a family in accordance with its own goals.

The humid tropics are characterized by high rainfall (that is, where rainfall exceeds potential evaporation for 5 or more months in a year) and thick vegetation cover, soil management in traditional agriculture is such that the topsoil is covered by the canopies of a multi-specific crop mixture. In such a system, the opening up of new farm land is done with simple tools, usually hoe, which disturb only the topsoil. Some large trees like the palm trees are left though sometimes pruned, but the rest of the cleared land is burnt leaving the ash mulch on the soil.

Soil erosion, pest and diseases incidence is reduced by growing a mixture of crops with varying canopy configuration. Yields are maintained at a fairly stable but low level, while the soil fertility status is maintained by fallowing. Farmers tend to adapt to change in soil fertility by planting those crops which required most nutrient first (such crops include maize, yam and plantains); tuber and legume crops which have a lower nutrient requirement are planted later (Kaping *et al*, 1995).

Some crops such as yam, cassava is usually intercropped with vegetables, plantation crops, sweet potato, melon, maize, rice and legumes. The intercropping pattern depends on the environmental conditions and the food preference of the region. Cassava-based intercropping systems can be divided into simple mixture (which consist of only two crop species) and complex mixture (which consist of three, four or more crop species). As a long duration crop (5 – 7 months), cassava is well suited to intercropping with short duration crops such as maize, melon, cowpea, okra, groundnut and several leafy vegetables (Wahua and Oruba, 1985).

In simple mixtures, arable crops are usually selected on the basis of difference in growth habit and time of maturity. For example, cassava (being a slow growing crop at the initial stages with 9 – 18 months to maturity), is often grown with maize (having rapid growth, about 100 – 120 days to maturity), cowpea, melon (rapid growth, 70 – 80 days to maturity), groundnut (rapid growth, 120 days to maturity) or okra (harvested over a period of 50 – 100 days).

The complex mixtures are also known to suppress infestation by weeds, reduce soil temperature, retain higher soil moisture up to a depth of about 20cm and produce higher organic matter than in the case of sole cropping or simple mixture intercropping (Okoh *et al*, 2001).

The cropping systems prevalent in any agricultural society of the zone are commodity based and have developed in response to the environmental conditions, culture and preference of the people (Nwosu, 1973).

2.25 **Moringa Based Cropping Systems**

Moringa is an important vegetable in many tropical and sub-tropical countries including Nigeria. Its annual production is comparatively higher than many other secondary vegetables. Most of the parts of *M. oleifera* have medicinal value. Leaves, flowers and unripe fruits are used as vegetables, and roots and barks are used for medicinal purpose (Anwar *et al.* 2007; Hartwell, 1995; Anon. 2009; Suarez *et al.* 2003; Fahey, 2005; Bau *et al.* 1994; Thurber and Fahey, 2009; Anon. 2010; Hossain *et al.* 2012).

Moringa *(Moringa oleifera* Lam.*)* is widely naturalized in the tropical and subtropical regions including Nigeria (ICRAF 2001, Duke 1983). In Nigeria, *Moringa* is an important homestead specie grown even in some compounds. *Moringa* may be propagated through seed or cutting and germination percent is very high (ICRAF 2001; Aregheore, 2002). It requires very little care and it is a drought tolerant species. *Moringa* is a fast growing species with light crown. Its soft and deciduous leaflets may easily detach, decompose and release nutrients to the under-storey crops. There is a great potential of growing *Moringa* tree as an important multipurpose species in the cropland agroforestry system situated above the flood level where wheat is also a major cereal crop (Odee, 1998). It has been reported that juice extracted from the leaves can be used to make foliar nutrient capable of increasing crop yield by up to 38%, (Rao *et al*, 1983). When cultivated intensively and then ploughed into the soil, *moringa* can act as a natural fertilizer for other crops (Dutt *et al*, 1984). According to Anyaegbu (2005), Fahey, (2005) a plant is considered suitable for alley farming if it has fast /high growth rate.

The relative ease with which it propagates through both sexual and asexual means and its low demand for soil nutrients and water after being planted makes its production and management easy. The introduction of this plant into a farm which has a bio-diverse environment can be beneficial for both the owner of the farm and the surrounding ecosystem (Foidl *et al* 2001). Organic fertilizers derived from *Moringa* oliefera seed processed with the right procedure can increase the soil aeration and richness of indigenous invertebrates, specialized endangered soil species, beneficial arthropods, earthworms and microbes (FAO, 2010).

According to Emmanuel *et al*, (2011), maize yield on the *Moringa* fertilizer plot produced the best result, that is, an average of 330.7cm height at maturity; average of 17 leaves; average of 337.0g weight of wet cob and an average of 205g weight of dry cob as compared to the control. This is an indication that within the period of application, planting and maturity of plants the fertilizer had decomposed and made mineral nutrient available for plant use as compared to the control. Other organic fertilizers from plant and animal sources require a long period for decomposition (Villablanca, 2007) before planting. But this study has shown that the moringa oleifera seed cake can be used without long pre-decomposition period of the organic matter to give an improved plant yield. It also shows that there was no adverse effect on the plant.

Moringa based cropping systems has been reported where sweet potato biomass weight as affected by the *Moringa* based systems was observed. The biomass weight of the stands in the alleys of the fallow species increased significantly, compared to those in control plots and those that received chemical fertilizer respectively, an indication that the fallow tree species had improved the soil fertility of the area. Also, growing the crop in the alleys of the fallow species significantly ($P>0.05$) increased the tuber yield of *Ipomea batata*. The highest

(P>0.05) tuber yield of *Ipomea batata* was obtained from the mixed *Moringa + Leucaena* alleys in both the second and third year of planting. This impressive performance of the stands in *Moringa+ Leucaena* alleys is an indication that the neighborhood effect between the two fallow species was complementary (Anyaegbu *et al*, 2012).

Sarmin (2014) reported that *Moringa oleifera* bark, leaf and root extracts affected differently the germination, growth and yield of wheat plant. Germination rate was decreased for all concentrations of plant extracts compared to control. For all extracts longest hypocotyl was recorded in 25% concentration followed by control and 50% concentrations, though 50% bark extract produced longer hypocotyl than the control. Radicle length was reduced with the increasing concentrations for leaf and root extracts. Hence, longest (47.63 mm) and smallest radicle was recorded from control and 100% concentrations, respectively. Shortest radicle for bark extract was noted in 50% and above this, radicle was again increased. Plant height, tiller number and spike length was less affected by leaf extract. However, shoot weight and number of grain/spike was severely affected at 50% concentration of leaf extract. Bark extract increased spike length, shoot weight, root weight, number of grain/spike upto75% concentrations. But flag leaf length and tiller number were decreased with increasing concentration of bark extracts. Growth and yield parameters suffered more in root extracts except spike length and number of grain per spike.

Anyaegbu (2014) reported that stands of okra applied with *Moringa oleifera* extracts under sole cropping system produced 76% and 70% more pods than the stands in the control plots while those under intercropping produced 76% and 74% than those in the control plots. Also, the pod yield of okra treated with *Moringa* extracts was 90% and 86% greater than those in the control plots under sole cropping situations while under inter cropping it was 90% either way. Rao *et al* (1983) reported that juice extracted from the leaves of *Moringa oleifera* can be used to make foliar nutrient capable of increasing crop yield by 38%. Anyaegbu, (2013) reported enhanced growth performance of *Telfaria occidentalis* with the application of *Moringa* extracts and increase in grain yield of maize has as a result of moringa application.

2.26 **Cassava Based Cropping Systems**

Cassava production in Africa in general and in Nigeria in particular occurs within a variety of cropping systems which, on a given parcel of land, could be in the form of monocrop **(**cassava is the only crop on the plot; this is found mainly on large-scale commercial farms), intercrop **(**cassava is grown alongside other crops on the same plot at the same time) and crop rotation **(**this involves continuous use of the same parcel of land while alternating the crops grown from one season to the next or from one year to the next). Under the traditional cropping system, which involves growing a mixture of different crops and varieties of crops on the same plot of land at the same time, there is limited scope for the intensification of any one of the crops. Furthermore, the system is complex and difficult to analyze to come up with evidence-based recommendations for improvements. More simple systems with just two or three crops are easier to analyze and therefore enable research results to be communicated and applied. Therefore, to achieve sustainable commercial production of cassava, the farmer should consider reducing the number of accompanying crops on the same plot (IITA, 2014).

The crops grown together with cassava in Africa vary from region to region, country to country, and locality to locality, due to differences in agro-ecological conditions and socio-cultural practices. The common intercrops with cassava include: cassava and maize, cassava and a legume (cowpea, soybean, groundnuts, pigeon pea); cassava and vegetables (peppers, fluted pumpkin, okra, melon, spinach spp., and *Solanum* species); cassava, yam and maize; cassava, maize and groundnut (IITA, 2014), and cassava + cocoyam in some locality.

Cassava farms in the form of the cassava intercropped with other crops is commonly known as the cassava-based production systems. Cassava based cropping systems has from time immemorial been the prevalent arable cropping system in the large guinea savanna vegetation agriculture in Nigeria (FAO, 2004). The predominance of the system has been occasioned by Nigeria's climate which is basically tropical and favourable for cassava production, farmer's level of technology and their socio-economic situations. Though cassava when cultivated as a sole crop results in high outputs, the greatest disadvantage of sole cropping is that in instances of pest or disease outbreaks that attacks the soled crop, the farmer usually loses a significant part of his crops and sometimes even lose all. The cassava based form of producing cassava is therefore preferred by farmers, as it ensures them against total crop losses. However producing cassava under different mixed cropping conditions will definitely impact on resource use in cassava production and consequently crops' yields.

Intercropping cassava (*Manihot esculenta* Crantz), with varying soybean [*Glycine max* (L.) Merrill] plant populations may influence not only the performance of the component crops but also the residual nitrogen contribution to the cropping system (Mbah and Ogidi, 2012). According to Olasantan and Lucas (1992) the architecture and height of crop canopy as well as days to utilization of soil and aerial environment of the plants properly contribute to the competitiveness and performance of component crops in intercropping. Furthermore, the penetration of light into plant stand is diminished through interception and absorption by the leaves and other parts of the shoot systems. Hence, in an intercropping system, light utilization by leaf and crop surfaces determine the potential shares of the light that are gained by the component crops. Introducing legumes, including, soybean into cassava-based cropping systems in the humid tropics of Southeast Nigeria is gaining increased attention because soybean fix atmospheric nitrogen and produce proteins, while cassava deplete the soil nitrogen and give carbohydrates. Cassava and soybean mixtures improve the diet of farmers as well as the soils of their farms (Mbah and Ogidi, 2012). Studies have also shown that, intercropping increased the number of tubers and fresh tuber yield of cassava, though not significantly. This could be due to better photosynthetic efficiency by intercrops than sole cassava. Also, cassava tuber initiation and bulking were not subjected to any intercrop competition, having harvested the soybean earlier before tuberization process commenced in cassava and total number of tubers increased with increase in soybean plant populations. However, fresh yield of cassava was not significantly affected by soybean plant populations in the two cropping seasons, though there were bigger individual sizes of root tubers in the intercrop as soybean populations increased. The big individual roots obtained could be attributed to more competition for light and other growth resources as soybean plant population increased under the additive mixtures (Mbah and Ogidi, 2012; Mbah and Muoneke, 2007; Mbah *et al*, 2009).

In an experiment conducted by Muoneke and Mbah (2007) on the productivity of cassava/okra intercropping system as influenced by okra planting density, cassava plant height, number of leaves and leaf area index of cassava were significantly affected by intercropping systems. Study shows that cassava plant were significantly shorter at 6 – 12 WAP in sole than in intercrop with okra especially at higher okra planting density. Increasing the population density of okra up to 56,000 plants/ha in the intercrop progressively increased plant height but decreased the number of leaves per plant and the LAI of cassava in both years. According to Olasantan and Aina (1987), in okra intercropping and Muoneke and Asiegbu (1997) in maize/okra mixture, high population densities induced higher plant height and reduced number of leaves and LAI of component crops, probably because of competition for light and other resources.

However, on cassava yield and yield components, study revealed that the number of tubers per plant (marketable and unmarketable), weight of fresh tubers per plant and tuberous root yield of cassava were not affected by intercropping in both cropping seasons. Fresh tuber yield and yield components of sole cassava were not significantly affected by intercropping. Among the intercrops in the two cropping seasons, total number of tubers per plant, and especially, number of unmarketable tubers increased with increase in okra plant population under the additive mixture series. Conversely, there was a decrease in the number and weight of marketable tubers per plant as well as tuber yield of cassava per hectare as okra plant density increased from 14,000 plants/ha to 56,000 plants /ha.

Adeniyan *et al* (2014) reported significant increase in plant height and fresh tuber yield of cassava when intercropped with maize with increased in plant population density of maize in cassava/maize intercropping system. Intercropping of cassava with maize at different plant population density of maize component at early stage after planting had effect on cassava growth due to above ground competition for light. Studies also shows that cassava intercropped with maize at the same date was shaded on later dates during its association with maize, thereby causing cassava to receive less insolation for photosynthetic action. The competition of cassava with maize for light resulted in the reduction in dry matter (DM) formation, and the stems to attain greater height would assimilate less. According to Adeniyan *et al*, (2014), increased in plant population density of maize in cassava/maize intercropping system significantly affected the plant height and fresh tuber yield of cassava.

Intercropping cowpea with maize and cassava significantly ($P < 0.05$) affected the performance of cowpea. The rank summation index computed for cassava under maize based intercropping system indicated that cowpea cultivar IT96D-610 was the best for all the parameters and under maize-cassava based intercropping system, cowpea cultivar IT96D-610 recorded seed yield of 2.4 t/ha while IT89KD-288 had 1.3 t/ha for seed yield. Cassava fresh tuber yield under the sole cropping recorded 22.2 t/ha as compared to 18.3 t/ha recorded under cowpea/maize/cassava intercrop (Adeniyan, *et al*, 2011). Performance of cassava in various associations with maize, cowpea, yam and upland rice was evaluated in two ecological zones of Nigeria to determine suitable food crops(s) for intercropping with cassava. Fresh root tuber yields of sole cassava were significantly higher than the yields under the various mixtures. Cassava/cowpea and cassava/maize gave the lowest cassava yield reduction of 11% and 15% respectively. Cassava intercropped with maize, however, gave the highest energy yield which was significantly higher than the returns from cassava/maize/cowpea/rice polyculture. The highest LER was observed with cassava/maize intercrop. Planting cassava in double rows between two rows of maize, cowpea or yam significantly improved cassava productivity over cassava monocrop (Trenbath, 1976).

Muoneke and Mbah (2007) reported that the optimum okra planting density for intercropping with cassava was 42,000 plants ha^{-1} as it had the highest yield advantage. Increasing the population density of okra up to 56,000 plants ha^{-1} in the intercrop, progressively decreased tuber yield. They attributed this situation to competition for growth resources, which was intensified at high densities of okra in cassava plots. Ezumah and Namky (1984) and Ikeorgu et al (1989) reported similar results in complex crop mixtures involving cassava/maize/okra/melon intercropping system. The land equivalent ratio (LER) of cassava-okra intercrop at the varied plant densities of okra were all above 1.00. The highest LER of 1.30 and the least of 1.10 were obtained when cassava was intercropped with okra at 42,000 plants ha^{-1} and 56,000 plants ha^{-1} respectively. The productivity of cassava-okra intercropping as determined by the LERs in all combinations was superior in resource use efficiency compared to growing the two crops separately. Cassava generally was more competitive than okra in the intercrop. The competition coefficient of cassava decreased as okra plant density increased up to 42,000 plants ha^{-1} and thereafter increased with further increase in plant density up to 56,000 plants ha^{-1}. The highest competition coefficient in cassava was obtained at the lowest intercrop population of okra at 14,000 plants ha^{-1}, but the reverse was the case in okra (Ijoyah & Usman, 2013).

Cassava/maize mixed cropping system is popular and widespread among the West African farmers. The popularity is attributed to the compatibility and complementarities of the crops (Ikeorgu, 1994). The faster – growing maize explores the environment early while the slower - growing cassava explores later. Other crops like melon, which has a creeping habit, could also be planted in the mixture to control weeds and soil erosion. Although intercropping produces a stable and sustainable system of cropping in the tropics, there is the need for development of appropriate spatial arrangements for intercropping. According to Ayoola and Makinde (2007), cassava planting pattern did not have significant effects on maize grain yields in both years of planting. Makinde et al, (2001), also found that maize grain yield was not significantly affected by spatial arrangement and intercropping with melon. Yield of melon under triangular planting pattern was significantly higher than that obtained under regular planting pattern. This could be attributed to competition for soil resources (nutrients and moisture). Competition for these resources would be higher under regular planting pattern where cassava was planted at 10,000 plants/ha in comparison with 5,000 plants/ha under triangular planting pattern. They also found out significant differences in cassava height at harvest under the two planting patterns with regular planting pattern producing taller plants (1.69 m) than triangular planting pattern (1.47 m) over the two years. Cock et al (1979) reported that cassava responded to increased competition by diverting more dry matter to stem. Jalloh (1995), also found that the stem of cassava planted with rice elongated due to competition with the component crop. Cassava fresh stem weight was significantly higher under triangular planting pattern (11. 40 tha^{-1}). Cassava root yield was significantly higher under regular planting pattern (10.97 tha^{-1}) than for triangular planting pattern (9.40 tha^{-1}) for the two years due to higher cassava population. Average number of tubers per plant was lower with triangular planting (5.30) than the regular planting that had average of 6.90 tubers per plant. Cassava tuber girth was significantly higher under triangular planting pattern (212 mm) than for regular planting pattern (143 mm) (Ayoola & Makinde, 2007). However, Cock et al. (1977) found that a disadvantage of growing cassava at high plant population is the decrease in root size which may lead to a decrease in the yield of commercially acceptable roots. Odurukwe (1986) reported that increased yields resulting from higher population density are achieved at the expense of size of tuber. He however pointed out that this is only important where tuber size determines marketability.

The intercropping patterns with a different planting density of cassava affected the extension of both root tubers and adventitious roots (Iijima et al, 2004). Although the length of cassava root tubers was sometimes analyzed for the tuber productivity (Manrique, 1990; Pinho et al., 1995), root tuber extensions in the soil, in situ, have not been reported previously. Root tuber extensions, both horizontally and vertically, were significantly restricted in higher-density cassava as compared with those in the lower-density (50% density). Deep root distribution in cassava has been reported in various papers. For example, the deepest cassava roots penetrated to 1 m (Aresta & Fukai, 1984) or even 2.6 m (Connor et al., 1981) in different field conditions and to 1.8 m within three months of planting in a root box (Izumi et al, 2002). In contrast, when cassava was intercropped with legume (Muhr et al., 1995) or other grass species (Tscherning et al., 1995), the roots penetrated from 0.5 to 0.75 m. Light interception under a cassava canopy increased as the density of the plants increased. As Ikeorgu (1991), Cenpukdee and Fukai (1992) demonstrated, light interception causes a reduction in the yield of intercrops. Although a cassava canopy strongly reduces the light penetration to the intercropped soybean, it may reduce the transpiration rates of soybean during dry season, which would help the plants to retain the soil water in the rooting zone.

2.27 **Maize based Cropping Systems**

Intercropping of legumes and cereals is an old practice in tropical agriculture that time back to ancient civilization. Legume – cereal is the most popular inter-cropping system in the tropics. Snaylon and Harris (1979) found legume-cereal as the most popular intercropping systems in the tropics. Systems that intercrop maize with a legume are able to reduce the amount of nutrients taken from the soil as compared to a maize monocrop. During absence of nitrogen fertilizer, intercropped legume will fix nitrogen from the atmosphere and not compete with maize for nitrogen resources (Adu-Gyamfi et al, 2007). The mixture of nitrogen fixing crop and non-fixing crop give greater productivity than mono-cropping. Banik and Sharma (2009) reported that cereal-legume intercropping systems were superior to monocropping (Hugar & Palled, 2008b; Pandita, 2001). Maize + French bean gave high maize equivalent yield over sole yield and kernel yield of maize was unaffected in maize + French bean intercropping. Akinnifesi et al (2006) revealed that without nitrogen fertilizer application, gliricidia + maize intercropping system gave high maize yield. West and

Griffith (1992) observed maize yield was increased by 26% in maize + soybean strip intercropping. Also, Ghaffarzadeh et al (1994) and Tsubo et al (2005) found out that, in maize-bean intercropping maize yield was not affected. Sharma and Tiwari (1996) reported that tomato intercropped with maize increased the number and weight of fruit per plant and total yield. In maize-okra intercropping, yield and yield components of okra was increased (Muoneke & Asiegbu, 1997). Maize-Kenaf-African yam bean intercropping gave highest value of LER compared to monocropping (Adeniyan et al 2007). Maize with pumpkins gave high LER (Cortes and Los 1997). Maize + potato intercropping performed better than sole potato (Begum et al, 1999) and maize yield was not affected due to intercropping (Ifenkwe et al, 1989).

In the humid tropics, maize is traditionally grown in intercrop with cassava (Agboola & Fayemi, 1971; Fagbamiye, 1977; Ikeorgu et al., 1984). In Nigeria, cassava and maize are the prominent crops in intercropping practices and have been widely studied (Ezumah et al, 1980). Jerome et al. (1988) conducted an explanatory survey in Cameroon and found that maize was mainly intercropped with cassava, while Oyedokun et al, (1989) observed that cassava is planted by most farmers once maize is established or just before maize matures or after it is harvested. Cassava/maize intercrop has been indicated to be productive and compatible mainly because maize is a short season crop while cassava is a long duration crop (Ikeorgu, 2002). The crops lend themselves to many transformed products and forms (Numfor, 1987). Consequently, cassava and maize production are increasing rapidly. Adeniyan et al, (2014) reported increases in plant population density of maize in maize/cassava intercrop directly increased maize plant height at tasselling, plant height at harvest and plant lodging percentage, but reduced stalk diameter, average cob weight, dry matter yield and grain yield. However, maize-cassava intercropping gave LER advantage.

Several workers have reported the effects of maize population density on agronomic characteristics of maize in an intercropping systems. Duncan (1958) and Early et al (1967) indicated that the effect is mainly due to competition for light, moisture and soil nutrients. According to Adeniyan et al (2014), maize plant population density at 80,000 plants/ha exerted strong effect on maize height, stalk diameter and lodging percentage. Enyi (1973) and Hunt et al (1977) explained the observed trend of plant height and internodes length with increasing plant population density to competition for light. Studies also shows that grain yield per hectare increased with increased plant population density from 20,000 plants per hectare to 40,000 plants per hectare but significantly dropped with further increased in plant population density from 40,000 plants per hectare to 80,000 plants per hectare. Plant population density resulting in competition affects vegetative and reproductive growth.

Maize reproductive response to plant population density has generally shown that individual plant yield decreases as plant per unit area increases (Duncan, 1958). Mixed cropping or intercropping is an important practice in tropical developing countries because of its several advantages (Fujita and Offosu-Budu, 1996; Isoken, 2000) and maize and cassava intercrop has been described as the most prevalent and most productive enterprise with highest net margins in Southern Guinea Savanna ecology (Fakayode et al., 2008).

Increase in maize production in Nigeria is due to the expansion in area of cultivation rather than an increase in yield (Ogundari et al., 2006). However, crop diversification with the maize-based intercropping system can contribute to increased yield per unit area without increasing the land area while creating a more resilient production system. Also, diversification within cropping systems maximizes the use of soil, water, and biological resources, and the benefits of on-farm nutrient cycling and pest and disease control (Kremen & Miles, 2012; Lin, 2011). The diversification of maize-based systems is crucial to improving food, nutrition, and livelihood security while providing insurance against climate uncertainties (Senger et al., 2017). Maize is suitable and adaptable for the intercropping system due to its wide inter-row spacing and erect growth habit, which allows for complementary benefits for the intercrops. Intercrops with different light distribution intensity and root systems can utilize resources more efficiently (Gong et al., 2020; Prasad & Brook, 2005). The combined yields and profits from intercropping systems often exceed those of monocultures; thus, it is popular among farmers. For example, maize intercropped with cowpea, soybean, potato, and groundnut showed a significant yield advantage compared to sole cropping in tropical agro-ecosystems (Begum et al., 2016; Mucheru-Muna et al., 2010; Chinaka and Obiefuna, 2000). Maize, when intercropped, is less susceptible to pests, diseases and weed infestations (Bilalis et al., 2010). More importantly, the inclusion of legumes in intercropping systems plays an essential role in soil fertility restoration through biological nitrogen fixation (Sanginga, 2003; van Kessel et al., 2000).

Higher grain yields achieved in the maize sole cropping than those of the intercrops is a function of the growth resources (e.g. space, light, nutrients, moisture) available to maize sowed as sole cropping than when intercropped with cowpea, groundnut, and sweet potato. Moreover, the increase in maize yields when intercropped with sweet potato could be attributed to complementary effect in terms of compatibility with light, space, nutrients and water use efficiencies than those of cowpea and groundnut (Oyeogbe et al, 2020). Competition for growth resources is a major tradeoff or exchange in intercropping systems, and hence, selecting crops that differ in photosynthetic activity, growth habit, duration, and nutrients demand are a prerequisite for higher productivity (Gong et al., 2020). In a similar study, Begum et al (2016); Chinaka and Obiefuna, (2000) reported that the system productivity of maize/sweet potato intercrops often exceeds that of sole crops due to synergism that favours the growth and yields of both crops. In a maize/sweet potato intercropping system, Begum et al (2016) and Ifenkwe et al, (1989) showed that potato yield is always higher when maize sowing is delayed (30-45 days) than when both crops are sowed simultaneously. This observation is as a result of maize canopy shading, which can intercept the availability of light, and consequently negatively affect the productivity of the intercrops. Thus, fine-tuning the planting dates of the intercrops can reduce the competition for growth resources, and hence increase productivity.

Increase in the cost of cultivation of the maize/ sweet potato than those of maize/cowpea and maize/ groundnut is due to the expenses incurred from additional agronomic management practices for the sweet potato. The yields of sweet potato positively affected the income generated than those of cowpea and groundnut. A good indicator of a cropping system is the actual profit obtained, which represents the suitability of a cropping system. Mucheru-Muna et al (2010) showed that the gross returns from maize/potato, maize/cowpea and maize/groundnut increased significantly than that of maize sole cropping. Thus, the higher net returns from the maize/sweet potato are reflective of the increased productivity of both crops under intercropping systems compared to those of cowpea and groundnut.

Interestingly, the benefit-cost ratio of the diversified cropping systems was greater than one, which shows that they were profitable.

Studies on maize based intercropping systems shows highest grain yield (6830 kg ha^{-1}), stover yield (9640 kg ha^{-1}) and harvest index (HI) (0.415) of maize was recorded in paired row maize intercropped with vegetable cowpea (maize + vegetable cowpea) in 2:2 row ratio. It was on par with maize + Black gram, sole maize and maize + green gram. Legumes have ability to fix atmospheric nitrogen to the soil so the grain yield of maize was increased by intercropped legumes. Paired row maize intercropped with legumes gave better yield compared to normal plant spacing of maize (Parimaladevi et al, 2019; Banik et al., 2000). Maize yield was increased due to intercropped with vegetable cowpea compared to other intercrops. Muoneke *et al* (2012) reported maize intercropped with vegetable cowpea, the grain yield of maize was increased. Choudhary, (2014) reported highest stover yield of maize was obtained in maize intercropped with cowpea. Increase in grain yield of maize was also reported by Ndakidemi and Dakora, (2005) due to intercropping with cowpea. According to Parimaladevi et al, (2019), higher intercrop yield (1845 kg ha^{-1}) was obtained in paired row maize intercropped with vegetable cowpea in 2:2 row proportion (maize + vegetable cowpea). Cowpea can tolerate shade produced from maize and fix atmospheric nitrogen to the soil. Nutrient competition between maize and vegetable cowpea will be less compared to other intercrops so yield will be increased in both crops. Maize equivalent yield of all the intercropping treatments are higher than sole maize. Highest maize equivalent yield (9668 kg ha^{-1}) was obtained in maize + vegetable cowpea (2:2) in paired rows. Maize equivalent yield (MEY) was higher in paired row planting pattern compared to normal plant spacing (Rana *et al*, 2001).

Intercropping cowpea with maize significantly ($P < 0.05$) affected the performance of cowpea cultivars. However, intercropping cowpea with maize and cassava significantly ($P < 0.05$) affected the performance of cowpea cultivars. Under maize-cassava based intercropping system, cowpea cultivar IT96D-610 recorded seed yield of 2.4 t/ha while IT89KD-288 had 1.3 t/ha for seed yield. There were significant differences in the yields of maize, cassava and cowpea. Maize grain yield under sole cropping recorded the highest value of 3.4 t/ha, this was neither significantly different from the value recorded under cowpea/maize intercrop (3.3 t/ha) nor from the value recorded under cowpea/maize/cassava intercrop (1.7 t/ha) (Adeniyan et al, 2011; Seran & Brintha, 2009b; Banik & Sharma, 2009; Hugar & Palled, 2008b; Pandita, 2001).

Hossain et al., (2001) in his work on maize-okra mixture reported that number of okra branches decreased as time of sowing okra into maize plots advanced. Similarly, the number of pods per plant significantly ($P \leq 0.05$) decreased as sowing of okra was delayed (Alfredo et al., 1999). Moniruzzaman et al., (2007) reported that yield of okra was highest when sown at the same time as maize but progressively decreased with delayed planting of okra. Moniruzzaman et al., (2007) also reported a decrease in okra yield with delayed planting of okra. They noted that the tallest okra plants and largest leaf area of okra obtained when okra was sown at earlier date could have promoted its highest pod yield. They therefore observed a correlation between the plant height and yield of okra. Intercropping okra with maize at the same time not only recorded the lowest competitive pressure but gave the highest LER of 1.75 with 42.9 % of land saved (Ijoyah et al, 2012 Snaylon & Harris, 1979; Adu-Gyamfi et al, 2007; Ifenkwe et al, 1989).

In maize/soybean intercropping system, an excellent study revealed that soybean-based cropping can reduce soil carbon and nitrogen losses and thus improve soil fertility and yields, which is important for sustainable agricultural development on a regional and global scale. Drinkwater et al (1998), suggested that soybean-based intercropping systems are ideal for increasing land-use efficiency and sustainability in modern agriculture. As one of the most important crops worldwide, soybean is capable of providing plant proteins and oil for humans and concentrated feeds for animals. In Nigeria and other countries of the world, farmers traditionally intercrop soybean with maize, wheat, sugarcane, cassava, sweet potato, potato, tobacco, and fruit crops, etc. (Knörzer et al. 2009; Li et al. 2013; Yang et al. 2014). Soybean-based intercropping was rediscovered by agronomists in the modern society due to its feature of nitrogen fixation (Knörzer et al. 2009). Comparative analyses of various crops intercropped with soybean have indicated that maize is the best partner in a soybean intercropping system. This is because these species possess complementary characteristics and both are thermophilic (warm) seed crops with similar sowing seasons. Maize is a nitrogen-consuming C4 crop that occupies a relatively higher ecological niche, while soybean is a nitrogen-fixing C3 crop that occupies a relatively lower ecological niche; these characteristics enable them to coexist harmoniously. Therefore, a maize-soybean intercropping system can be implemented in any area worldwide where maize and soybean are grown (Sharma & Tiwai, 1996; Muoneke & Asiegbu, 1997; Khatiwada, 2000; Adeniyan et al, 2007; Cortes & Los, 1997; Begum et al, 1999).

The deployment of numerous semi-dwarfed but high-yielding maize cultivars can also reduce the influence of shade on intercropped soybean (Yan et al. 2010; Gong et al. 2014). The semi-dwarfed varieties facilitate close planting, which minimizes the differences in biomass and leaf area index between a maize-soybean strip intercropping system and a monocropped maize or soybean system (Yang et al. 2014, 2015). Combined with compact-planting strategies, the crop density of strip-intercropping is increased. As a result, the yield of maize is similar to that in sole cropping while extra soybean production can be obtained, providing additional benefits compared with maize-sole cropping (Akinnifesi et al, 2006; West & Griffith, 1992; Ghaffarzadeh et al, 1994; Tsubo et al, 2005).

The land equivalent ratio (LER) and yield are critical indices to assess land output. A study on Chinese traditional single-row maize-soybean intercropping model indicated that the highest LER did not exceed 1.2, and the average grain yield reached 7 274 kg ha^{-1} for maize and 1 004 kg ha^{-1} for soybean (Lv et al. 2014). By contrast, the LER typically ranges between 1.64 and 2.27; the corresponding average grain yield is approximately 6 790–11 475 kg ha^{-1} for maize and 1 510–2 364 kg ha^{-1} for soybean in the maize-soybean relay-strip-intercropping system in Southwest China (Deng et al. 2013; Cui et al. 2014; Liu et al. 2014; Yang et al. 2015; Rahman et al. 2016), which indicates much higher values than those obtained using the traditional models (Raji 2007; Lv et al. 2014). Studies also demonstrated that soybean cropping increases the retention of soil carbon and nitrogen through the maize-soybean rotation system (Drinkwater et al. 1998). Recent studies also showed that maize yields in a two- and three-year maize-soybean alternative rotation were 9.4 and 12.6% higher, respectively, compared with a maize-sweet potato rotation system. The results suggest that the soybean-based maize strip intercropping increases the phosphorus availability and APase activity in the soil thus improving soil fertility and production of the following crop (Wang et al. 2012, 2017). Actually, in the maize-soybean strip intercropping systems, annually alternative rotation between maize and soybean strips has been used to prevent soil continuous cropping obstacles and improve the sustainable production of the farmland. Comparing to successive maize-soybean strip intercropping systems, maize grain yield, absorption amount of nitrogen, phosphorus, and potassium in maize were increased by 7.5, 18.5, 9.1, and 14.2%, respectively, without significant changes in soybean yield, by annual maize- and soybean strip alternative rotation (Yong et al. 2015). Alternatively, extra soybean production is obtained without affecting maize yield in current strip intercropping systems, which balances the high crop productivity and sustainability.

Takim et al, (2020) reported that the plant population of maize in the intercropping of maize-sweet potato did not differed, the reduction in grain yield of the intercropped maize might be associated with inter-specific competition between the intercrop components for growth resources and the depressive effects of sweet potato. Dasbak and Asiegbu (2009) explained that sharing of growth resources among components crops under intercropping can limit growth and accumulation of dry matter compared to sole cropping where competition exists and in this study, the competitive ability of maize increased with an increased in number of sweet potato vines planted. When 3 vines of sweet potato were intercrop between maize stands, the competitive ability of the maize (3.78) was higher than 0.42 obtained for sweet potato. Although, the yield of maize varieties was depressed in intercropping compared to sole cropping, the sweet potato yield compensated for this depression and the higher LER recorded in intercropping plots indicated yield advantage over sole cropping which demonstrated a better land utilization and cumulative yield. Saad et al, (2016) reported that LER were highest from plots where cauliflowers and lettuces were intercropped at different plating populations as compared with monocropping patterns. Nedunchezhiyan et al, (2011) viewed that, a strip intercropping system involving sweet potato + pigeon pea resulted in a higher land equivalent ratio (1.31) and net return ($623.9) compared to the other forms of intercropping and to monocropping; and Workayehu (2014) reported that intercropping was more effective and efficient than sole crops in the use of environmental resources as demonstrated by higher LER. Asiimwe et al. (2016) observed that, LER >1.2 obtained at maize-sweet potato intercrop with maize densities of 41,666 and 55,555 plants/ha in northern Uganda and Idoko et al (2018) in Makurdi-Nigeria concluded that LER values for all the intercrop combinations have shown that it is advantageous to intercrop maize with sweet potato.

Emuh and Agboola (2000) reported that by the second week after planting, maize was tallest in association wih sweet potato and pigeon pea, though not significantly so, compared to other mixtures. The better performance of sole maize compared to maize in the mixtures could be attributed to competition among the crops in mixtures for the same growth resources as were available for sole maize.

Throughout Central America, a common intercrop of corn-beans-squash is traditionally grown. Grown together, these three crops optimize available resources. The corn towers high over the other two crops while the beans climb up the corn stalks. The squash plants sprawl along the ground capturing light that filters down through the canopy and shades the ground. The shading discourages weeds from growing. This mixture was compared to the individual crops grown separately near Tabasco, Mexico (Amador, 1980). In the study, corn yields were considerably higher in the mixture than in a pure stand planted at optimum densities. Bean and squash yields suffered considerable yield reductions when grown in mixture. In this example, if corn was the most important crop, it was beneficial to grow it in mixture with squash and beans. The beans and squash were just a bonus. The LER for the whole mixture was considerable higher (1.6) than any of the pure stands.

Canadian researchers (Martin et al, 1988) worked with several corn-soybean intercrop-seeding rates to determine their economic advantages as silage. Pure stands of corn and soybeans were grown for comparison planted at 24,000 corn seed per acre or soybeans planted at 200,000 seed per acre. Results showed that intercrops were more cost effective than pure stands over both years the study was conducted. The study featured five experimental intercrop seeding rates with two planting arrangements (alternate and within the row). They concluded that a planting rate of 16,000 corn seed per acre (67% of the full corn rate) with 135,000 soybean seed per acre (67% of the full bean rate) planted within the same rows along with 53 lbs. of N/ac gave the highest economic returns. Note: the planter was set to drop 151,000 seeds per acre. This mixture gave a LER of 1.14 over pure stand yields. The crude protein level of the intercrop silage was considerably higher than for pure corn silage. A slightly higher yield was achieved from full stands of both corn and beans in alternate rows (LER=1.23) but the cost of production was higher, thus offsetting the improved yields.

2.28 **Sweet Potato Based Cropping Systems**

Ijoyah and Jimba (2011) reported that in a sweet potato-okra intercropping system, the highest number of okra pods per plant and highest okra yield were obtained from okra sown at the same time as sweet potato. The highest number of pods produced could have been influenced by its highest number of branches and leaves obtained when planting of both crops was done at the same time. This view support Ijoyah et al (2010) who reported that the number of pods would depend on the intensity of growth of the plant. The largest leaf area produced when planting of both crops was done at the same time might have promoted its greatest yield. This view supports Moniruzzaman et al (2007) who observed a correlation between leaf area and pod yield. The number of sweet potato tubers and tuber yield decreased as time of planting okra into sweet potato plots advanced. The greatest intercrop tuber yield was also obtained from sweet potato planted at the same time as okra. This finding agreed with that of Uzozie (2001) who reported that best cassava yield was obtained when maize was planted at the same time in a cassava-maize intercropping system. Sweet potato planted at the same time as okra gave the highest LER of 2.39, indicating the highest yield advantage.

Njoku et al (2007) in their work on the effect of intercropping varieties of sweet potato and okra in South-eastern Nigeria, reported that the interaction of okra and sweet potato cultivars significantly affected total number of tubers per plant but not tuber yield. Irrespective of okra cultivar, sweet potato variety ‘TIS 87/0087’ intercrop produced more tubers than ‘TIS 8164’ and that of ‘TIS 2532.OP.1.13’. In sweet potato cultivar x okra cultivar intercropping ‘TIS 87/0087’ sweet potato with ‘NHAe 47-4’ okra gave the highest number of tubers per plant. Okwuowulu and Asiegbu (2000); Okorie and Okpala (2000) also reported superior performance of ‘TIS 87/0087’ sweet potato and ‘NHAe 47-4’ okra compared with other cultivars. The presence of sweet potato, a planophile (having the leaves more or less horizontal or probably low or flat leaf erectness) did not significantly depress okra fresh pod yield, probably because the sweet potato conserved soil moisture and reduced weed growth. Ikeorgu (1984) had reported that melon (a planophile) improved the yield of companion crops by conserving soil moisture, thereby making the environment more conducive for plant growth and development. The various cultivar interactions were not significant for okra fresh pod yield. The LER of the sweet potato and okra cultivars were all above 1.00, indicating that higher productivity per unit area was achieved by growing the two crops together than by growing them separately. The highest LER of 3.10 was obtained by intercropping 'TIS 2532 OP.1.13' sweet potato and 'NHAe 47-4' okra, depicting 160 % yield advantage in growing the cultivars together. Muoneke and Asiegbu (1997) obtained similar results in okra/cowpea intercropping system. Essien et al, (2015) reported an increase in sweet potato tuber yield as attributed to decomposition of organic matter from moringa litter falls.

Takim et al, (2020) reported that the maximum yield of sweet potato in the intercrop was obtained from 1(one) vine of sweet potato (33,333 plants/ha) planted between maize stands (8.12 ton/ha) while 6.05 ton/ha from a (2) two vines of sweet potato (66,666plants/ha) planted between maize stands was the lowest compared to 9.13 ton/ha obtained from sole sweet potato plots. The difference in yield occurred due to variation in plant population as well as other yield attributes not reported. It was observed that, the number of vines planted determined the number of plants per plot also each stem at full establishment behaves as separate sweet potato plant since each has its own root and shoot system (Akintoye et al. 2009; Islam et al, 2014; Ogbologwung et al, 2016); and similar observation were reported on yams (Okpara et al., 2013; Ikoro et al., 2014) but sweet potato at plant population above 33,333 plants/ha probably had reached the carrying capacity, thus additional seedlings are destroyed through allelopathy, competition (self – thinning), shading effects provided by the previously emerged stems, or any combination of the above factors might have led to low tuber yield.

Emuh and Agboola (2000) reported that tuber yield of sweet potato was significantly higher in sole crops than in the intercrops and also sweet potato in association with maize was significantly higher than in the three crop mixtures.

2.29 **Levels in Intercropping Systems**

2.29.1 Escalating Diversity and Stability to a Higher Level

Ecologists tell us that stable natural systems are typically diverse, containing many different types of plants, arthropods, mammals, birds, and microorganisms. In stable systems, serious pest outbreaks are rare, because natural controls exist to automatically bring populations back into balance. By planting crop mixtures, which increase farm-scape biodiversity, crop ecosystems can become more stable, and pest problems can be reduced. There is overwhelming evidence that plant mixtures support lower numbers of pests than do pure stands (Altieri et al, 1978); and there are two schools of thought on why this occurs. One suggests that higher natural enemy populations persist in diverse mixtures due to more continuous food sources (nectar, pollen, and prey) and habitat. The other thought is that pest insects who feed on only one type of plant have greater opportunity to feed and breed in pure crop stands because their resources are more concentrated than they would be in a crop mixture (Altieri et al, 1978). Regardless of which reason you accept, the crops growing together in the mixture complement one another, resulting in lower pest levels.

In the Paramour's system, all the nitrogen needs of the cotton crop are met with cover crops except for 10 units per acre of starter nitrogen and another 15 units applied while spraying herbicides. Petiole samples taken every week to monitor plant nitrogen show that cotton grown with lupines maintains a normal range of tissue nitrogen throughout the growing season. The nitrogen level in cotton grown solely with fertilizer is very high initially, then subsequently falls back to a lower level. In one comparative year, the cotton grown following lupine produced 96 more pounds of lint, with only 25 units of commercial nitrogen, compared to a field with 125 units of nitrogen and no lupines. Additionally, the lupine field required less spraying for insects-only twice compared to 5 sprays for the commercial nitrogen field. This reduction saved 60% on insecticides, amounting to $35 per acre. The reduction in need for pesticides is believed due to the large population of beneficial insects generated and sustained in this system. The lupines provide food for aphids and thrips, which attract ladybugs, big-eyed bugs and fire ants as predators. When the cotton gets big enough to shade out the lupines, the beneficial insects move to the cotton rather than migrate from the field. The Paramours estimate that improved yields, combined with cost reductions, are netting them an additional $184 per acre with the strip tillage lupine system when compared to the conventional management system (Altieri et al, 1978; Alteri & Liebman, 1994).

Alfalfa is one of the best crops for attracting and retaining beneficial insects. This characteristic can be enhanced further. Strip-cutting alfalfa (i.e. cutting only half of the crop in alternating strips at any one time) maintains two growth stages in the crop; consequently, some beneficial habitat is available at all times. In some cases alfalfa is mixed with another legume and a grass (Alteri, 1994; Ricon-Votora, 1986).

Planting cotton into strip-killed crimson clover improves soil health, cuts tillage costs, and allows cotton to grow without any insecticides and only 30 pounds of nitrogen fertilizer. Cotton intercropped with crimson clover yielded over three bales of lint per acre compared with 1.2 bales of lint per acre in the rest of the field (Dimerger, 1995).

2.29.2 **Escalating Diversity and Stability to an Even Higher Level**

The diversity created by intercropping can be enhanced even further by integrating livestock (single or mixed species) into the cropping plan as harvesters. Allowing animals to harvest feed crops in the field puts gain on animals at the cost of crop production – considerably less than the purchase price of the grain. Grazing animals and other livestock can be managed on croplands to reduce costs, increase income, and increase diversity. There are ways of incorporating animals into cropping without the farmer getting into animal husbandry or ownership directly. Collaboration with neighbors who own animals will benefit both croppers and livestock owners. Grazing or hogging off corn residue is one example where a cost can be turned into a profit. The animals replace the price per acre stalk mowing cost and produce income in animal gains (Grossman, 1993; Willy, 1983).

CHAPTER THREE

MATERIALS AND METHODS

3.1 **Materials**

3.1.1 **Description of Experimental Site and Cropping History**

This study was carried out at the Teaching and Research Farm of the Department of Crop Science and Technology, Federal University of Technology, Owerri during 2015/2016 cropping seasons. The site is geographically located between Latitude $05^0 27^1$N and Longitude $07^0 02^1$E with altitude 55m above sea level. The area has annual rainfall range between 1500 – 3000mm which begins from April to August (long) and September to November (short) wet periods. The rain which usually starts in April and ends in November, with a short period of relative moisture stress in August is traditionally referred to as "August break".

Owerri is located within the humid tropical rain forest vegetation zone of Southeastern Nigeria, ecologically characterized by bimodal rainfall pattern. The soils of the Owerri are acidic and are classified as ultisols (Nwosu *et al*, 2021), with low mineral reserve and are therefore low in fertility (Eshett, 1993); characterized by deep porous red soils derived from sandy deposits in the coastal plain which is highly weathered and coarse textured (Onweremadu *et al*, 2007; Ofoh *et al*, 2010). The area has average maximum temperature of 35^0C and minimum of 17^0C with relative humidity of 89 to 93% (Nkwopara *et al*, 2020, Nwajiuba & Onyeneke, 2010).

The experiment was carried out on area that had been left fallow for one year. The area was previously cultivated with annual crops. During the period of fallow, the land was covered mainly with elephant grass (*Pennisetum purpureum*), Gamba grass (*Andropogon gayanus*), Siam weed (*Chromolena odorata*), *Cynodon dactylon*, *Cyparus spp*, *Euphobia spp* and *Ageratum conyzoides*. The choice of the experimental site was primarily because of the intensity and diversity of systems of farming due to climatic and soil conditions of the area.

3.1.2 **Planting Materials**

The planting materials used were sourced from Research and Tertiary Institutions including; the Department of Forestry, Federal University of Technology, Owerri, Imo State, Federal College of Agriculture, Ishiagu, Ebonyi State, National Root Crop Research Institute, Umudike, Abia State and National Cereal Research Institute, Badeggi, Niger State.

3.2 **Methods**

3.2.1 **Land preparation**

The experimental site which occupied an area of 51m x 20m = 1020m^2 (0.102/ha) was cleared, packed and was tilled manually, aimed at pulverizing the soil to achieve some measure of weed control and to incorporate crop residues into the soil thereby loosening the soil for effective planting. After clearing, the field was marked out into blocks and plots before ridges were constructed manually.

3.2.2 **Experimental Design and Treatments**

The experimental site was demarcated into blocks and plots, and was laid out in a randomized complete block design (RCBD) with 11 treatments replicated 3 times. Each experimental block contained 11 plots, each plot measured 5m x 4m for both sole and intercrop, giving a total of 33 plots. Both the blocks and plots were separated from each other by a path of 1.5m and 0.5m, respectively. Cross bars were constructed on each block and plot to reduce the effect of run-off water on the site.

The treatment used for the experiment were:

Sole Moringa (SMo)

Sole Cassava (SCa)

Sole Maize (SMa)

Sole Sweet potato (SSp)

Moringa + Maize (Mo + Ma)

Moringa + Cassava (Mo + Ca)

Moringa + Sweet potato (Mo + Sp)

Moringa + Cassava + Maize (Mo + Ca + Ma)

Moringa + Cassava + Sweet potato (Mo + Ca + Sp)

Moringa + Maize + Sweet potato (Mo + Ma + Sp) and

Moringa + Cassava + Maize + Sweet potato (Mo + Ca + Ma + Sp)

3.2.3 **Processing of Moringa seeds**

Moringa dry pods were procured from the Department of Forestry, Federal University of Technology, Owerri, Imo State. Seeds (dehisced from dry pods) were bagged and were treated (seed dressing) with Agron star 42ws* (20% thimethoxam + 20% metalaxyl-M + 2% Difenoconazol), to prevent attack by pest.

3.2.4 **Cultural Practices**

i. ***Pre-Planting Operation***: Seed viability test was done on Moringa to ascertain germination potentials of the seeds. Thirty seeds were randomly selected for the test. Surface sterilization of the seed samples were carried out by washing the seed samples with 1% mercuric chloride for 30 minutes. 10 seeds were placed on a soaked filter paper in a petri-dish and was monitored daily for 3 days, and the germination counts recorded.

ii. ***Planting of Moringa Seeds***: The seeds of Moringa were planted 3 seeds/hole at a distance of 1m x 1m at a depth of 3cm. On emergence, the seedlings were thinned down to 1 plant/stand at 2 weeks after planting (WAP).

iii. ***Planting of Maize Seeds***: The maize variety used was Oba super II. The seeds of maize were planted at three seeds/hole at a distance of 1m x 1m at a depth of 3cm. The seedlings were later thinned down to 1 plant/stand giving a plant population of 10,000 plants/ha.

iv. ***Planting of Cassava Stem***: The cassava variety TMS 98/0505 released by IITA was used. The choice of the variety was because it has ecological adaptability, with intermediate height and with little or no branching habit, and early maturing. The stem was cut at 25cm long with at least 5 nodes. The stem was planted at an inclined position of about 45^0 on the crest of the ridge at a distance of 1m x 1m. During planting, care was taken to ensure that the buds are not inverted as this will bring about delayed sprouting.

v. ***Planting of Sweet potato vine***: The vines of sweet potato (var. UMUSPO I pink fleshed skin) were cut at a length of 25cm containing at least 5 nodes. The vines was planted at a distance of 1m x 1m apart, and were planted at inclined position with 2 nodes buried in the soil at 2cm deep on the crest of the ridge. The choice of the variety was because of its adaptability and early maturing characteristics.

vi. ***Weed Control***: Weeds were controlled manually with hoe during the growth period. This was done as at when necessary. However, first weeding was done one month after planing on the experimental plot.

3.2.5. **Data Collection**

3.2.5.1. ***Weed Flora Composition***:

The composition of weed flora on the site were collected before bush clearing and first weeding. This was done by using 0.2cm x 0.2cm quadrant tool. Species of weeds on the experimental site were identified and counted (Table 1and 4).

3.2.5.2. **Soil Sampling and Analysis:**

The pre-planting and post-harvest composite soil samples for the two cropping seasons (2015 and 2016) were collected at 0-20cm depth using soil auger. The soil samples were carefully labeled, air dried, crushed and sieved through a 2.0mm mesh and analyzed for physico-chemical properties in the laboratory according to standard methods as follows:

i. **Particle size**: This was determined by the hydrometric method using sodium hexametaphosphate and sodium carbonate mixture as dispersing agent as described by Benton (2001).

ii. **Soil pH**: The soil pH was determined in distilled water and 0.1N KCl solution using a soil to solution of 1:25 (Udo *et al*, 2009).

iii. **Organic Carbon**: This was determined by the wet oxidation method of Walkley and Black (1934). The value obtained was multiplied by 1.729 to obtained organic matter content as modified by Pansu and Gautheyrosu, (2006).

iv. **Total Nitrogen**: This was determined by the micro-kjeldahl digestion and distillation method using sulphuric acid and $CuSO_4$ and $NaSO_4$ catalyst mixture (Simmone *et al,* 1994).

v. **Available Phosphorus**: The available phosphorus was determined by the Bray II method (Udo et al, 2009).

vi. **Total Exchangeable Basis (TEB)**: Sodium (Na) and Potassium (K) were determined from ammonium acetate using auto-electric flame photometer. Calcium (Ca) and Magnessium (Mg) were determined by the complexometeric titration method as described by Udo et al, (2009).

vii. **Exchangeable Acidity (EA)**: This was determined by titrimetric method using one normal potassium chloride (1.0NKCl) extract (Mclean, 1982).

viii. **Base Saturation (BS)**: Base saturation was determined by calculation as the percentage ratio of total exchangeable bases (TEB) to effective cation exchange capacity (ECEC), using the procedure outlined by Anderson and Ingram (1993). BS = TEB/ECEC x 100.

ix. **Effective Cation Exchange Capacity (ECEC)**: This was determined by calculation by adding the determined total exchangeable bases (TEB) values (Na^+, K^+, Ca^{2+} and Mg^{2+}) to the determined exchangeable acidity (EA) values (Al and H).

x. **Electrical Conductivity (EC)**: This was determined by conductivity bridge and cell method as described by Udo and Ogunwale (1986).

3.2.5.3. **Soil Microbial Analysis**

Soil samples were collected from the experimental site at a depth of 0 – 20cm before and after planting to determine the change on the following soil microbial population:

i. **Soil Bacteria**: This was estimated using 10-fold serial dilution plate technique as described by Cheesbrough (2004).

ii. **Soil Fungi**: This was estimated using soil 10-fold serial diluted plate as described by Prashanthi *et al,* (2021).

iii. **Soil Nematode**: This was estimated using USDA Nematode extraction technique as described by Dewang (2012).

3.2.5.4. **Climatic Data Collection**

The climatic data for the experimental area was collected from 2014, 2015 and 2016 cropping seasons.

3.2.5.5. **Growth Parameters**

The determination of growth parameters was done at 2 weeks after planting (WAP) and at 2 weeks interval. Five plants in each treatment were randomly selected and tagged for measurement from each plot. The following growth parameters were taken:

i. **Percentage Emergence/Establishment count**: The number of sprouted and established cassava and sweet potato cuttings were taken 3 weeks after planting (WAP). Moringa and maize emergence and establishment counts were taken 7 days after planting (DAP). These were done by counting the number of emerged crop stands on plot bases against the number planted per plot and expressed as percentage.

ii. ***Plant Height (cm***):

Moringa/Maize/cassava: Five plants in each treatment were randomly selected and tagged/plot. Plant height of the selected and tagged plants were measured from the base to the last leaf that is well opened or developed.

Sweet potato: The length of the main vine of sweet potato was measured from the base to the area of the last leaf that is well opened.

iii. ***Stem girth/Vine girth (cm)***: The stems of Moringa, Maize and Cassava selected and tagged from each treatment were determined and mean recorded. The vine of the selected and tagged sweet potato plant was measured and recorded.

iv. ***Leaf number***: The number of functional leaves of each plant of the selected and tagged were counted and recorded.

v. ***Leaf area (cm^2)***:

Maize: The leaf area of the selected and tagged maize was determined by the non-destructive method as described by Ogoke *et al* (2003) and Aban *et al* (2017), and the length and width was multiplied by leaf factor (0.75) as described by Wahua (1985).

Cassava: The leaf area of cassava was determined by measuring the length and width of the selected and tagged plant and the central leaf, and product obtained was multiplied by 0.44 (leaf factor) as described by Ogoke et al (2003, 2009).

Sweet potato: The leaf area of the selected and tagged central leaf was determined by measuring the length and width of the selected and tagged plant and the product obtained was multiplied by leaf factor (0.45) as described by Ogoke et al (2003).

Moringa: The leaf area of moringa was determined using tracing method. The leaf was spread over a graph sheet of paper and the outlined of the leaf was traced. The boxes covered by the leaf were counted and calculated to determine the leaf factor. Therefore, the length and width of the selected and tagged central leaf of the selected and tagged plant were measured and the product obtained was multiplied by the estimated leaf factor of 2.59 (Field survey, 2015, 2016 and Abana et al, 2017).

3.2.5.6 **Yield Parameters**

a. **Maize yield**:

i. ***Number of cob/plot***: The cobs were harvested per treatment basis and the number of cob in each treatment were determined by counting.

ii. ***Fresh weight of cob***: The harvested cobs were weighed using top load weighing balance according to treatments on plot bases and was later converted to tones per hectare (t/ha^{-1}).

i. ***Dry weight of cob***: The harvested cobs were shade dried, weighed and the constant and final weight recorded.

ii. ***Weight of 1000 seeds***: After shelling, 1000 seeds were selected randomly and was weighed.

iii. ***Number of rows/cob***: One cob per plant was selected and tagged and the number of rows of the selected and tagged cobs per treatment were counted and recorded.

iv. ***Number of seeds/cob***: The number of seeds of selected and tagged cobs were determined by counting the grains and mean recorded.

v. ***Length of cob***: The length of the selected and tagged cobs were measured and recorded.

vi. ***Fresh stalk weight***: At harvest, the fresh stalks were cut per treatment and weight of stalks obtained.

vii. ***Dry stalk weight***: The harvested stalks were shade dried and measured and constant weight recorded.

b. **Sweet potato yields**

i. ***Number of storage roots (tubers)***: The tubers per treatment were determined by counting and recorded.

ii. ***Weight of storage roots (tubers)***: The weight of tubers in each treatment were determined using top load balance and the results converted to tonnes per hectare (t/ha^{-1}).

iii. ***Length and Circumference***: Length and circumference of marketable and non-marketable storage roots were measured and recorded.

iv. ***Dry matter yields***: Dry matter content of the tuber of the selected and tagged plant in each treatment were determined by oven drying method, and the constant weight recorded.

v. ***Fresh biomass weight at harvest***: At harvest, the fresh biomass of sweet potato were collected per treatment and mean recorded.

vi. ***Dry biomass weight at post-harvest***: The biomass of the sweet potato after harvesting were shade dried per treatment, weighed and recorded at a constant weight.

C. **Cassava Yields**

i. ***Top growth weight***: At harvest, the cassava stems and leaves were cut and weighed fresh per treatment using top load balance and results obtained were converted to tonne per hectare (t/ha^{-1}).

ii. ***Number of storage roots (tubers)***: The number of tubers per treatment were determined by counting at harvest and recorded.

iii. ***Weight of storage roots (tubers)***: The tubers harvested per treatment were weighed and recorded.

iv. ***Dry matter content***: Fresh tuber of the selected and tagged plant per treatment were collected, washed and sliced. The sliced samples were oven dried for 3 days at temperature of 65^0C, and constant weight obtained and recorded.

D. **Moringa yields**

i. ***Fresh Leaf yield***: The leaves of moringa were harvested at 12 months after planting (MAP), and weight of the leaves harvested per treatment were determined using top load balance and the result converted to tonne per hectare (t/ha^{-1}).

ii. ***Dry leaf yield***: The fresh leaves harvested were shade dried and constant weight determined and recorded.

iii. ***Number of pod***: The number of pod per treatment were counted and recorded.

iv. ***Number of seeds/pod***: The number of seeds per pod of the selected and tagged plant were counted and recorded.

v. ***Weight of seed***: Seeds were weighed after shelling from the pod, and this was done per treatment.

vi. ***Length of pod***: The fruit length of the selected and tagged plant were measured at harvest and mean recorded.

3.2.6. **Data Analysis**

i. ***Growth and Yield Parameters***: All the growth and yield parameters of all the crops were subjected to statistical analysis of variance (ANOVA) using Genstat package and treatment means that showed least significant difference at 5% probability level were separated using LSD ($P \leq 0.05$).

ii. ***Determination of land equivalent ratio (LER)***: The land equivalent ratio was determined by the use of Harwood and Co-workers (IRRI, 1974) procedure:

$$LER = \frac{\text{intercrop yield of crop A}}{\text{Sole crop yield of crop A}} + \frac{\text{intercrop yield of crop B}}{\text{sole crop yield of crop B}} + \frac{\text{intercrop yield of crop X}}{\text{sole crop yield of crop X}}$$

= relative yield of crop A + relative yield of crop B + relative yield of crop X (i)

Land equivalent ratio could be computed as

$$LER = {}_{i=1}^{n} \sum \{Y_1/Y^m{}_1\}$$

Where Y_1 = yield of intercropping

Y^m = yield of crop in sole cropping (ii)

n= total number of crops in the intercropping system (Mason *et al*, 1986).

LER greater than 1.0 for any particular crop combination mean that intercropping yielded more than growing number of stands of crop as sole crops, and LER less than 1.0 implies that the intercropping was less beneficial than sole cropping.

iii. ***Cost – Benefit Analysis***

Cost-benefit of producing sole and crop mixtures as affected by cropping system were analysed using partial budgeting to determined economic returns.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 RESULTS

Table 4.1: **Weed Flora Composition on the Experimental Site before Clearing**:

Weed species	**Family**	**Morphology**	**Life cycle**
Amaranthus viridis	Amaranthaceae	Broadleaf	Annual
Celasia argentea	Amaranthaceae	Broadleaf	Annual
Ageratum conyzoides	Asteraceae	Broadleaf	Annual
Chromolaena odorata	Asteraceae	Broadleaf	Perennial
Synedrella nodiflora	Asteraceae	Broadleaf	Annual
Aspilia africana	Asteraceae	Broadleaf	Annual/P
Bidens piloso	Asteraceae	Broadleaf	Annual
Emilia coccinea	Asteraceae	Broadleaf	Annual
Tridax procunbens	Asteraceae	Broadleaf	Annual
Sclerocarpus africanus	Asteraceae	Broadleaf	Annual
Synedrella nondiflora	Compositae	Broadleaf	Perennial
Commelina eracta	Commelinaceae	Spiderwort	Perennial
Commelina diffusa	Commelinaceae	Sedge	Perennial
Aneilema aequinoctiale	Commelinaceae	Broadleaf	Perennial

Aneilema beniniense	Commelinaceae	Broadleaf	Perennial
Ipomoea violaceae	Convolvulaceae	Broadleaf	Annual
Ipomoea involcucrata	Convolvulaceae	Broadleaf	Annual
Cyperus rotundus	Cyperaceae	Sedge	Perennial
Mariscus umbellatus	Cyperaceae	Sedge	Perennial
Cyperus esculentus	Cyperaceae	Sedge	Perennial
Mariscus flabelliformis	Cyperaceae	Sedge	Perennial
Mariscus alternifolius	Cyperaceae	Sedge	Perennial
Cassia accidentalis	Caesalpiniaceae	Broadleaf	Annual
Euphorbia hyssopifolia	Euphorbiceae	Broadleaf	Annual
Euphorbia hirta	Euphorbiaceae	Broadleaf	Annual
Euphorbia heterophylla	Euphorbiaceae	Broadleaf	Annual
Imperata cylindrica	Gramineae	Grass	Perennial
Setaria barbata	Gramineae	Broadleaf	Annual
Cynadon dactylon	Gramineae	Grass	Perennial
Digitaria horizontalis	Gramineae	Grass	Annual
Paspalum orbiculare	Gramineae	Grass	Perennial
Setaria longiseta	Gramineae	Grass	Annual
Rottboellia cochinchinensis	Gramineae	Grass	Annual
Eleusine indica	Gramineae	Grass	Annual
Panicum maximum	Gramineae	Grass	Annual
Andropogon gayanus	Gramineae	Grass	Annual
Andrpogon tectorum	Gramineae	Grass	Annual

Anthephora ampullaceae	Gramineae	Grass	Annual
Axonopus compressus	Gramineae	Grass	Annual/P
Brachiaria deflexa	Gramineae	Grass	Annual
Brachiaria falcifera	Gramineae	Grass	Perennial
Spigelia anthermia	Longaniaceae	Broadleaf	Annual
Mimosa pudica	Mimosaceae	Broadleaf	Annual
Urena lobate	Malvaceae	Broadleaf	Annual
Sida acuta	Malvaceae	Broadleaf	Perennial
Peperomia pellucida	Piporceae	Broadleaf	Annual
Calopogonum mucunoides	Papilionaceae	Broadleaf	Annual
Centrosema pubescens	Papilionaceae	Broadleaf	Annual
Portulaceae oleraceae	Portulcaceae	Broadleaf	Perennial
Talinum triangulare	Portulacaceae	Broadleaf	Annual
Oldenlandia carymbosa	Rubiaceae	Broadleaf	Annual
Mitracarpus scaber	Rubiaceae	Broadleaf	Annual
Physalis angulate	Solanaceae	Broadleaf	Annual
Solanum nigrum	Solanaceae	Broadleaf	Annual
Solanum torvum	Solanaceae	Broadleaf	Annual
Schwemkia americana	Solanaceae	Broadleaf	Annual
Corchorus olitorius	Tiliaceae	Broadleaf	Annual
Laportea aestuans	Urticaceae	Broadleaf	Annual
Laportea ovalifolia	Urticaceae	Broadleaf	Annual/P
Pouzolzia guineensis	Urticaceae	Broadleaf	Annual

Stachytarpheta cayennensis	Verbenaceae	Broadleaf	Annual/P
Stachytarpheta jamaicensis	Verbenaceae	Broadleaf	Perennial

P = Perennial

Source: Field survey, 2015

4.1.1 **Weed Flora Composition on the Study Site before Clearing**:

It was observed that (Table 4.1), weed flora composition on the site composed of 62 species that made up of 21 families. The family of *Graminaeae*, *Asteraceae* and *Cyperaceae* were most represented with 24.19%, 12.90% and 8.06%, respectively. The family of *Solanaceae* and *Commelinaceae* were also represented with 6.45% each while *Euphorbiaceae* and *Urticaceae* accounted for 4.23% each. However, the families of *Papilionaceae, Rubiaceae, Amaranthaceae, Convolvocaceae, Malvaceae, Portulaceae* and *Verbenaceae* accounted for 3.23% each while the families of *Piporceae, Mimosaceae, Compositae, Longaniaceae, Tilaceae* and *Caesalpinaceae* accounted for 1.61% each. On weeds life cycle. Annual weeds species were observed to be predominant (66.13%), while perennial weeds accounted for 33.87% of the total weed flora on the site. On weed morphology, broadleaf weeds were predominant (66.13%), grass (22.58%) while sedge and spiderwort constituted only 9.68% and 1.61%, respectively. Most of the species of weed flora observed were widespread across the field but with low density.

4.1.2 **Soil Physico-chemical Properties of the Study Site before and after planting for both first and second seasons of Cropping**

The pre-planting and post-harvest physico-chemical properties of the soil of the experimental site is shown in table 4. 2. From the results of the study, particle size analysis showed that irrespective of the cropping season, the textural class was sandy-clay-loam with sand occurring at above 700g/kg for both seasons, except in post-harvest of 2016 cropping season. The soil reactions generally indicated soil acidity irrespective of the cropping season. However, significant decline in pH values were observed in the post-harvest soil sample in the second season (5.01 and 3.97 in H_2O and KCl_2), respectively compared to the first season. The first season pre-planting soil analysis showed low values of organic carbon and organic matter (0.94 and 1.62%), respectively. However, a consistent increase in the values of both organic carbon and organic matter were observed in the first season post-harvest, second season pre-planting and post-harvest samples; and the Total Nitrogen was low in the first season, but increased to moderate values in the second season.

Similarly, available phosphorus followed the same trend with nitrogen. Even though phosphorus was generally low in both seasons, a consistent increase in concentration from first season to second season was observed. Proportionate increases in the concentration of the exchangeable bases from first to second cropping seasons were observed. Nevertheless, the studied soil fertility indices in the experimental site indicated low soil fertility status and thus requires good agronomic practices in order to support sustainable crop production.

Results obtained generally showed greater improvement in soil fertility status due to moringa/cassava/maize/sweet potato intercropping systems and this may have corroborated with the observed improvement in the agronomic parameters of the studied crops.

4.1.3 **Effect of Moringa/Cassava/Maize/Sweet potato intercropping Systems on Soil Microbial Population after Harvest**

The effect of moringa/cassava/maize/sweet potato intercropping systems on soil microbial population is presented in Table 4.3a and b. The results obtained showed that there was significant ($P \geq 0.05$) difference on soil microbial population on the Bacteria and Nematode counts while fungi count did not show any significant difference among the treatment used. Results (Table 3) shows that intercropping caused variations on the microbial population of the soil. The plot intercropped with Mo + Ca + Ma + Sp (Moringa + Cassava + Maize + Sweet potato) gave the highest bacterial count (5.8) followed by plot intercropped with Mo + Ca + Sp (5.6), while plot intercropped with sole maize (SMa) gave the least bacterial population count (1.8).

The highest fungal population count (4.9) was obtained from plot with crop combination of Mo + Ca + Ma + Sp, followed by 4.6 population count in plot with crop combinations of Mo + Ca + Sp and Sole sweet potato (Ssp), respectively. While the least fungi population count of 2.8 was obtained in sole maize plot.

Results also revealed that the highest number of viable nematode was recorded from the crop combination plot of Mo + Ca + Ma + Sp, followed by crop combination of Mo + Ca +

Sp with 5 viable nematode, while 2 viable nematode being the least was obtained from the plot with sole maize, moringa + maize, respectively.

4.1.4 **Effect of Moringa/Cassava/Maize/Sweet potato Intercropping Systems on Weed Flora Composition at 5 Weeks after Planting (WAP)**

Results obtained (Table 4.4) shows the effect of moringa/cassava/maize/sweet potato intercropping systems on weed flora composition. The results shows that species of weed population were generally low among the treatments. However, it was observed that sole cropping produced the highest weed species population than in crop mixtures. This probably due to the fact that the soil was bare, with few stands of crops and weed species received adequate growth resources.

It was also observed that weed flora composition on the site composed of 57 weed species that made up of 16 families compared to the initial weed flora composition. The family of *Graminaeae*, *Asteaceae*, *Cyperaceae* and *Malvaceae* were most represented with 29.82%, 26.32%, 8.77% and 5.51%, respectively.

Results (Table 4. 4) also indicated that Annual weed species were observed to be predominant with 45.61% while Perennial weed species produced 43.86% of the total weed for a composition in the experimental area. However, weed species with both Annual and perennial life cycle accounted for 12.28% of the total weed flora composition on the study site.

On the morphology of weed species, broadleaf weeds were predominant (61.40%), Grass (29.82%), Sedge (7.02%), while Spiderwort constituted 1.75% of the total weed species composition. Result (Table 4. 4) shows that most of the total weed species flora observed were widespread across the treatment but with low density.

However, the decrease in the total number of weed species observed on the site compared with the initial weed flora composition could be attributed to the ability of the intercropping system to suppress the weed, and new weed species observed in the experimental site when compared with the initial weed flora composition count could be attributed to local weed spread in the area. Some species of weeds such as *Axonopus compresus, Centrosema pubescens, Panicum maximum, Cyathula prostrate, Oldenlandia spp, Aspillia afircana, Corchorus olitorius, Ageratum conyzoides* and *Tridax procumbens* were observed in some treatments with very high frequency occurrence, while some weed spices such as *Sida spp., Oldenlandia Spp., Imperata cylindrical, Cynodon dactylon, Ageratum conyzoides and Tridax procumbens* were observed across all the treatments as well as show highest frequency occurrence.

Table 4. 2: Pre-planting and Post-harvest Physical and Chemical Properties of the Soil in the Study Site for the 2015 and 2016 Cropping Seasons

		First season (2015)		Second season (2016)	
Properties	Units	Pre-panting	Post-harvest	Pre-planting	Post-harvest
Sand	g/kg	800.40	800.65	710.50	690.33
Silt	g/kg	50.00	69.00	87.30	96.70
Clay	g/kg	136.00	92.00	197.70	210.00
Texture		**Sandy-clay-loam**		**Sandy-clay-loam**	
pH (H_2O)		5.85	5.62	5.23	5.01
pH (KCl_2)		4.93	4.79	4.11	3.97
Organic C.	%	0.94	1.18	1.90	2.00
Organic M.	%	1.62	2.03	3.29	3.46
Total N	%	0.06	0.09	0.19	0.22
Available P	mg/kg	5.04	2.03	8.62	8.91
Ex. Calcium	cmo/kg	0.99	0.80	2.40	2.15
Ex. Potassium	cmol/kg	0.01	0.01	0.28	0.16
Ex. Magnesium	cmol/kg	0.57	0.27	1.21	1.00
Ex. Sodium	mo/kg	0.02	0.01	0.09	0.04
TEA	Cmol/kg	2.35	2.80	2.00	2.36
ECEC	Cmol/kg	4.33	3.43	5.98	5.71

BS	%	35.26	31.39	66.56	58.67

Where C is carbon, M is matter, P is phosphorus, TEA is total exchangeable acidity, N is nitrogen, ECEC is effective cation exchange capacity and BS is base saturation.

Table 4.3a: **Initial Microbial Population of the Study Site**

Micro-organisms	Values
Bacteria ($Cfug^{-1}$)	$7.5x10^{4}$
Fungi ($Cfug^{-1}$)	$3.6x10^{4}$
Nematode (unc 100g)	15

Cfu = Colony forming Unit, variable nematode count, fungi count, bacterial count

Table 4.3b: **Effect of Intercropping Systems on Soil Microbial Population at Harvest**

Treatments	Bacteria ($x10^{4}$) (Cfu/g soil)	Fungi ($x10^{4}$) (Cfu/g soil)	Nematode ($x10^{4}$) (vnc/100g soil)
SMo	$2.2x10^{4}$	$3.4x10^{4}$	3 variables
SCa	$2.8x10^{4}$	$3.7x10^{4}$	3 variables
SMa	$1.8x10^{4}$	$2.8x10^{4}$	2 variables
SSp	$3.7x10^{4}$	$4.6x10^{4}$	3 variables
Mo + Ma	$3.2x10^{4}$	$3.0x10^{4}$	2 variables
Mo + Ca	$4.3x10^{4}$	$3.4x10^{4}$	4 variables
Mo + Sp	$4.8x10^{4}$	$4.4x10^{4}$	4 variables
Mo + Ca + Ma	$4.7x10^{4}$	$4.3x10^{4}$	3 variables
Mo + Ca + Sp	$5.6x10^{4}$	$4.6x10^{4}$	5 variables
Mo + Ma + Sp	$5.4x10^{4}$	$4.5x10^{4}$	4 variables
Mo + Ca + Ma + Sp	$5.8x10^{4}$	$4.9x10^{4}$	12 variables
LSD ($P \geq 0.05$)	1.15	ns	2.19

SMo = Sole moringa, SCa = Sole cassava, SMa = Sole maize, SSp = Sole sweet potato, Mo = Moringa, Ca = Cassava, Ma = Maize, Sp = Sweet potato

Table 4.4: **Effect of Moringa/Cassava/Maize/Sweet potato Intercropping Systems on Weed Flora Composition on the Experimental Site at 5 Weeks after Planting (WAP)**

Treatment	Weed species	Family	CN	M	LC	FQ
	Ageratum conyzoides	Asteraceae	Goat weed	BL	A	3
	Chromolaena odorata	Asteraceae	Siam weed	BL	P	5
SMo	*Calopogonum mucunoides*	Papilionaceae	Calopo	BL	A	5
	Mimosa pudica	Mimosaceae	Sensitive plant	BL	A	2
	Imperata cylindrica	Gramineae	Spear grass	G	P	5
	Tridax procumbens	Asteraceae	Tridax	BL	A	1
	Cynodon dactylon	Graminaeae	Bahama grass	G	P	1
	Oldenlandia carymbosa	Rubiaceae	Linn	BL	P	9
	Aspilia africana	Asteraceae	Aspilia	BL	A/P	9
SCa	*Centrosema pubescens*	Papilionaceae	Centro	BL	A	15
	Cynadon dactylon	Gramineae	-	G	A	7
	Ageratum conyziodes	Asteraceae	Goat weed	BL	A	3
	Cynodon dactylon	Graminaeae	Bahama grass	G	P	2
	Digitaria horizontalis	Gramineae	Digitera	G	A	5
	Paspalum orbiculare	Gramineae	Paspalum	G	A	7
SMa	*Aspilia africana*	*Asteraceae*	*Aspilia*	*BL*	*A/P*	*7*
	Sida acuta	Malvaceae	Sida	BL	P	7
	Panicum maximum	Graminaeae	Guinea grass	G	A	15
	Imperata cylindrica	Graminaeae	Spear grass	G	P	3
	Imperata cylindrica	Graminaeae	Spear grass	G	P	7
Ssp	*Desmodium scorpiurus*	Papilionoideae	Sadam clover	BL	A/P	5
	Sida cordifolia	Malvaceae	Heartley sida	BL	P	4
	Tridax procumbens	Asteraceae	Tridax	BL	A	2

Mo + Ma	*Cleome rutidosperms*	Cleomaceae	Spider flower	BL	A	2
	Vernonia perrtteti	Asteraceae	Iron weed	BL	A	5
	Chromolaena odorata	Asteraceae	Siam weed	BL	A/P	4
	Ageratum conyziodes	Asteraceae	Goat weed	BL	A	12
	Cyathula prostrate	Amaranthaceae	Pasture weed	BL	A	15
Mo + Ca	*Achyranthes aspera*	Amaranthaceae	Horsewhip	BL	A	5
	Trianthera portulacestrum	Aizoaceae	Desert horse	BL	A	3
	Nelsonia canescens	Acanthaceae	Blue pussyleaf	BL	P	7
	Paspalum serobiculatum	Graminaeae	Kodo millet	G	A/P	3
	Kyllinga pumila	Cyperaceae	Lowspikes	S	P	7
	Ageratum conyziodes	Asteraceae	Goat weed	BL	A	2
Mo + Sp	*Sida acuta*	Malvaceae	Sida	BL	P	5
	Ageratum conyzoides	Asteraceae	Goat weed	BL	A	1
	Oldenlandia lancifolia	Rubiaceae	Cotycose	BL	P	13
	Corchorus olitorius	Tiliaceae	Malta jute	BL	A	12
	Cyperus esculentus	Cyperaceae	Yellow nutsedge	S	P	8
Mo+Ca+Ma	*Axonopus compresus*	Graminaeae	Carpet grass	G	A	16
	Tridax procumbens	Asteraceae	Tridax	BL	P	11
	Chyropogun ociculatus	Graminaeae	Love grass	G	P	3
	Cynodon dactylon	Graminaeae	Bahama grass	G	P	2
	Ageratum conyziodes	Asteraceae	Goat weed	BL	A	1
Mo+Ca+Sp	*Boerhavia erecta*	Nyctaginaceae	Erect spiderling	BL	A/P	3
	Peperomia pellucida	Piperaceae	Shiny bush	BL	A	8
	Commelina benghalensis	Commelinaceae	-	SP	P	3
	Cynodon dactylon	Graminaea	Bahama grass	G	P	3
Mo+Ma+Sp	*Commelina benghalensis*	Commelinaceae	Spiderwort	SP	P	3
	Tridax procumbens	Asteraceae	Tridax	BL	A	1
	Cyperus esculentus	Cyperaceae	Yellow nutsedge	S	P	3
	Andropogon tectorum	Graminaeae	Giant bluestem	G	A/P	3
	Cynodon dactylon	Graminaeae	Bahama grass	G	P	2
Mo+Ca+ Ma+Sp	*Cyperus rotundum*	Cyperaceae	Nutsedge	S	P	2
	Tridax procumbens	Asteraceae	Tridax	BL	A	1
	Mariscus alternifolius	Cyperaceae	-	S	P	2
	Cynodon dactylon	Graminaeae	Bahama grass	G	p	1

CN= Common name, M= Morphorlogy, LC= Life cycle, FQ= Frequency, BL= Broadleaf, G= Grass, S= Sedge, SP= Spiderwort

4.1.5 **Meteorological Data Showing Annual Rainfall (mm), Temperature (^{0}C) and Relative Humidity (%) for 2014, 2015 and 2016**

The climatic data of the experimental site are shown (Table 4.5). It was observed that the peak of rainfall during the experimental period was in the months of October and August in 2014, 2015 and 2016, respectively; while the lowest rainfall was in the month of December. Dry spell was observed in January 2014 and 2015 and in the month of December 2015, respectively.

Temperature was very high in March 2014, February 2015 and in March 2016. However, temperatures in January and December were observed to be low in the year 2014 and 2015 and in May, June and October, 2016.

Relative humidity was observed to be high in August in 2014, July, August and September in 2015 and August in 2016. The lowest percentages of relative humidity were observed in the months of December in 2014, January 2015 and in November 2016. The climatic data however, revealed that there was heavy rainfall, high temperature and high relative humidity in all the years recorded.

4.1.6 **Effect of Moringa/Cassava/Maize/Sweet potato Intercropping Systems on Maize Plant Height (cm^2) at 2, 4, 6, 8, 10 and 12 weeks after planting (WAP) in 2015 and 2016 Cropping Seasons**

Results obtained (Table 4.6) shows the effect of cropping systems on maize plant height at 2, 4, 6, 8, 10 and 12 WAP. The effect of cropping systems on maize plant varied significantly ($P \geq 0.05$) at 6, 8, 10 and 12 WAP in 2015 and 2016, respectively. The tallest maize plant was recorded in sole maize (SMa) with a height of 129.20 and 123.10cm at 12 WAP both in 2015 and 2016, respectively. However, the shortest maize plant at 12 WAP (98.76cm) in 2015 and (60.20cm) in 2016 was recorded in the cropping system combinations of moringa + Cassava + Maize (Mo + Ca + Ma) and Moringa + Cassava + Maize + Sweet potato (Mo + Ca + Ma + Sp), respectively. This indicated percentage difference of 9.71 – 23.81 and 5.78 – 51.09 percent at 12 WAP in 2015 and 2016, respectively.

Result (Table 4.6) also indicated that there was no significant difference among the treatment used at 2 and 4 WAP. However at 2 WAP, Moringa + Maize + Sweet potato (Mo + Ma + Sp) crop mixtures produced the tallest plant (8.91cm), while sole maize (SMa) had the shortest plant (7.00cm) and at 4 WAP, Moringa + Maize (Mo + Ma) crop combinations produced the tallest plant (18.07cm) while sole maize (SMa) produced the shortest plant of 16.73cm. This representing percentage range of 2.24 – 21.44 and 1.49 – 7.42 at 2 and 4 WAP in 2015. In 2016 however, there was no significant difference at 2 and 4 WAP.

From the result (Table 4.6), sole maize produced the tallest plant (7.40cm) while the crop combination of Mo + Ca + Ma + Sp produced the shortest maize plant (6.80cm) in 2016 cropping season. At 4 WAP, Mo + Ca + Ma crop mixtures had the tallest (18.87cm) maize plant while the shortest maize plant (16.09cm) was observed in crop mixtures of Mo + Ca + Ma + Sp. This representing 0.95 – 8.11 and 1.06 – 14.73 percent range at 2 and 4 WAP in 2016, respectively.

4.1.7 **Effect of Moringa/Cassava/Maize/Sweet potato Intercropping Systems on Maize Leaf Number at 2, 4, 6, 8, 10 and 12 WAP in 2015 and 2016 Cropping Season**

Results obtained (Table 4.7) shows the effect of Moringa/Cassava/Maize/Sweet potato intercropping systems on maize number of leaves. The number of leaves per plant as influenced by the cropping systems indicated no statistical significance at 2, 4, 6, 8, 10 and 12 WAP in both cropping seasons. However, among the treatment used sole maize cropping produced the highest number of leaves (10.81 and 11.83) in 2015 and (13.67 and 13.93) in 2016 at 10 and 12 WAP, respectively. The smallest number of leaves was observed from crop mixtures of Mo + Ca + Ma + Sp with 10.36 and 11.27 in 2015 cropping season and 13.13 and 13.53 number of leaves in 2016 cropping season at 10 and 12 WAP, respectively. The result indicated the percentage range of 3.15 – 4.16 and 1.09 – 4.73 in 2015, 1.98 – 3.95 and 1.44 – 2.87 in 2016 cropping system.

Table 4.5: **Meteorological Data Showing Annual Precipitation (mm), Temperature (^{0}C) and Relative Humidity (%) for the Year 2014, 2015 and 2016**

Months/Year	Total Rainfall (mm)			Temperature (^{0}C)			Relative humidity (%)		
	2014	2015	2016	2014 Max/min	2015 Max/min	2016 Max/min	2014	2015	2016
January	0.00	0.00	0.76	33/21	33/20	33/24	72.12	61.13	73.29
February	32.00	52.67	32.20	35/23	35/23	33/24	73.68	73.14	76.00
March	85.34	84.33	86.31	36/24	34/23	34/24	71.56	73.81	73.65
April	258.50	237.84	356.33	32/22	30/24	33/24	73.83	74.17	74.88
May	204.27	206.32	243.55	32/23	29/23	31/23	75.81	76.18	77.90
June	228.59	225.77	228.77	30/22	30/23	31/22	76.83	78.91	77.67
July	207.52	255,32	206.55	29/22	29/23	30/23	77.90	79.42	79.68
August	266.19	299.02	276.83	30/22	28/32	29/22	79.58	79.71	80.00
September	242.74	254.33	268.02	29/22	30/23	29/22	77/63	79.67	79.07
October	379.48	415.02	381.26	31/23	33/23	31/22	76.35	77.90	76.94
November	0.78	32.21	0.32	35/22	33/23	32/23	73.03	73.60	65.47
December	0.24	0.00	0.30	33/21	32/21	32/20	69.09	70.74	70.14

Source: ADP Owerri, 2015 and 2016

Table 4.6: Effect of Moringa/Cassava/Maize/Sweet potato Intercropping Systems on Maize Plant Height (cm^2) at 2, 4, 6, 8, 10 and 12 Weeks after Planting (WAP) in 2015 and 2016 Cropping Seasons

	2015 (Weeks after planting)						2016 (Weeks after planting)					
Treatment	2	4	6	8	10	12 (WAP)	2	4	6	8	10	12 (WAP)
SMa	7.00	16.73	40.07	126.20	129.13	129.20	7.40	18.67	48.93	69.20	123.00	123.10
Mo + Ma	8.51	18.07	39.93	106.07	116.60	116.62	7.26	16.23	42.07	65.20	115.80	115.98
Mo+Ca+Ma	8.89	17.60	34.40	85.47	98.75	98.76	7.33	18.87	31.48	46.73	113.47	114.50
Mo+Ma+Sp	8.91	17.60	34.40	85.47	112.81	112.83	7.20	17.47	33.53	44.40	109.80	109.81
Mo+Ca+Ma+Sp	7.80	17.80	30.60	61.33	106.13	106.15	6.80	16.09	20.47	27.60	60.17	60.20
LSD ($P \geq 0.05$)	NS	NS	3.70	5.10	4.26	4.33	NS	NS	3.11	5.61	5.63	5.89

SMa = Sole maize, Mo + Moringa, Ma = Maize, Ca = Cassava, Sp = Sweet potatoe, NS = Not significant

4.1.8 **Effect of Moringa/Cassava/Maize/Sweet potato Intercropping Systems on Maize Stem Girth (cm^2) at 2, 4, 6, 8, 10 and 12 WAP in 2015 and 2016 Cropping Season**

Maize stem girth as influenced by cropping systems is presented in Table 4.8. The result obtained shows no significant difference ($P \geq 0.05$) in both cropping years, respectively. From the result obtained, bigger stem girth was recorded in the treatment of sole maize with 13.98 and 15.99cm at 12 WAP in 2015 and 2016, respectively. The smallest stem girth; 9.63 and 9.20cm at 12 WAP was recorded in the treatment of Mo + Ca + Ma + Sp crop combinations (combination of all the component crops). Results (Table 8) also revealed that at 10 WAP, sole maize produced the biggest stem (13.95 and 15.97cm) while the smallest stem (9.61 and 9.00cm) was recorded in crop combination of Mo + Ca + Ma + Sp in both cropping seasons, indicating 22.22 – 31.11 and 19.22 – 43.64 percentage range in both 2015 and 2016 cropping seasons.

Table 4.7: Effect of Moringa/Cassava based Intercropping Systems on Maize Leaf Number at 2, 4, 6, 8, 10 and 12 Weeks after Planting (WAP) in 2015 and 2016 Cropping Seasons

	2015 (Weeks after planting)						2016 (Weeks after planting)					
Treatment	2	4	6	8	10	12	2	4	6	8	10	12
SMa	4.00	7.33	8.60	8.80	10.81	11.83	3.90	7.73	9.58	11.47	13.67	13.93
Mo + Ma	3.53	7.20	7.60	8.26	10.43	11.70	3.87	7.53	9.40	11.07	13.40	13.73
Mo+Ca+Ma	3.73	7.10	7.51	8.27	10.47	11.53	3.80	7.47	9.20	10.73	13.33	13.72
Mo+Ma+Sp	3.60	6.80	7.08	8.23	10.40	11.42	3.53	7.42	9.13	10.27	13.16	13.67
Mo+Ca+Ma+Sp	3.50	6.53	6.90	8.19	10.36	11.27	3.47	7.33	9.11	10.07	13.13	13.53
LSD (P≥0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

SMa = Sole maize, Mo + Moringa, Ma = Maize, Ca = Cassava, Sp = Sweet potatoe

Table 4.8: Effect of Moringa/Cassava/Maize/Sweet potato Intercropping Systems on Maize Stem Girth (cm^2) at 2, 4, 6, 8, 10 and 12 Weeks after Planting (WAP) in 2015 and 2016 Cropping Seasons

	2015						2016					
	(Weeks after planting)						(Weeks after planting)					
Treatment	2	4	6	8	10	12	2	4	6	8	10	12
SMa	1.61	4.53	8.03	8.73	13.95	13.98	1.08	4.45	6.21	8.55	15.97	15.99
Mo + Ma	1.61	4.57	7.67	8.57	10.85	10.86	1.03	4.33	5.61	8.10	12.90	13.40
Mo+Ca+Ma	1.60	4.53	7.57	8.53	9.67	9.69	1.01	4.33	4.99	8.07	9.32	10.30
Mo+Ma+Sp	1.55	4.33	7.43	8.50	9.65	9.65	1.00	4.28	4.95	8.03	9.15	9.70
Mo+Ca+Ma+Sp	1.53	4.20	7.33	8.48	9.61	9.63	1.00	4.29	4.94	8.01	9.00	9.20
LSD ($P \geq 0.05$)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

SMa = Sole maize, Mo + Moringa, Ma = Maize, Ca = Cassava, Sp = Sweet potato

4.1.9 **Effect of Moringa/Cassava/Maize/Sweet potato Intercropping Systems on Maize Leaf Area (cm^2) at 2, 4, 6, 8, 10 and 12 WAP in 2015 and 2016 Cropping Season**

Leaf area of maize as influenced by cropping systems is shown in Table 4.9. The result showed significant difference ($P \geq 0.05$) at 6, 8, 10 and 12 WAP in 2015, while in 2016; the result was significantly difference ($P \geq 0.05$) at 4, 6, 8, 10 and 12 WAP. The largest leaf area (443.65cm^2 and 418.60cm^2) recorded on the treatment of sole maize crooping at 10 and 12 WAP in 2015 and 2016 cropping seasons. Respectively. The least leaf area of maize when compared to the other treatments was observed in the treatment combination of all the component crops (Mo + Ca + Ma + Sp) with 11.80cm^2 and 11.80cm^2 at 2WAP in both 2015 and 2016 cropping seasons, respectively.

4.1.10a **Effect of Moringa/Cassava/Maize/Sweet potato Intercropping Systems on Maize Yield and Yield Components at Harvest for 2015 and 2016 Cropping Season**

Effect of Cropping Systems on Number of Cobs of Maize per plot:

The number of cobs per plot as influenced by the cropping systems is presented in Table 4.10a. Result obtained indicated that there was no statistical significant difference among the cropping systems in both cropping years. However, in 2015 sole maize cropping produced the highest number of cobs (22.00), followed by Mo + Ma and Mo + Ca + Ma crop mixtures with 19.00, each. In 2016 cropping season, sole maize cropping produced the highest number of cobs (23.75), followed by Mo + Ma (20.25) crop mixtures. The least number of cobs (11.30 and 18.33) was obtained from Mo + Ca + Ma + Sp crop combinations in both 2015 and 2016 cropping seasons, respectively.

Table 4.9: Effect of Moringa/Cassava/Maize/Sweet potato Intercropping Systems on Maize Leaf Area (cm) at 2, 4, 6, 8, 10 and 12 Weeks after Planting (WAP) in 2015 and 2016 Cropping Seasons

	2015 (Weeks after planting)						2016 (Weeks after planting)					
Treatment	2	4	6	8	10	12	2	4	6	8	10	12
SMa	14.80	69.83	167.75	170.15	443.65	441.75	14.80	70.06	152.17	175.30	416.75	418.60
Mo + Ma	14.40	68.78	137.40	162.85	403.35	434.55	14.40	69.55	132.06	170.14	407.09	403.01
Mo+Ca+Ma	14.35	66.48	120.43	150.22	378.75	406.40	12.50	60.44	119.06	133.07	346.77	340.90
Mo+Ma+Sp	12.50	65.30	114.25	160.68	395.70	428.40	14.35	64.89	128.77	134.16	351.60	351.66
Mo+Ca+Ma+Sp	11.80	62.00	112.90	126.77	252,15	349.37	11.80	59.73	112.75	118.75	320.80	321.14
LSD (P≥0.05)	NS	NS	10.01	13.25	18.17	23.14	NS	5.39	10.51	6.40	10.19	20.25

SMa = Sole maize, Mo + Moringa, Ma = Maize, Ca = Cassava, Sp = Sweet potat

Effect of Cropping Systems on maize Fresh Cob Weight with Husk (FCWH) (g) at Harvest in 2015 and 2016 Cropping Seasons

The effect of cropping systems on maize fresh cob weight with husk is presented in Table 4.10a. The result showed a significant difference (P≥0.05) among the treatment in both 2015 and 2016 cropping seasons. Result obtained shows that, among the cropping systems, sole maize had the highest fresh cob weight per plant with 1371.00 and 1339.51g, followed by Mo + Ma crop mixtures with 1021.27 and 1106.55g while Mo + Ca + Ma + Sp crop mixtures produced the least fresh cob weight of 877.47 and 626.75g both in 2015 and 2016 cropping years, respectively. This indicating 25.51 – 35.99 and 17.39 – 53.21 percentage difference at harvest in 2015 and 2016, respectively.

Effect of Cropping Systems on maize Fresh Cob Weight without Husk (FCWOH) (g) at Harvest in 2015 and 2016 Cropping Seasons

Result obtained (Table 4.10a) shows fresh cob weight without husk (FCWOH) as influenced by cropping systems. The result showed significant difference (P≥0.05) when mean weight were compared with each other. In both cropping seasons, the fresh cob weight without husk recorded highest in sole maize treatment with 878.69g and 854.50g, followed by Mo + Ma crop combinations with 631.77g and 673.66g while the least fresh cob weight without husk was recorded in crop mixtures of Mo + Ca + Ma + Sp with 478.83g and 493.80g in both 2015 and 2016 cropping seasons, respectively. The result however, represented 28.10 – 45.57 and 21.16 – 42.21 percentage difference in both 2015 and 2016, respectively.

Table 4.10a: Effect of Moringa/Cassava/Maize/sweet potato Intercropping Systems on Maize Yield and Yield Components at Harvest in 2015 and 2016 Cropping Seasons

	2015							2016						
Treatment	NOC	FCWH (g)	FCWOH (g)	DCWH (g)	DCWOH (g)	CL (cm)	CC (cm)	NOC	FCWH (g)	FCWOH (g)	DCWH (g)	DCWOH (g)	CL (cm)	CC (cm)
SMa	22.00	1371.00	878.69	597.77	338.08	15.63	12.27	23.75	1339.51	854.50	563.16	314.17	15.70	13.01
Mo+Ma	19.00	1021.27	631.77	484.03	287.50	15.47	11.81	20.25	1106.55	673.66	388.50	262.08	15.55	11.90
Mo+Ca+Ma	19.00	918.67	601.97	467.81	260.40	15.27	11.67	20.10	875.80	522.40	360.13	233.16	15.20	11.82
Mo+Ma+Sp	18.67	907.97	584.47	392.60	249.37	15.20	11.61	19.05	798.08	501.89	332.66	226.82	15.18	11.59
Mo+Ca+Ma+Sp	11.30	877.47	478.83	337.80	231.43	15.13	11.56	18.33	626.75	493.80	301.29	217.18	15.10	11.38
LSD (0.05)	NS	15.25	11.63	14.08	12.60	NS	NS	NS	9.77	12.11	9.47	11.34	NS	NS

NOC = Number of cob, FCWH = Fresh cob weight with husk, FCWOH = Fresh cob weight without husk, DCWH = Dry cob weight with husk, DCWOH= Dry cob weight without husk, CL = Cob length, CC = Cob circumference

Effect of Cropping Systems on Maize Dry Cob Weight with Husk (DCWH) (g) in 2015 and 2016 Cropping Season

Results obtained (Table 4.10a) shows dry cob weight with husk (DCWH) as influenced by cropping systems. The result varied significantly among the cropping systems. The highest dry cob weight with husk was recorded in sole maize cropping; 597.77 and 563.16g in 2015 and 2016, respectively. This was followed by 484.03 and 388.50g, recorded in Mo + Ma crop mixtures, respectively. The least dry cob weight with husk was recorded in treatment combination of Mo + Ca + Ma + Sp with dry cob of 337.80 and 301.29g both in 2015 and 2016, respectively. This indicated percentage range of 19.03 – 43.49 and 31.01 – 46.50 in 2015 and 2016, respectively.

Effect of Cropping Systems on Maize Dry Cob Weight without Husk (DCWOH) (g) in 2015 and 2016 Cropping Season

The weight of dry cob without husk is presented in Table 4.10a. There was significant difference among the treatments used. However, among the cropping systems, sole maize cropping produced the highest weight of dry cob without husk with 338.08 and 314.17g in 2015 and 2016 cropping years, respectively. The least was also recorded in the treatment of Mo + Ca + Ma + Sp crop combinations which is the combination of all the crop components with 231.43g and 217.18g in 2015 and 2016, respectively. The result represented 14.37 – 31.55% and 14.99 – 30.87% in 2015 and 2016 cropping years, respectively.

Effect of Cropping Systems on Maize Cob Length (CL) (cm) in 2015 and 2016 Cropping Season

The effect of cropping systems on maize cob length showed no significant difference ($P \geq 0.05$) among the treatments in 2015 and 2016 cropping years (Table 4.10a). However, maize cob length ranged from 15.13cm in Mo + Ca + Ma +Sp crop mixtures to 15.63cm in sole maize cropping during the first year trial. In the second year trial, the range was 15.10cm to 15.70cm. However, among the treatments used, sole maize produced the longest cob (15.63cm and 15.70cm), while Mo + Ca + Ma + Sp had the shortest cob (15.13cm and 15.10cm) in 2015 and 2016, respectively. This indicated 1.02 – 3.19% and 9.55 – 3.82% in 2015 and 2016 cropping years, respectively.

Effect of Cropping Systems on Maize Cob Circumference (CC) (cm) in 2015 and 2016 Cropping Seasons

Results obtained (Table 4.10a) shows the effect of cropping systems on maize cob circumference. There was no significant difference (P≥0.05) among the treatment used. However, sole maize (SMa) cropping gave the highest cob circumference (12.27cm and 13.01cm), while Moringa + Cassava + Maize + Sweet potato (Mo + Ca + Ma + Sp) crop combinations produced the least maize cob circumference of 11.56 and 11.38cm in 2015 and 2016 cropping seasons, respectively. This represent 3.75 – 5.79% and 8.55 – 12.53% difference in 2015 and 2016 cropping seasons, respectively.

4.1.10b **Effect of Maize Yield and Yield Components as influenced by Cropping Systems in 2015 and 2016 Cropping Years**

Effect of Cropping Systems on Maize Number of Rows per Cob (NOR/C)

Results obtained (Table 4.10b) shows the effect of cropping systems on maize number of seed rows per cob. There was significant difference (P≥0.05) among the treatment used in the experiment in 2015 and 2016. The number of rows of seed per cob was observed ranging from 17.13 – 17.67 in 2015, and 17.40 – 17.69 was recorded in 2016. However, sole maize produced the highest seed rows (17.67 and 17.69), while Mo + Ca + Ma + Sp produced the least seed rows (17.13 and 17.40) per cob in 2015 and 2016, respectively.

Effect of Cropping Systems on Number of Maize Seeds per Row (NOSR) in 2015 and 2016 Cropping seasons

The number of seeds per row of maize cob as influenced by cropping systems is presented in Table 4.10b. The result indicated no significant difference (P≥0.05) in both 2015 and 2016. The range of number of seeds per row of maize cob was 35.61 – 37.37 and 35.25 – 38.25 in 2015 and 2016 cropping years, respectively.

Effect of Cropping Systems on Maize Cob Weight after Shelling (WCAS) (g) in 2015 and 2016 Cropping Seasons

Result (Table 4.10b) shows the effect of cropping systems on maize cob weight after shelling the seeds. There was no significant difference (P≥0.05) among the treatment. However, sole maize produced the highest weight (14.33 and 14.81g), followed by

Moringa + Maize (Mo + Ma) crop mixture (13.14 and 13.60g) while the least weight of 12.58 and 13.20g was recorded in crop mixtures of Mo + Ca + Ma + Sp in 2015 and 2016, respectively.

Table 4.10b: Effect of Moringa/Cassava/Maize/Sweet potato Intercropping Systems on Maize Yield and Yield Components at Harvest in 2015 and 2016 Cropping Seasons

	2015						2016					
Treatment	NORC	NOSR	WOCAS (g)	100S (g)	WOGY (g)	Grain Yield (t/ha)	NORC	NOSR	WOCAS (g)	100S (g)	WOGY (g)	Grain Yield (t/ha)
SMa	17.67	37.37	14.33	28.83	1628.45	2.34	17.69	38.25	14.81	28.95	1707.25	2.45
Mo+Ma	17.60	36.27	13.14	28.66	1492.90	2.17	17.58	36.33	13.60	28.70	1561.58	2.20
Mo+Ca+Ma	17.53	35.87	13.01	28.67	1066.07	2.10	17.53	35.44	13.22	28.55	1092.69	2.09
Mo+Ma+Sp	17.50	35.80	12.89	27.67	1002.45	2.08	17.50	35.40	13.20	28.03	1016.11	2.10
Mo+Ca+Ma+Sp	17.13	35.61	12.58	27.07	936.73	0.83	17.40	35.25	13.20	27.56	975.06	0.75
LSD (P≥0.05)	NS	NS	NS	NS	15.02	0.61	NS	NS	NS	NS	14.59	0.55

NORC = Number of row per cob, NOSR = Number of seed per row, WOCAS = Weight of cob after shelling, 100S = One hundred seeds, WOGY = Weight of grain yield, t/ha = Tons per hectare

Effect of Cropping Systems on Maize Weight of 100 (One Hundred) Seeds (g) in 2015 and 2916 Cropping Seasons

The weight of 100 seeds (g) as influenced by cropping systems indicated no significant difference (P≥0.05) in 2015 and 2016 (Table 4.10b). From the result, sole maize produced the heaviest seed weight (28.83g and 28.95g) in 2015 and 2016, respectively. This was followed by Mo + Ca + Ma crop mixtures with 28.67g in 2015 and Mo + Ma crop mixture with 28.70g in 2016. The least seed weight (27.07 and 27.56g) was recorded in Mo + Ca + Ma + Sp crop mixtures in 2015 and 2016, respectively.

Effect of Cropping Systems on Maize Grain Yield (t/ha)

Results obtained (Table 4.10b) shows the effect of cropping systems on maize grain yield (t/ha) in 2015 and 2016 harvest. The result showed significant difference (P≥0.05) when other cropping systems were compared to the treatment of Mo + Ca + Ma + Sp in 2015 and 2016 cropping seasons. The sole maize cropping had 2.34 and 2.42t/ha of grain yields, followed by Mo + Ma which produced 2.17 and 2.20t/ha of grain yields, while the least yield; 0.83 and 0.75t/ha was recorded in Mo + Ca + Ma + Sp treatment combinations, representing 7.26 – 64.53 and 9.09 – 69.00 percent range in 2015 and 2016 cropping seasons, respectively.

4.1.11 **Effect of Cropping Systems on Cassava Plant Height (cm^2) at 2, 4, 6, 8, 10 and 12 Weeks after Planting (WAP) in 2015 and 2016 Cropping Seasons**

Results obtained (Table 4.11) shows cassava plant height as influenced by cropping systems in 2015 and 2016 cropping years. There was significant difference (P≥0.05) on cassava plant height at 8. 10 and 12 WAP in 2015 and 2016 cropping seasons. From the result on the table, the significant tallest cassava plant was recorded in sole cassava; 178.05cm and 184.93cm at12 WAP in 2015 and 2016, respectively. The result obtained also showed decrease in cassava plant height as the number of component crops increases (Table 4.11). However, the shortest cassava plant; 135.20cm and 122.60cm in 2015 and 2016 was observed in crop combination of all the component crops of moringa + Cassava + Maize + Sweet potato (Mo + Ca + Ma + Sp). This indicated 17.06 – 21.87 and 12.11 – 33.70 percent range at 12 WAP in 2016 and 2016 cropping seasons, respectively.

4.1.12 **Effect of Cropping Systems on Cassava Number of Leaves at 2, 4, 6, 8, 10 and 12 Weeks after Planting (WAP) in 2015 and 2016 Cropping Seasons**

The number of cassava leaves per plant as influenced by cropping systems varied significantly among the treatment used (Table 4.12). The sole cassava (SCa) cropping produced the highest number of leaves per plant (179.44 and 195.33), followed by Moringa + Cassava (Mo + Ca) crop mixtures with 170.07 and 114.90 at 12 WAP in 2015 and 2016, respectively. This indicated 5.22 – 44.49 and 41.18 – 45.17 percentage difference at 12 WAP in 2015 and 2016, respectively. Result (Table 4.12) also revealed that, the least number of leaves per plant (99.60 and 107.09) was recorded in the treatment combination of moringa + cassava + maize + sweet potato at 12WAP in 2015 and 2016 cropping seasons, respectively.

Table 4.11: Effect of Moringa/Cassava/Maize/Sweet potato Intercropping Systems on Cassava Plant Height (cm) at 2, 4, 6, 8, 10 and 12 weeks after planting (WAP) in 2015 and 2016 Cropping Seasons

	2015						2016					
Treatment	2	4	6	8	10	12	2	4	6	8	10	12
SCa	24.07	31.87	73.45	96.07	119.00	173.05	24.07	31.73	77.85	108.16	145.18	184.93
Mo+Ca	24.93	32.00	67.60	85.53	103.80	143.53	23.73	31.60	66.33	96.77	123.67	162.53
Mo+Ca+Ma	24.87	32.02	60.33	84.46	102.27	141.60	23.93	31.33	65.87	95.61	122.46	159.00
Mo+Ca+Sp	24.88	31.87	60.20	84.45	101.06	140.20	24.77	31.67	65.83	93.14	121.28	156.13
Mo+Ca+Ma+Sp	24.87	31.60	60.13	83.33	99.95	135.20	23.73	31.60	65.53	92.20	121.20	122.60
LSD (P≥0.05)	NS	NS	NS	3.06	4.30	4.92	NS	NS	NS	3.02	4.50	4.62

SCa = Sole cassava, Mo = Moringa, Ca= Cassava, Ma = Maize, Sp = Sweet potato

4.1.13 **Effect of Cropping Systems on Cassava Stem Girth (cm) at 2, 4, 6, 8, 10 and 12 Weeks after Planting (WAP) in 2015 and 2016 Cropping Seasons**

Cassava stem girth as affected by cropping systems is presented in Table 4.13. The result obtained only varied significantly among the treatments at 10 and 12 WAP. The biggest stem girth; 6.69cm and 7.52cm at 12 WAP in 2015 and 2016 cropping years was recorded in sole maize cropping, respectively. This was followed by 5.72cm and 5.71cm recorded in the treatment combinations of Mo + Ca and the smallest stem girth of 2.93cm and 3.60cm was recorded in crop combination of Mo + Ca + Ma + Sp; representing 14.49 – 56.20% and 24.07 – 52.13% difference at 12 MAP in 2015 and 2016, respectively.

4.1.14 **Effect of Cropping Systems on Cassava Leaf Area (cm^2) at 2, 4, 6, 8, 10 and 12 Weeks after Planting in 2015 and 2016 Cropping Season**

Result obtained (Table 4.14) shows the effect of cropping systems on cassava leaf area. There was no significant difference (P≥0.05) across the treatment used at 12 WAP both in 2015 and 2016 cropping seasons. However, at 12 WAP, sole cassava produced the highest leaf area (38.72 and 62.15cm^2), followed by Mo + Ca (36.98 and 61.98cm^2); while the least leaf area was obtained from Mo + Ca + Ma + Sp crop combinations in both 2015 and 2016 cropping seasons.

4.1.15 **Effect of Cropping Systems on Cassava Yield and Yield Components at Harvest in 2015 and 2016 cropping Seasons**

Effect of Cropping Systems on Cassava Number of Storage Roots (Tubers)

Results (Table 4.15) shows number of cassava tubers as influenced by cropping systems in 2015 and 2016 cropping seasons. There was varied significant difference (P≥0.05) among the treatment used. However, cassava planted sole produced the highest number of tubers per plant with 6.33 and 7.01 tubers, followed by treatment of Mo + Ca with 5.14 and 6.55 tubers as recorded in 2015 and 2016 cropping seasons, respectively. The result (Table 4.15) also revealed that, treatment combinations of Mo + Ca + Ma produced 4.20 and 5.30 number of tubers per plant in 2015 and 2016, respectively. The least number of tubers per plant; 2.52 and 3.02 was recorded in the treatment combination of moringa + cassava + maize + sweet potato (Mo + Ca + Ma + Sp) cropping systems. This indicated 0.18 – 0.60 and 0.07 – 0.57 percentage difference in 2015 and 2016 cropping years, respectively.

Effect of Cropping Systems on Cassava Storage Root (Tuber) Yields (t/ha) in 2015 and 2016 Cropping Seasons

Results (Table 4.15) shows tuber yields as influenced by cropping systems differed significantly among cropping systems in 2015 and 2016 cropping years. Cassava planted sole produced significant higher tuber yields; 33.60 and 35.97t/ha in 2015 and 2016, respectively. This was followed by 31.52 and 31.09t/ha of tubers recorded in the treatment combinations of Moringa + Cassava. The treatment combinations of Mo + Ca + Ma produced tuber yield of 28.33 and 26.45t/ha in 2015 and 2016, respectively. The least tuber yields; 16.97 and 19.44t/ha was recorded in the treatment combination of Mo + Ca + Ma + Sp, respectively. This indicated a percentage range of 0.47 – 0.58 and 0.14 – 0.45 in 2015 and 2016 cropping seasons, respectively.

Effect of Cropping Systems on Cassava Dry Matter Content (g) in 2015 and 2016 Cropping Seasons

Dry matter content of cassava tubers as influenced by cropping systems showed no significant difference (P≥0.05) among the treatment used (Table 4.15). The highest dry matter accumulation was recorded in sole cassava cropping (84.23%), followed by 78.77 in Mo + Ca crop mixtures, while the least dry matter accumulation; 77.48% was recorded in treatment of Mo + Ca + Ma + Sp crop mixtures, representing 0.06 – 0.08 percent difference in 2015 cropping season. In 2016 cropping season, dry matter accumulation as influenced by the cropping systems also showed no significant difference (P≥0.05) among the treatments used. However, Mo + Ca crop mixtures produced the highest dry matter content (89.07%), followed by Mo + Ca + Ma (86.23%), while the least was recorded from sole cropping (80.87%), representing 0.03 – 0,07 percentage difference.

Effect of Cropping Systems on Cassava Top Growth (kg) in 2015 and 2016 cropping Seasons

Results (Table 4.15) showed the effect of cropping systems on the weight of cassava top growth at harvest in 2015 and 2016 cropping seasons. There was significant difference

($P \geq 0.05$) among the treatment used. However, sole cassava produced the highest top growth of 187.93 and 193.23kg in 2015 and 2016, respectively. The treatment combination of moringa + cassava (Mo + Ca) had top growth weight of 166.73 and 168.40kg in 2015 and 2016, respectively. The least weight of cassava top growth of 136.80 and 138.17kg was recorded in the treatment of all the component crop mixtures (Mo + Ca + Ma + Sp) in 2015 and 2016 cropping seasons, respectively. This indicated 0.11 – 0.27 percentage difference.

Table 4.12: Effect of Moringa/Cassava/Maize/Sweet potato Intercropping Systems on Cassava Leaf Number at 2, 4, 6, 8, 10 and 12 weeks after planting (WAP) in 2015 and 2016 Cropping Seasons

	2015						2016					
Treatment	2	4	6	8	10	12	2	4	6	8	10	12
SCa	24.00	46.60	73.47	107.14	185.40	179.44	24.27	46.53	71.40	117.13	140.80	195.33
Mo+Ca	23.93	46.93	68.65	91.07	130.07	170.07	23.80	46.47	68.73	105.81	132.55	114.90
Mo+Ca+Ma	24.00	47.00	65.55	90.66	128.47	103.27	24.53	45.87	67.83	93.42	128.40	107.50
Mo+Ca+Sp	23.98	46.87	65.42	89.73	128.27	101.00	24.60	46.00	67.50	93.22	125.70	107.47
Mo+Ca+Ma+Sp	23.53	46.60	64.93	89.48	126.11	99.60	24.47	46.93	67.43	93.13	125.42	107.09
LSD ($P \geq 0.05$)	NS	NS	5.09	4.75	7.26	9.19	NS	NS	NS	3.60	8.11	13.28

SCa = Sole cassava, Mo = Moringa, Ca= Cassava, Ma = Maize, Sp = Sweet potato

Table 4.13: Effect of Moringa/Cassava/Maize/Sweet potato Intercropping Systems on Cassava Stem Girth (cm) at 2, 4, 6, 8, 10 and 12 weeks after planting (WAP) in 2015 and 2016 Cropping Seasons

	2015						2016					
Treatment	2	4	6	8	10	12	2	4	6	8	10	12
SCa	1.00	1.34	2.90	3.65	5.16	6.69	1.59	1.77	2.83	4.86	7.16	7.52
Mo+Ca	1.03	1.33	2.10	3.12	4.61	5.72	1.57	1.76	2.33	3.90	5.56	5.71
Mo+Ca+Ma	1.00	1.30	2.02	3.07	3.89	5.06	1.49	1.73	2.29	3.65	4.97	5.00
Mo+Ca+Sp	1.03	1.29	1.98	3.03	3.50	4.50	1.47	1.69	2.27	3.43	4.35	4.46
Mo+Ca+Ma+Sp	1.00	1.28	1.95	2.01	2.34	2.93	1.45	1.65	2.02	3.30	3.38	3.60
LSD ($P \geq 0.05$)	NS	NS	NS	NS	2.06	2.13	NS	NS	NS	NS	2.11	2.35

SCa = Sole cassava, Mo = Moringa, Ca= Cassava, Ma = Maize, Sp = Sweet potato

Table 4.14: Effect of Moringa/Cassava based Intercropping Systems on Cassava Leaf Area (cm) at 2, 4, 6, 8, 10 and 12 weekzs after planting (WAP) in 2015 and 2016 Cropping Seasons

	2015						2016					
Treatment	2	4	6	8	10	12	2	4	6	8	10	12
SCa	23.26	26.63	36.22	37.86	38.72	38.93	28.96	38.42	49.93	56.45	59.98	62.15
Mo+Ca	22.70	24.46	31.14	32.30	34.84	36.98	25.70	38.40	49.90	54.98	59.08	61.98
Mo+Ca+Ma	22.50	22.57	30.70	31.24	31.70	35.15	22.51	37.84	42.26	50.73	57.78	61.03
Mo+Ca+Sp	22.36	22.44	30.59	30.60	30.67	32.60	22.20	37.40	42.15	50.07	67.13	60.88
Mo+Ca+Ma+Sp	21.33	22.13	30.11	30.15	30.22	31.75	21.99	36.39	46.02	49.74	56.07	60.09
LSD ($P \geq 0.05$)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

SCa = Sole cassava, Mo = Moringa, Ca= Cassava, Ma = Maize, Sp = Sweet potato

4.1.16 **Effect of Cropping Systems on Sweet Potato Vine Length (cm) at 2 , 4, 6, 8, 10 and 12 Weeks after Planting (WAP) in 2015 and 2016 Cropping Saesons**

Results obtained (Table 4.16) showed the effect of cropping systems on sweet potato vine length in 2015 and 2016 cropping years. There was significant difference (P≥0.05) among treatments at 2, 4, 6, 8, 10 and 12 WAP in both 2015 and 2016 cropping seasons. However, sole sweet potato cropping produced the longest vine length; 276.87 and 250.73cm at 12 WAP in 2015 and 2016, respectively. Treatment of moringa + sweet potato (Mo + Sp) crop mixtures had vine length of 240.08 and 246.70cm at 12WAP, while the shortest vine length at 12 WAP (150.59 and 173.40cm) was recorded in crop combination treatment of moringa + cassava + maize + sweet potato (Mo + Ca + Ma + Sp) in 2015 and 2016, respectively.

4.1.17 **Effect of Cropping Systems on Sweet Potato Number of Leaves at 2, 4, 6, 8, 10 and 12 Weeks after Planting (WAP) in 2015 and 2016 Cropping Seasons**

The result (Table 4.17) showed the effect of cropping systems on number of leaves of sweet potato at 2, 4, 6, 8, 10 and 12 WAP. The result indicated that, there was significant difference (P≥0.05) among the treatments used. From the results, sole sweet potato cropping produced the highest number of leaves (112.55 and 101.39), followed by 83.16 and 93.60 in crop mixture of Mo + Sp at 12 WAP in 2015 and 2016, respectively. The least number of leaves (58.13 and 64.30) was recorded in crop combination of Mo + Ca + Ma + Sp at 12 WAP in 2015 and 2016, respectively.

Table 4.15: Effect of Moringa/Cassava/Maize/Sweet potato Intercropping Systems on Cassava Yield and Yield Components in 2015 and 2016 Cropping Seasons

	2015					2016				
Treatment	NOSR/P	WOTG/P (kg)	DMC (g)	Tuber Yield (t/ha)	Tuber ratio	NOSR/P	WOTG /P (kg)	DMC (g)	Tuber Yield (t/ha)	Tuber ratio
SCa	6.33	187.93	84.23	33.60	5.59	7.01	193.23	80.87	35.97	5.37
Mo+Ca	5.14	166.73	78.77	31.52	5.25	6.55	168.40	89.07	31.09	5.42
Mo+Ca+Ma	4.20	148.50	78.60	28.33	5.24	5.30	140.95	86.23	26.45	5.33
Mo+Ca+Sp	3.78	140.43	77.55	22.43	6.26	3.91	138.38	84.20	25.06	5.52
Mo+Ca+Ma+Sp	2.52	136.80	77.48	16.97	8.06	3.02	138.17	82.14	19.44	7.11
LSD ($P \geq 0.05$)	2.03	7.13	NS	3.40	0.04	2.81	4.81	NS	5.40	0.23

NOSR/P = Number of storage root per plant, WOTG/P = Weight of top growth per plant, DMC = Dry matter content

4.1.18 **Effect of Cropping Systems on Sweet Potato Number of Branches at 2, 4, 6, 8, 10 and 12 Weeks after Planting in 2015 and 2016 Cropping Seasons**

Result obtained (Table 4.18) showed that there was significant difference (P≥0.05) among the treatment at 6, 8, 10 and 12 WAP. However, at 12 WAP, sole sweet potato cropping produced the highest number of branches (32.11 and 37.60, followed by Mo + Sp (25.61 and 27.45), while the least number of branches (18.53 and 20.07) was recorded from crop mixtures of Mo + Ca + Ma + Sp in both 2015 and 2016, respectively. This representing 0.02 – 0.42 and 0.27 – 0.47 percent difference in both 2015 and 2016 cropping seasons, respectively.

4.1.19 **Effect of Cropping Systems on Sweet Potato Leaf Area (cm^2) at 2, 4, 6, 8, 10 and 12 Weeks after Planting in 2015 and 2016 Cropping Seasons**

Result presented (Table 4.19) shows high level of significance among the treatments in the cropping systems. At 12 WAP, sole sweet potato cropping had the highest leaf area (60.55 and 59.34cm^2), while the least leaf area (33.15 and 31.05cm^2) was obtained in crop combination of Mo + Ca + Ma + Sp in both 2015 and 2016, respectively. This indicated 0.11 – 0.45 and 0.14 – 0.48 percentage difference in both 2015 and 2016 cropping seasons, respectively.

Table 4.16: Effect of Moringa/Cassava/Maize/Sweet potato Intercropping Systems on Sweet potato Vine Length (cm^2) at 2, 4, 6, 8, 10 and 12 Weeks after planting (WAP) in 2015 and 2016 Cropping Seasons

	2015						2016					
Treatment	2	4	6	8	10	12	2	4	6	8	10	12
SSp	7.80	47.33	130.70	196.55	230.69	276.87	6.80	43.66	138.09	194.11	226.60	250.73
Mo+Sp	7.87	31.07	126.40	187.05	218.70	240.08	7.24	36.40	124.07	173.19	203.73	246.70
Mo+Ca+Sp	7.33	28.27	108.73	133.14	160.93	195.25	6.00	25.66	115.51	126.12	156.11	186.33
Mo+Ma+Sp	7.20	27.13	125.14	161.09	199.42	228.07	6.50	28.71	120.30	168.13	187.33	210.43
Mo+Ca+Ma+Sp	7.13	19.27	87.52	119.13	135.88	150.59	5,90	20.48	73.45	130.15	158.70	173.40
LSD (P≥0.05)	NS	3.55	4.82	11.20	13.70	16.25	NS	3.92	7.16	8.14	9.30	18.70

SCa = Sole cassava, Mo = Moringa, Ca= Cassava, Ma = Maize, Sp = Sweet potato

Table 4.17: Effect of Moringa/Cassava based Intercropping Systems on Sweet potato Number of Leaves at 2, 4, 6, 8, 10 and 12 Weeks after planting (WAP) in 2015 and 2016 Cropping Seasons

	2015						2016					
Treatment	2	4	6	8	10	12	2	4	6	8	10	12
SSp	5.05	20.07	35.07	47.33	83.50	112.55	4.53	29.59	41.08	63.77	79.66	101.39
Mo+Sp	5.07	19.87	28.40	32.40	61.40	83.16	4.33	22.06	32.50	48.10	63.70	93.60
Mo+Ca+Sp	4.80	18.73	25.13	30.93	38.39	61.17	4.13	16.33	21.17	33.60	50.22	70.60
Mo+Ma+Sp	4.90	20.01	29.60	32.33	53.50	80.06	4.27	19.45	31.88	42.70	61.60	90.31
Mo+Ca+Ma+Sp	4.87	18.90	23.09	29.67	35.06	58.13	4.01	15.71	27.09	30.33	48.76	64.30
LSD ($P \geq 0.05$)	NS	NS	6.22	3.98	4.72	5.66	NS	4.86	7.35	6.77	3.96	4.01

SCa = Sole cassava, Mo = Moringa, Ca= Cassava, Ma = Maize, Sp = Sweet potato

4.1.20 **Effect of Cropping Systems on Sweet Potato Yield and Yield Components in 2015 and 2016 Cropping Seasons**

Effect of Cropping Systems on Number of Storage Root in 2015 and 2016 Cropping Seasons

Result obtained (Table 4.20) showed the yield and yield components of sweet potato as influenced by cropping systems. The result revealed significant difference (P≥0.05) on number storage roots among the treatment. At harvest, sole sweet potato cropping produced the highest number of storage roots (3.61 and 4.22), followed by Mo + Sp with 2.57 and 2.77 storage roots while Mo + Ca + Ma + Sp crop combinations produced the least number of storage roots of 1.03 and 1.20 in both 2015 and 2016, respectively. This indicated 0.29 – 0.71 and 0.34 – 0.72 percentage difference in both 2015 and 2016 cropping season, respectively.

Effect of Cropping Systems on Sweet Potato Number of Marketable Storage Roots in 2015 and 2016 Cropping Seasons

Result (Table 24.0) also revealed a significant difference (P≥0.05) among the treatment used on sweet potato number of marketable storage roots. However, sole sweet potato cropping had the highest number of marketable storage roots (1.75), followed by Mo + Ma + Sp (1.25), while crop mixture of Mo + Ca + Sp and Mo + Ca + Ma + Sp produced no marketable storage roots in 2015 cropping season. In 2016 cropping season, sole sweet potato produced the highest number of marketable storage roots (2.13), followed by Mo + Sp (1.89) crop combinations, while crop combinations of Mo + Ca + Sp and Mo + Ca + Ma + Sp did not produce any marketable storage root.

Effect of Cropping Systems on Sweet Potato Number of Non-Marketable Storage Roots in 2015 and 2016 Cropping Seasons

The number of non-marketable storage roots was significant (Table 4.20). The results indicated that, sole sweet potato cropping had the highest number of non-marketable storage roots (1.86 and 2.09) in 2015 and 2016, followed by Mo + Sp (1.43) crop mixtures in 2015 and Mo + Ca + Sp (1.66) in 2016 cropping season, respectively. Crop mixtures of

Mo + Ca + Ma + Sp produced the least number of non-marketable storage roots (0.73 and 1.20) in both 2015 and 2016 cropping seasons, respectively.

Effect of Cropping Systems on Sweet Potato Length of Marketable Storage Roots in 2015 and 2016 Cropping Seasons

Result obtained (Table 4.20) also revealed that there was significant difference (P≥0.05) among the treatment on the length of marketable storage roots in 2015 and 2016 cropping seasons. The result (Table 20) revealed that, sole sweet potato cropping produced the longest marketable storage root (15.41 and 18.20cm^2), followed by crop mixture of Mo + Sp with 12. 30 and 15.10cm^2 marketable storage roots. The least and shortest length of marketable storage roots of 7.52 and 7.70cm^2 was recorded from the cropping systems of Mo + Ca + Ma + Sp crop combinations in 2015 and 2016, respectively.

Effect of Cropping Systems on Sweet Potato Marketable Storage Root Circumference (cm^2) in 2015 and 2016 Cropping Seasons

Result presented (Table 4.20) showed that there was significant difference (P≥0.05) among the treatments in 2015 and 2016 cropping seasons. However, sole sweet potato produced the biggest storage root circumference (18.57 and 20.20cm), followed by 13.12 and 17.12cm from the cropping systems of moringa + sweet potato (Mo + Sp), while the smallest marketable storage root circumference of 8.11 and 9.20cm was recorded from crop mixtures of Mo + Ca + Ma + Sp in 2015 and 2016 cropping years, respectively. This indicated 0.29 – 0.56 and 0.15 – 0.54 percent difference in 2015 and 2016 cropping seasons, respectively.

Table 4.18: Effect of Moringa/Cassava/Maize/Sweet potato Intercropping Systems on Sweet potato Number of Branches at 2, 4, 6, 8, 10 and 12 Weeks after planting (WAP) in 2015 and 2016 Cropping Seasons

	2015						2016					
Treatment	2	4	6	8	10	12	2	4	6	8	10	12
SSp	0.00	4.45	9.38	20.70	28.20	32.11	0.00	5.61	14.25	24.12	36.69	37.60
Mo+Sp	0.00	4.14	8.25	16.40	21.30	25.61	0.00	5.20	9.16	18.44	25.12	27.45
Mo+Ca+Sp	0.00	4.33	5.11	12.40	18.40	22.10	0.00	5.60	8.28	14.35	20.09	20.75
Mo+Ma+Sp	0.00	4.60	7.75	14.14	20.30	25.32	0.00	5.74	9.20	17.49	25.01	27.41
Mo+Ca+Ma+Sp	0.00	4.56	5.09	9.35	15.01	18.53	0.00	5.00	7.41	11.33	17.14	20.07
LSD ($P \geq 0.05$)	NS	NS	2.14	3.70	5.20	5.57	NS	NS	3.81	4.25	5.16	5.25

SCa = Sole cassava, Mo = Moringa, Ca= Cassava, Ma = Maize, Sp = Sweet potato

Table 4.19: Effect of Moringa/Cassava/Maize/Sweet potato Intercropping Systems on Sweet potato Leaf Area (cm^2) at 2, 4, 6, 8, 10 and 12 Weeks after planting (WAP) in 2015 and 2016 Cropping Seasons

	2015						2016					
Treatment	2	4	6	8	10	12	2	4	6	8	10	12
SSp	14.30	35.31	60.36	69.40	63.45	60.55	11.64	38.31	57.18	61.30	61.25	59.34
Mo+Sp	13.75	32.40	50.14	60,12	57.09	53.41	11.55	31.60	48.33	53.40	54.60	51.30
Mo+Ca+Sp	14.01	32.51	41.06	50.62	50.00	46.75	11.88	27.36	37.14	45.30	44.36	43.15
Mo+Ma+Sp	13.33	31.70	50.11	54.30	53.20	50.44	11.46	30.11	45.12	48.91	46.42	44.33
Mo+Ca+Ma+Sp	13.18	25,40	30.25	34.25	34.11	33.15	10.89	25.30	30.41	33.60	33.10	31.05
LSD ($P \geq 0.05$)	NS	3.49	3.81	4.33	4.55	4.13	NS	3.80	4.25	4.82	3.91	3.74

SCa = Sole cassava, Mo = Moringa, Ca= Cassava, Ma = Maize, Sp = Sweet potato

Effect of Cropping Systems on Sweet Potato Fresh Biomass Weight (kg) in 2015 and 2016 Cropping Seasons

Results obtained (Table 4.20) showed significant difference (P≥0.05) among the treatments used in both 2015 and 2016 cropping seasons. Results indicated that, moringa + cassava + sweet potato (Mo + Ca + Sp) crop combinations produced the highest (14.93kg) weight of fresh biomass, followed by crop mixtures of Mo + Ca + Ma + Sp weight (14.47kg) of fresh biomass, while Mo + Sp crop mixtures had the least fresh biomass weight (11.80kg) in 2015 cropping season. However, in 2016 cropping season, sole sweet potato (Ssp) produced the highest biomass weight (25.90kg), followed by Mo + Ma + Sp crop mixtures (24.67kg), while Mo + Sp crop mixtures had the least weight (18.40kg) of fresh biomass.

Effect of Cropping Systems on Sweet Potato Dry Biomass Weight (g) in 2015 and 2016 Cropping Seasons

Results presented (Table 4.20) showed sweet potato dry biomass weight as influenced by the cropping systems. There was significant difference (P≥0.05) among the treatment in the cropping systems. The result revealed that Mo + Ca + Sp produced the highest dry biomass weight (4.17g), followed by all the crop combinations (3.07g), while the least (2.67g) was produced by Mo + Sp crop combinations in 2015 cropping season. In 2016 cropping season, sole sweet potato produced the highest dry biomass weight (12.60g), followed by crop combinations of Mo + Ca + Ma + Sp (11.87g), while Mo + Sp mixtures had the least dry biomass weight of 7.17g.

Effect of Cropping Systems on Sweet Potato Dry Matter Content(g) and Root Tuber Ratio in 2015 and 2016 Cropping Seasons

Results (Table 4.20) also showed significant difference (P≥0.05) among the treatments used on sweet potato dry matter accumulation in 2015 and 2016 cropping seasons, respectively. However, Mo + Ma + Sp crop mixtures produced the highest dry matter accumulation (65.07 and 73.17), while Mo + Ca + Ma + Sp crop mixtures gave the least (48.83 and 59.90) dry matter content in both 2015 and 2016 cropping seasons, respectively. This indicated 0.02 – 0.25 and 0.05 – 0.18 percentage difference in both 2015 and 2016 cropping seasons, respectively.

Root tuber ratio (RTR) results was not significantly different from other treatments in 2015 cropping season but was significantly difference (P≥0.05) among the treatments in 2016 cropping seasons. However, Mo + Ma + Sp crop combinations produced the highest root tuber ratio (5.64), while Mo + Sp crop mixtures had the least (0.07) root tuber ratio in 2015 cropping season. In 2016 cropping season, Mo + Ca + Ma + Sp crop mixtures produced the highest (1.26) root tuber ratio, while Mo + Sp crop mixtures had the least (0.64) toot tuber ratio, representing 0.82 – 0.99 and 0.13 – 0.49 percent difference in 2015 and 2016 cropping seasons, respectively.

Effect of Cropping Systems on Sweet Potato Storage Root Yield (t/ha) in 2015 and 2016 Cropping Season

Results obtained (Table 4.20) showed sweet potato storage root yield (t/ha) as influenced by cropping systems. There was significant difference (P≥0.05) among the cropping systems. The result revealed that sole sweet potato cropping produced the highest yield (30.16 and 33.49 t/ha), followed by Mo + Sp crop mixture with 26.45 and 28.90t/ha in both 2015 and 2916 cropping seasons, respectively. However, the result (Table 20) also shows that crop mixtures of Mo + Ca + Ma + Sp produced the least storage root yield (14.50 and 16.25t/ha) in both 2015 and 2016 cropping season, respectively. This represent 0.12 – 0.52 and 0.13 – 0.51 percent difference in 2015 and 2016, respectively.

4.1.21 **Effect of Cropping Systems on Moringa Percentage Establishment (%) and Plant Height (cm^2) in 2015 and 2016 Cropping Seasons**

Results obtained (Table 4.21) showed the effect of cropping systems on moringa oleifera percentage establishment. There was no significant difference among the treatment used. The result shows that moringa + maize (Mo + Ma), moringa + sweet potato (Mo + Sp), moringa + cassava + maize (Mo + Ca + Ma), and moringa + cassava + maize + sweet potato (Mo + Ca + Ma + Sp) crop combinations produced the highest percentage establishment (100%) in 2015 cropping seasons, while sole moringa (SMo) (95.00%) and moringa + cassava + sweet potato (Mo + Ca + Sp) produced the least (95.00) percentage establishment each in 2015. However in 2016, there was no significant difference among the treatment used. From the result, sole moringa, moringa + cassava, moringa + cassava + maize, moringa + cassava + sweet potato, moringa + maize + sweet potato and moringa + cassava +

maize + sweet potato cropping combinations produced the highest (100%) percentage establishment, while moringa + sweet potato produced the least (96.00%) establishment.

Result (Table 4.21) showed the effect of cropping systems on moringa plant height at 2, 4, 6, 8 and 10 months after planting (MAP) in 2015 and 2016 cropping seasons. The result revealed a significant difference ($P \geq 0.05$) on moringa plant height among the treatment used. From the result, sole moringa cropping produced the tallest plant (282.60 and 324.80cm^2), followed by Mo + Ma with 186.77 and 231.30cm^2, while Mo + Ca + Ma + Sp crop combinations produced the shortest plant height (140.44 and 153.91cm^2) at 10 MAP in both 2015 and 2016 cropping seasons, respectively. This however, represent 0.34 – 0.50 and 0.29 – 0.53 percent range in 2015 and 2016, respectively.

Table 4.20: Effect of Moringa/Cassava/Maize/Sweet potato Intercropping Systems on Sweet potato Yield and Yield Components at Harvest in 2015 and 2016 Cropping Seasons

	2015										2016									
Treatment	NOSR/P	NOMSR/P	NONMSR/P	LOMSR (cm)	COMSR (cm)	FBW (kg)	DBW (g)	DM (g)	YOSR (t/ha)	RTR	NOSR/P	NOMSR/P	NONMSR/P	LOMSR (cm)	COMSR (cm)	FBW (kg)	DBW (g)	DMC (g)	YOSR (t/ha)	RTR
SSp	3.61	1.75	1.86	15.41	18.57	13.60	3.03	62.05	30.16	0.45	4.22	2.13	2.09	18.20	20.20	25.90	12.60	64.17	33.40	0.78
Mo+Sp	2.57	1.14	1.43	12.30	13.12	11.80	2.67	63.56	26.45	0.07	2.77	1.89	0.88	15.10	17.12	18.40	7.17	65.47	28.90	0.64
Mo+Ca+Sp	1.37	0.00	1.37	8.03	10.25	14.93	4.17	64.01	19.80	0.75	1.66	0.00	1.66	9.44	13.21	24.13	11.73	69.40	22.07	1.09
Mo+Ma+Sp	1.98	1.25	1.03	10.21	12.40	12.30	2.97	65.07	23.18	5.64	2.09	0.91	1.18	12.20	15.40	24.67	10.33	73.17	25.18	0.98
Mo+Ca+Ma+Sp	1.03	0.00	0.73	7.52	8.11	14.47	3.07	48.83	14.50	0.99	1.20	0.00	1.20	7.70	9.20	20.53	11.87	59.90	16.25	1.26
LSD (P≥0.05)	1.01	1.05	0.87	3.41	3.23	3.13	1.50	2.41	4.31	NS	1.38	1.18	0.82	2.79	3.18	1.50	1.09	2.65	3.60	0.62

NOSR/P = Number of storage roots per plant, NOMSR/P = Number of marketable storage root per plant, NONMSR/P = Number of non-marketable storage root per plant, LOMSR = Length of marketable storage root, COMSR = Circumference of marketable storage root, YOSR = Yield of storage root, DMC = Dry matter content, FBW = Fresh biomass weight, DBW = Dry biomass weight, RTR = Root tuber ratio

4.1.22 **Effect of Moringa/cassava/maize/sweet potato Intercropping Systems on Moringa Leaf Number at 2, 4, 6, 8 and 10 MAP in 2015 and 2016 Cropping Seasons**

Results obtained (Table 4.22) showed moringa leaf number as influenced by motinga/cassava/maize/sweet potato intercropping systems in 2015 and 2016 cropping seasons. There was no significant difference (P≥0.05) among the treatments used on leaf number at 2, 4, 6, 8 MAP, except at 10 WAP in 2015. However, at 2 MAP, Mo + Ca + Sp crop mixtures produced the highest leaf number (4.07), while the least (3.60) was obtained from crop combinations of Mo + Ca + Ma in 2015 cropping season. At 10 MAP, Mo + Ma + Sp crop mixtures produced the highest leaf number (12.87), while Mo + Ca + Ma + Sp crop combinations had the least (11.33) leaf number, representing 0.02 – 99.11 and 0.01 – 0.12 percentage range in 2015 cropping season. In 2016 cropping season, Mo + Ca + Ma crop combinations produced the highest number of leaves (4.27) at 2 MAP, while the least leaf number (3.93) was when moringa was planted sole. However, at 10MAP, Mo + Ca + Sp, Mo + Ca and sole moringa produced the highest leaf number (13.53) each while Mo + Ma had the least (11.13) leaf number, representing 0.03 – 0.08 and 0.004 – 0.18 percentage difference in 2016 cropping season.

4.1.23 **Effect of Moringa/Cassava/maize/sweet potato Intercropping Systems on Moringa Leaf Area at 2, 4, 6, 8 and 10 MAP in 2015 and 2016 Cropping Seasons**

The results (Table 4.23) showed no significant difference (P≥0.05) in 2015 cropping season, except in 2016 at 8 and 10 MAP. The result at 2 MAP revealed that Mo + Ca + Sp crop combinations produced the highest leaf area (7.94cm^2), while the least leaf area (6.47cm^2) was observed in moringa sole cropping. However, at 10 MAP, Mo + Sp crop mixture produced the highest leaf area (36.61cm^2) while the least leaf area (30.73cm^2) was observed when Mo + Ca + Ma + Sp crop combinations were intercropped. This represented 0.04 – 0.19 and 0.02 - 0.16 percentage difference in 2015 cropping season. In 2016 cropping season, leaf area was highest when Mo + Ca + Ma + Sp was combined (3.57cm^2) while the least leaf area (1.40cm^2) was from Mo + Ma crop mixtures at 2 MAP. At 10 MAP, moringa sole cropping produced the highest leaf area (36.93cm^2), while the least leaf area (22.20cm^2)

was from Mo + Ma crop mixtures. This represented by 0.28 – 0.61 and 0.03 – 0.40 percentage difference in 2016 cropping season, respectively.

4.1.24 **Effect of Cropping Systems on Moringa Number of Branches at 2, 4, 6, 8 and 10 MAP in 2015 and 2016 Cropping Seasons**

The result (Table 4.24) showed that there was significant difference (P≥0.05) among the treatment used on number of moringa branches. At 10 MAP, sole moringa cropping had the highest number of branches 23.40 and 22.90) while Mo + Ca + Ma + Sp crop combinations had the least number of branches (8.81 and 9.35) in 2015 and 2016 cropping seasons, respectively. This indicated 0.34 – 0.62 and 0.21 – 0.59 percentage difference in 2015 and 2016, respectively.

4.1.25 **Effect of Cropping Systems on Moringa Stem Girth (cm^2) at 2, 4, 6, 8 and 10 Months after Planting (MAP) in 2015 and 2016 Cropping Seasons**

Result obtained (Table 4.25) showed moringa stem girth as influenced by cropping systems at 2, 4, 6, 8 and 10 MAP. There was significant difference (P≥0.05) among the treatment at 6, 8 and 10 MAP in 2015 and 2016 cropping seasons. However, at 10 MAP, sole moringa cropping produced the biggest stem girth (10.45 and 10.59cm), followed by 10.18 and 10.30cm from Mo + Ma mixture, while Mo + Ca + Ma + Sp crop combinations produced the smallest stem girth with 5.85 and 5.95 cm in 2015 and 2016, respectively.

4.1.26 **Effect of Cropping Systems on Moringa Pod Yield and Yield Components in 2015 and 2016 Cropping Seasons**

Effect of Cropping Systems on Moringa Number of Pods/Plant in 2015 and 2016 Cropping Seasons

Results obtained (Table 4.26) showed moringa number of pods as influenced by cropping systems. There was significant difference (P≥0.05) among the treatment used on the number of pods produced. The result revealed that sole moringa cropping produced the highest number of pods (20.33 and 23.81) followed by 16.67 and 18.20 from crop mixtures of Mo + Ca and Mo + Ma in 2015 and 2016 cropping systems, respectively.

Moringa/cassava/maize/sweet potato (Mo + Ca + Ma + Sp) crop combinations had the least with 12.78 and 13.09 number of pods both in 2015 and 2016 cropping seasons, respectively. This indicated 0.18 – 0.37 and 0.34 – 0.45 percent difference in 2015 and 2016, respectively.

Table 4.21: Effect of Moringa/Cassava/maize/sweet potato Intercropping Systems on *Moringa oleifera* Establishment percentage and Plant Height (cm^2) at 2, 4, 6, 8 and 10 months after planting (MAP) in 2015 and 2016 Cropping Seasons

	2015						2016					
Treatment	Estab. (%)	2	4	6	8	10	Estab. (%)	2	4	6	8	10
SMo	95.00	11.81	53.40	112.60	158.40	282.60	100.00	14.76	60.91	123.71	172.18	324.80
Mo+Ma	100.00	11.25	47.20	106.18	135.25	186.77	98.00	12.30	50.80	120.49	150.75	231.30
Mo+Ca	98.00	12.01	45.00	109.70	140.60	173.60	100.00	11.49	48.77	119.20	142.50	184.62
Mo+Sp	100.00	11.40	46.80	99.50	121.70	162.41	96.00	11.50	48.68	100.08	133.61	177.51
Mo+Ca+Ma	100.00	11.33	44.00	99.12	120.66	165.12	100.00	11.39	46.18	88.75	131.73	158.66
Mo+Ca+Sp	95.00	11.40	44.16	89.60	119.58	149.60	100.00	12.01	50.51	97.60	125.30	162.31
Mo+Ma+Sp	99.00	11.38	46.14	102.40	122.47	152.18	100.00	12.30	44.50	101.75	142.16	160.08
Mo+Ca+Ma+Sp	100.00	11.40	37.40	85.12	101.08	140.44	100.00	11.14	43.13	81.60	112.19	153.91
LSD ($P \geq 0.05$)	NS	NS	3.61	5.40	6.18	7.11	NS	NS	3.39	5.66	5.81	6.30

Estab. = Establishment

Table 4.22: Effect of Moringa/Cassava/maize/sweet potato Intercropping Systems on *Moringa oleifera* Number of Leaves at 2, 4, 6, 8 and 10 months after planting (MAP) in 2015 and 2016 Cropping Seasons

	2015					2016				
Treatment	2	4	6	8	10	2	4	6	8	10
SMo	3.93	7.66	8.13	8.87	11.80	3.93	6.13	7.27	11.87	13.53
Mo+Ma	3.80	7.20	8.33	8.93	12.60	4.07	6.00	7.33	11.60	11.13
Mo+Ca	3.80	7.40	8.00	9.27	12.53	4.13	6.27	7.20	7.47	13.53
Mo+Sp	4.00	7.20	8.00	9.07	12.80	4.13	6.00	7.07	12.33	13.47
Mo+Ca+Ma	3.60	6.33	8.60	9.20	12.40	4.27	6.13	7.33	10.67	12.60
Mo+Ca+Sp	4.07	6.87	8.33	9.13	12.73	4.07	6.27	7.40	8.47	13.53
Mo+Ma+Sp	3.73	6.87	8.27	8.93	12.87	4.07	5.93	7.40	10.07	12.80
Mo+Ca+Ma+Sp	3.80	6.47	8.20	9.00	11.33	4.13	5.93	7.20	7.47	11.80
LSD ($P \geq 0.05$)	NS	NS	NS	NS	1.47	NS	NS	NS	5.26	NS

SMo = sole moringa, Ma = maize, Ca = cassava, Sp = sweet potato

Table 4.23: Effect of Moringa/Cassava/maize/sweet potato Intercropping Systems on *Moringa oleifera* Leaf Area (cm^2) at 2, 4, 6, 8 and 10 months after planting (MAP) in 2015 and 2016 Cropping Seasons

	2015					2016				
Treatment	2	4	6	8	10	2	4	6	8	10
SMo	6.47	10.85	15.06	18.80	34.19	2.57	6.13	13.55	12.70	36.93
Mo+Ma	7.61	10.55	15.45	18.83	35.57	1.40	5.63	13.14	11.63	22.20
Mo+Ca	6.56	10.92	14.64	19.89	34.88	1.89	6.14	12.00	18.82	34.71
Mo+Sp	6.92	10.82	15.58	19.27	36.61	1.73	6.22	13.25	18.24	35.67
Mo+Ca+Ma	7.59	9.31	14.94	19.53	31.63	1.85	5.44	14.29	16.77	35.09
Mo+Ca+Sp	7.94	10.74	14.79	20.20	35.91	1.55	6.64	14.16	19.10	24.65
Mo+Ma+Sp	7.61	10.62	14.44	19.26	35.57	1.67	6.12	14.51	13.74	33.96
Mo+Ca+Ma+Sp	7.07	10.00	15.07	18.75	30.73	3.57	5.82	14.25	24.35	32.91
LSD ($P \geq 0.05$)	NS	NS	NS	NS	NS	NS	NS	NS	0.28	1.26

SMo = sole moringa, Ma = maize, Ca = cassava, Sp = sweet potato

Table 4.24: Effect of Moringa/Cassava/maize/sweet potato Intercropping Systems on *Moringa oleifera* Number of Branches at 2, 4, 6, 8 and 10 months after planting (MAP) in 2015 and 2016 Cropping Seasons

	2015					2016				
Treatment	2	4	6	8	10	2	4	6	8	10
SMo	0.00	2.11	5.31	11.25	23.40	0.00	2.52	6.42	13.16	22.90
Mo+Ma	0.00	1.56	4.40	8.12	15.51	0.00	1.72	4.70	9.38	18.16
Mo+Ca	0.00	1.23	3.77	7.35	12.33	0.00	1.50	3.82	9.01	13.18
Mo+Sp	0.00	2.01	4.12	8.44	14.26	0.00	2.33	4.66	10.25	15.39
Mo+Ca+Ma	0.00	1.30	2.68	7.05	13.77	0.00	1.52	3.79	8.42	13.90
Mo+Ca+Sp	0.00	1.20	2.15	6.82	14.01	0.00	1.28	3.12	6.77	15.08
Mo+Ma+Sp	0.00	1.01	1.79	4.73	10.56	0.00	1.17	2.10	4.92	11.36
Mo+Ca+Ma+Sp	0.00	0.75	1.03	3.68	8.81	0.00	1.01	1.39	5.63	9.35
LSD ($P \geq 0.05$)	NS	0.91	2.06	3.14	3.59	NS	1.06	2.13	3.20	3.67

Smo = Sole Moringa, Ca= Cassava, Ma = Maize, Sp = Sweet potato

Effect of Cropping Systems on Length of Moringa Pod in 2015 and 2016 Cropping Seasons

The result (Table 4.26) also showed a significant difference ($P \geq 0.05$) among the treatment on the length of pod in 2015 and 2016 cropping season. The result (Table 4.26) revealed that, sole moringa cropping produced the longest length of pod (35.57 and 36.18cm), followed by 35.13 and 35.70cm from crop mixture of Mo + Ma while Mo + Ca + Ma + Sp crop mixtures had the shortest length with 29.52 and 28.48cm of moringa pods in 2015 and 2016 cropping seasons, respectively.

Effect of Cropping Systems on Number of Seeds per Pod in 2015 and 2016 Cropping Seasons

Result obtained (Table 4.26) shows the effect of cropping systems on the number of moringa seeds per pod. There was no significant difference among the treatment used. However, the result revealed that, moringa + maize (Mo + Ma) and moringa + sweet potato (Mo + Sp) crop mixtures produced the highest number (15.40) of seeds per pod, while Mo + Ca + Ma + Sp crop mixtures produced the least number of seeds per pod in 2015 cropping season. This indicated 0.01 – 0.09 percentage difference. In 2016 cropping season, sole moringa cropping produced the highest number of seeds per pod (15.90) followed by Mo + Ca + Sp crop mixtures treatment with 15.80 number of pod while the least number of seeds per pod (14.20) was recorded from crop mixtures of Mo + Ca + Ma + Sp, indicating 0.01 – 0.11 percent difference in 2016 cropping season.

Table 4.25: Effect of Moringa/Cassava/maize/sweet potato Intercropping Systems on *Moringa oleifera* Stem Girth (cm^2) at 2, 4, 6, 8 and 10 months after planting (MAP) in 2015 and 2016 Cropping Seasons

	2015					2016				
Treatment	2	4	6	8	10	2	4	6	8	10
SMo	1.46	1.93	2.41	5.63	10.45	1.59	2.01	4.25	5.18	10.59
Mo+Ma	1.33	1.84	2.15	4.92	10.18	1.43	2.00	4.16	5.01	10.30
Mo+Ca	1.35	1.83	2.06	4.31	7.90	1.40	1.84	3.88	6.68	8.20
Mo+Sp	1.31	1.81	2.00	4.25	7.81	1.42	1.78	3.36	6.38	7.94
Mo+Ca+Ma	1.40	1.75	1.95	4.12	6.95	1.36	1.75	3.27	5.42	6.83
Mo+Ca+Sp	1.25	1.45	1.83	3.95	6.90	1.33	1.66	3.08	5.21	6.71
Mo+Ma+Sp	1.29	1.48	1.72	3.80	5.20	1.37	1.72	3.21	5.60	7.35
Mo+Ca+Ma+Sp	1.22	1.36	1.52	2.75	5.85	1.34	1.47	2.80	5.18	5.92
LSD ($P \geq 0.05$)	NS	NS	1.06	2.18	2.51	NS	NS	1.33	1.49	2.36

Smo = Sole Moringa, Ca = Cassava, Ma = Maize, Sp = Sweet potato

Table 4.26: Effect of Moringa/Cassava/maize/sweet potato Intercropping Systems on *Moringa oleifera* Yield and Yield Components at Harvest in 2015 and 2016 Cropping Seasons

	2015						2016					
Treatment	NOP/P	LOP/P (cm)	NOS/P	Fresh Leaf Yield (t/ha)	Dry Leaf Yield (g)	Seed Yield (t/ha)	NOP/P	LOP/P (cm)	NOS/P	Fresh Leaf Yield (t/ha)	Dry Leaf Yield (g)	Seed Yield (t/ha)
SMo	20.33	35.57	15.30	18.67	3.07	1.04	23.81	36.18	15.90	16.05	2.88	1.08
Mo+Ma	16.00	35.13	15.40	17.85	3.33	0.93	18.20	35.70	15.58	17.45	3.43	1.03
Mo+Ca	16.67	33.60	14.31	16.33	2.63	0.67	15.69	32.60	14.83	17.03	3.01	0.97
Mo+Sp	16.63	34.16	15.40	18.54	3.30	1.01	16.40	34.80	15.41	18.05	3.32	1.06
Mo+Ca+Ma	16.59	31.92	14.30	16.09	2.16	0.77	14.90	32.19	14.78	16.34	2.53	0.64
Mo+Ca+Sp	15.35	30.85	15.18	17.36	3.03	0.78	16.70	30.77	15.80	18.01	3.07	0.79
Mo+Ma+Sp	15.13	31.45	14.77	16.56	2.05	0.90	14.25	32.08	15.05	17.83	3.03	0.93
Mo+Ca+Ma+Sp	12.78	29.52	13.98	16.38	2.02	0.63	13.09	28.48	14.20	16.73	2.11	0.74
LSD ($P \geq 0.05$)	2.17	2.25	NS	0.53	0.11	0.45	2.74	3.78	NS	0.62	0.67	0.52

NOP/P = Number of pod per plant, LOP/P = Length of pod per plant, NOS/P = Number of seeds per pod

Effect of Cropping Systems on Moringa Fresh Leaf Biomass Yield (t/ha) in 2015 and 2016 Cropping Seasons

Result obtained (Table 4.26) also showed that there was significant difference (P≥0.05) among the treatments used on moringa fresh biomass leaf yield as influenced by cropping systems in both 2015 and 2016 cropping seasons. The result however revealed that, sole moringa cropping produced the highest fresh leaf biomass yield (18.67t/ha), followed by Mo + Sp crop mixtures (18.54t/ha), while the least fresh leaf biomass yield (16.09t/ha) was recorded from crop combinations of Mo + Ca + Ma in both 2015 cropping seasons. This representing 0.69 – 13.82 percent difference in 2015 cropping season. On the contrary in 2016 cropping season, Mo + Sp crop mixtures produced the highest fresh leaf yield (18,05tha), followed by Mo + Ca + Sp crop mixtures (18.01t/ha), while the least fresh leaf yield (16.05t/ha) was observed from sole moringa cropping, representing 0.22 – 11.08 percent difference.

Effect of Cropping Systems on Moringa Dry Leaf Biomass Yield (g) in 2015 and 2016 Cropping Seasons

Results presented (Table 4.26) showed that, there was significant difference (P≥0.05) among the treatment used. However, Mo + Ma intercrop produced the highest dry leaf yield (3.33), contrary to sole moringa in fresh biomass leaf yield, followed by Mo + Sp intercrop (3.30), while the least dry leaf yield was produced from crop combinations of Mo + Ca + Ma + Sp (2.02), representing 0.90 – 39.34 percentage diffrence in 2015 cropping season. However in 2016 cropping season, moringa + maize intercrop produced the highest dry leaf biomass yield (3.43), followed by Mo + Sp intercrop (3.32), while the least dry leaf yield (2.11) was obtained from crop combinations of Mo + Ca + Ma + Sp intercrop, representing 3.21 – 38.48 percentage difference.

Effect of Cropping Systems on Moringa Seed Weight in 2015 and 2016 Cropping Seasons

Results (Table 4.26) indicated a significant difference (P≥0.05) among the treatment used on moringa seed weight. The result showed that sole moringa (SMo) cropping produced the highest seed weight (1.04 and 1.08t/ha), followed by moringa + sweet potato (Mo + Sp) crop combinations with 1.01 and 1.06t/ha in 2015 and 2016 cropping seasons, respectively. The least seed weight (0.63t/ha) was observed in all the crop combinations (Mo + Ca + Ma + Sp) in 2015 cropping season, while Mo + Ca + Ma crop mixtures produced 0.64t/ha seed weight in 2016 cropping season. This indicated percentage range of 0.03 – 0.39 and 0.02 – 0.41 in 2015 and 2016 cropping seasons, respectively.

4.1.27 **Cost of Production and Economic Returns to management (#/ha) and Cost – Benefit Ratio as Influenced by Moringa/Cassava/maize/sweet potato intercropping Systems in 2015 and 2016 Cropping Seasons**

The cost of production and economic returns to management are shown in Table 4.27a and b. The highest cost of production occurred in crops intercrop due to cost of planting materials and cultural operations while the least was from the control under sole cropping. The use of moringa in intercropping with cassava gave the highest economic returns (#3,595,600), followed by Mo + Sp (#3,595,000). The least economic returns was observed when moringa was intercropped with Ca + Ma + Sp (#11,000) in 2015 cropping season. In 2016 cropping season, the highest economic returns (#4,368,650) was observed in Mo + Sp intercrop, followed by Mo + Ca intercrop (#3,614,200), while the least (-#8,430) was with moringa in Mo + Ca + Ma + Sp crop combinations. However, the highest benefit-cost ration (10.14, 4.88) and (14.26, 10.91) were observed in Mo + Ca + Ma + Sp, Mo + Ca + Sp and in Mo + Ca + Ma + Sp crop combinations in both 2015 and 2016 cropping seasons, respectively. The least benefit-cost ration (0.03) was observed when cassava was intercropped with moringa and also when cassava was intercropped with moringa + maize crop combinations in 2015 and 2016 cropping seasons, respectively.

4.1.28 **Effect of Cropping Systems on Land Equivalent Ratio (LER) in 2015 and 2016 Cropping Seasons**

Results (Table 4.28) indicated that land equivalent ratio (LER) ranged from 2.78 to 5.59 and 2.10 to 4.99 in 2015 and 2016, respectively. The land equivalent ratio greater than 1.0 implies that intercropping yielded more than growing the same number of stands of each crop as sole crops. The result showed that the highest intercropped yield was observed when cassava was intercropped with moringa (31.52), followed by Mo + Ca +

Ma (28.33) while the least yield was when moringa was intercropped with Ca + Ma + Sp (0.83) in 2015 cropping season.

In 2016 cropping season, result showed that the highest intercropped yield was when moringa and cassava were intercropped (31.09), followed by Mo + Sp intercrop (28.90) while the least was observed when moringa was intercropped with Ca + Ma + Sp (0.75). However, moringa intercropped with cassava + maize + sweet potato produced land equivalent ratio of 5.59 and 4.99 in both 2015 and 2016 cropping seasons, respectively.

Table 4.27a: Cost of Production and Economic Returns to Management (#/ha) as Influenced by Sole and Crop Combinations in 2015 Cropping Season

	Sole cropping systems				Intercropping systems						
A. Cost of Production	SMo	SCa	SMa	SSp	MO + Ca	Mo + Ma	Mo + Sp	Mo + Ca + Ma	Mo + Ca + Sp	Mo + Ma + Sp	Mo + Ca + Ma + Sp
	12,000	12,000	12,000	12,000	12,000	12,000	12,000	12,000	12,000	12,000	12,000
i.Bush clearing											
	15,000	15,000	15,000	15,000	15,000	15,000	15,000	15,000	15,000	15,000	15,000
ii.Ridging											
	20,000	-	-	-	20,000	20,000	20,000	20,000	20,000	20,000	20,000
iii.Cost of inputs	-	1000	-	-	1000	-	-	1000	1000	-	1000
a. Moringa	-	-	500	-	-	500	-	500	-	500	500
b. Cassava	-	-	-	1000	-	-	1000	-	1000	1000	1000
c. Maize											
d. Sweet potato											
iv.Cost of planting	10,000	10,000	10,000	10,000	12,000	12,000	12,000	12,000	12,000	12,000	12,000
v.Cost of soil analysis	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000
vi.Cost of weeding	20,000	20,000	20,000	20,000	20,000	20,000	20,000	20,000	20,0000	20,000	20,000
vii.Cost of harvesting	15,000	15,000	15,000	15,000	18,000	18,000	18,000	20,000	20,000	20,000	20,000
Total cost of production (TC)	102,000	83,000	82,500	83,000	108,000	107,500	108,000	110,500	111,000	110,500	111,500
B. Yield (t/ha)											
i. Moringa	1.75	-	-	-	1.55	1.78	1.70	1.52	1.07	1.18	0.98
ii. Cassava	-	33.60	-	-	31.52	-	-	28.33	22.43	-	16.97
iii. Maize	-	-	2.34	-	-	2.17	-	2.10	-	2.08	0.83
iv. Sweet potato	-	-	-	30.16	-	-	26.45	-	19.80	23.18	14.50
C. Total Gross Revenue (GR)	218,750	-	-	-	193,750	222,500	212,500	190,000	133,750	147,500	122,500
i. Moringa	-	3,948,000	-	-	3,703,600	-	-	3,328,725	2,635,525	-	1,993,975
ii. Cassava	-	-	397,800	-	-	368,900	-	357,000	-	353,600	141,100
iii. Maize	-	-	-	4,222,400	-	-	3,703,000	-	2,772,000	3,245,200	2,030,,000
iv. Sweet potato											

D.	Return to management (GRT)											
i.	Moringa	116,750	-	-	-	85,750	115,000	104,500	79,5000	22,750	37,000	11,000
ii.	Cassava	-	3,865,000	-	-	3,595,600	-	-	3,218,275	2,524,525	-	1,882,475
iii.	Maize	-	-	315,300	-	-	261,400	-	246,500	-	243,100	29,600
iv.	Sweet potato	-	-	-	4,139,400	-	-	3,595,000	-	2,661,000	3,134,700	1,918,500
E.	Cost- benefit ratio											
i.	Moringa	0.87	-	-	-	1.26	0.93	1.03	1.39	4.88	2.99	10.14
ii.	Cassava	-	0.02	-	-	0.03	-	-	0.03	0.04	0.45	0.06
iii.	Maize	-	-	0.26	-	-	0.41	-	0.45	-	0.45	3.77
iv.	Sweet potato	-	-	-	0.02	-	-	0.03	-	0.42	0.04	0.06

N/B

i. The prevailing market price of 1tonne of dry moringa leaves was #125,000 as at the time of harvest in 2015

ii. The prevailing market price of 1 tonne of cassava root tubers was #117,000 as at the time of harvest in 2015

iii. The prevailing market price of 1 tonne of maize grain was #170,000 as at the time of harvest in 2015

iv. The prevailing market price of 1 tonne of sweet potato storage roots was #140,000 as at the time of harvest in 2015

Table 4.27b: Cost of Production and Economic Returns to Management (#/ha) as Influenced by Sole and Crop Combinations in 2016 Cropping Season

	Sole cropping system				Intercropping systems						
A.Cost of Production	SMo	SCa	SMa	SSp	MO + Ca	Mo + Ma	Mo + Sp	Mo + Ca + Ma	Mo + Ca + Sp	Mo + Ma + Sp	Mo + Ca + Ma + Sp
i.Bush clearing	15,000	15,000	15,000	15,000	15,000	15,000	15,000	15,000	15,000	15,000	15,000
ii.Ridging	20,000	20,000	20,000	20,000	20,000	20,000	20,000	20,000	20,000	20,000	20,000
iii.Cost of inputs											
e. Moringa	5,800	-	-	-	5,800	5,800	5,800	5,800	5,800	5,800	5,800
f. Cassava	-	800	-	-	800	-	-	800	800	-	800
g. Maize	-	-	780	-	-	780	-	780	-	780	780
h. Sweet potato	-	-	-	850	-	-	850	-	850	850	850
iv.Cost of planting	12,000	12,000	12,000	12,000	15,000	15,000	15,000	15,000	15,000	15,000	15,000
v.Cost of soil analysis	15,000	15,000	15,000	15,000	15,000	15,000	15,000	15,000	15,000	15,000	15,000
vi.Cost of weeding	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,0000	25,000	25,000
vii.Cost of harvesting	18.000	18,000	18,000	18,000	20,000	20,000	20,000	22,000	22,000	22,000	22,000
Total cost of production (TC)	105,580	105,800	105,780	105,850	116,600	116,580	110,850	119,380	119,450	119,430	120,230
B.Yield (t/ha)											
i.Moringa	1.90	-	-	-	1.62	1.81	1.71	1.48	0.99	1.01	0.86
ii.Cassava	-	35.97	-	-	31.09	-	-	26.45	25.06	-	19.44

iii.Maize	-	-	2.45	-	-	2.20	-	2.09	-	2.10	0.75
iv.Sweet potato	-	-	-	33.40	-	-	28.90	-	22.07	25.18	16.25
C.Total Gross Revenue (GR)											
i.Moringa	247,000	-	-	-	210,600	235,300	222,300	192.400	128,700	131,300	111,800
ii.Cassava	-	4,316,400	-	-	3,730,800	-	-	3,174,000	3,007,200	-	2,332,800
iii.Maize	-	-	428,750	-	-	385,000	-	365,750	-	367,500	131,250
iv.Sweet potato	-	-	-	5,071,150	-	-	4,368,650	-	3,301,400	3,902,900	2,518,750
D.Return to management (GRT)											
i.Moringa	236,420	-	-	-	94,000	118,720	111,450	73,020	9,250	11,870	-8,430
ii.Cassava	-	4,210,600	-	-	3,614,200	-	-	3,054,620	2,887,750	-	2,212,570
iii.Maize	-	-	322,970	-	-	268,420	-	246,370	-	248,070	11,020
iv.Sweet potato	-	-	-	5,071,150	-	-	4,368,650	-	3,301,400	2,973,470	2,398,520
E.Cost- benefit ratio											
i.Moringa											
ii.Cassava	0.45	-	-	-	1.24	0.98	0.99	1.63	12.91	10.06	14.26
iii.Maize	-	0.03	-	-	0.03	-	-	0.03	0.42	0.04	0.05
iv.Sweet potato	-	-	0.33	-	-	0.43	-	0.48	-	0.48	10.91
	-	-	-	0.02	-	-	0.03	-	0.04	0.04	0.05

N/B

v. The prevailing market price of 1tonne of dry moringa leaves was #130,000 as at the time of harvest in 2016

vi. The prevailing market price of 1 tonne of cassava root tubers was #120,000 as at the time of harvest in 2016

vii. The prevailing market price of 1 tonne of maize grain was #175,000 as at the time of harvest in 2016

viii. The prevailing market price of 1 tonne of sweet potato storage roots was #155,000 as at the time of harvest in 2016

Table 4.28: **Summary of Yield and Land Equivalent Ratio (LER) as Influenced by Different Cropping Systems (t/ha) in 2015 and 2016 Cropping Seasons**

Treatments/Cropping systems	Sole	Intercropping systems							
2015		Mo+ Ca	Mo + Ma	Mo + Sp	Mo + Ca + Ma	Mo + Ca + Sp	Mo + Ma + Sp	Mo + Ca + Ma + Sp	**LER**
Moringa	1.75	1.55	1.78	1.70	1.52	1.07	1.18	0.98	5.59
Cassava	33.60	31.52	-	-	28.33	22.43	-	16.97	2.95
Maize	2.34	-	2.17	-	2.10	-	2.08	0.83	3.07
Sweet potato	30.16	-	-	26.45	-	19.80	23.18	14.50	2.78
2016									
Moringa	1.90	1.81	1.62	1.71	1.48	0.99	1.01	0.86	4.99
Cassava	35.97	31.09	-	-	26.45	25.06	-	19.44	2.84
Maize	2.45	-	2.20	-	2.09	-	2.10	0.75	2.10
Sweet potato	33.40	-	-	28.90	-	22.07	25.18	16.25	2.77

4.2 **DISCUSSION**

The pre-planting first season soil analysis showed that the soil was low in fertility with high proportion of sand. This could be attributed to the high concentration of quartz in the mineral fractions of the soil. This is in line with the work of Azu et al (2018) on chemistry and mineralogy of soil derived from different parent materials which stated that soils of Southeastern Nigeria contains high concentration of quartz in the mineral fractions. Results obtained from the study indicating low soil fertility which could also be attributed to leaching due to heavy rainfall in the study area. This findings also agrees with the work of Krienke (2015), Pease (2020), who jointly reported that Sandy textured soils of Southeastern Nigeria are prone to acidity due the leaching of basic cations consequent of the heavy tropical rains. Results of the experiment also revealed that essential elements including organic carbon, nitrogen, phosphorus, basic cations were generally low at the first stage of experimentation. The pattern of cropping/crop combinations and a good agronomic practices is required in order to support sustainable crop production. However, apart from pH which decreased from first season to second season pre-planting, post-planting and pre-planting, post-harvest, respectively, consistent increase in the concentrations of these nutrient indices was observed in the first season post-planting, second season pre-planting and post-planting. Integration of moringa in the cropping system may have significantly influenced the results. Apart from the medicinal importance of moringa, studies have shown that it has the ability of enhancing soil fertility status due to leaf-fall and branch fall which may have decomposed to affect the soil positively. This is in line with the work of Azu et al., (2020), who reported an increased in soil fertility due to inclusion of moringa leaves compost in soil fertility management. In the present study, the leaf-fall and branch fall may have decomposed to affect the soil positively.

Moreover, the presence of some nutrient elements for plant use in the study site could be attributed to the presence of some microbes in the soil of the study area that plays active role in soil fertility as a result of involvement in the cycle of nutrients like carbon and nitrogen which are required for plant growth and development. The increase in number of beneficial microbes in the study site could be attributed to the association of *Moringa oleifera* in the cropping systems. This agrees with the work of Chamkhi (2022), Adline and Devi (2014), who jointly reported that organic materials from moringa can increase soil aeration and richness of indigenous invertebrates, specialized endangered soil species, beneficial arthropod, earthworm and microbes. However, the result also showed that crop management practices like intercropping increased microbial population than sole cropping (Table 3b). The result of the study is therefore, suggesting that rather than growing sole crop, it is better to intercrop to enhance microbial load in the soil and to change microbial community in a cropping system. This agrees with the work of Xiao et al (2023) and Chen et al (2019), who stated that change in microbial community and activity by intercropping could affect C and N dynamics, and this may be attributed to the ability of microbial community to regulate carbon and nitrogen – use efficiency.

The result obtained from the present study indicated high presence of microbes in the intercrop systems than sole. This could be attributed to crop interactions in the environment creating conducive environment for microbes to thrive since the environment might have resembles the natural environment with different species of crops. This agrees with the work of Mala et al, (2020), Wang et al, (2014), who reported that intercropping is one way of introducing more biodiversity into agro-ecosystem that mimic natural ecosystem and are more dynamic biologically than sole crops. Moreover, from the study moringa might have help in nutrient deposition creating a better environment for the microbes to regulate and recycle the soil fertility. This also in line with the work of Horn et al, (2022), who jointly stated that higher species richness may be associated with nutrient recycling characteristics that often regulate soil fertility, and significantly reduce the negative impact of pest, including weeds and limits nutrient loses through leaching.

The result of the experiment on the study area have also shown that enhanced nutritional uptake is not the only reason for yield increase under intercropping systems, but many other unknown causes might have also affected it such as soil management practice, cropping pattern, microbial activity and environmental conditions. This is in line with the work of Jalilian et al, (2017), Fang-Gou et al, (2017) and Acosta-Martnez et al (2010) jointly stated that soil microbial activity, soil enzyme activities and crop yield could be affected by land management practices.

The result obtained from the experiment in the study area showed that species of weeds population were generally low across the treatment even though sole cropping produced the highest weed species population than in crop combinations. This could be attributed to the fact that, in sole cropping the soil was bare with few stands of crop and weed species received adequate growth resources at the early stages of growth. However, the reduction in species of weed in intercropping could be attributed to the increase in the number of crop species and population density which ultimately increased the leaf cover thereby suppressing weed growth. This is in line with the work of Chunfeng et al, (2021), Andrew et al (2015) and Seran et al (2010) who jointly reported that crop species population density, sowing geometry, duration, growth rhythm of the component crop, the moisture and fertility status and tillage influences weed flora in cropping systems, and according to Mohammandkhani et al, (2023) and Victor et al, (2020), mixed cropping reduces weed incidence. Moreover, the decrease in weed flora in the crop combination than in sole cropping could also be attributed to usurping of resources by crop species from weeds, making use of the resources not exploited by weeds and convert into harvestable materials. However, intercrop system might have demonstrated weed control advantages over sole crops by enhancing greater crop yield; and less weed growth might have been achieved as intercrops were more effective than sole crops in usurping resources from weeds or suppressing weed growth through allelopathy. This is in line with the work of Gebru (2015) and Olorunmaiye (2010), who jointly stated that intercropped crops suppresses weeds growth by preventing the weeds to utilize growth resources in its ecosystem.

The decrease in weed flora composition in intercropped plots compared to sole plots in the study area could also be attributed to increase in plant density which might have shaded the weeds. This study supports the work of Nze et al (2017), who reported that increased rate of sawdust materials significantly influenced fresh weeds biomass beginning from the early stage of pineapple development to the later stage, because the dry sawdust materials does not decompose fast enough as a result of high C: N ratio and as such has the capability of suppressing germinating weed seeds. Findings from the present study also showed that intercropping moringa/cassva/maize/sweet potato poved its potentiality on weed growth suppression than sole cropping. This agrees with the work Shiyam et al (2011), who observed low weed prevalence in mulched pineapple/cocoyam intercrop plots indicating high weed smothering efficiency of sawdust mulch.

The differences in growth components among crop species could be attributed to the inherent crop species characteristics. This work is in line with the work of Gomez et al (2022) and Lithourgidis et al, (2011), who jointly stated that different varieties of a particular crop respond differently to intercropping. The result of the study also revealed that increase in growth components could be as a result of differences in nature of competition in the cropping systems. This is in line with the work of Yildirim and Ekina (2017), and Ren et al (2016), who jointly reported that different crop varieties will differ in their nutrient requirements and their responds to fertilizers. However, the results of the study show that the differences in plant heights, stem girths, leaf numbers and leaf areas probably reflects the differences in the nature of competition between the crops involved, sole cropping, the crop mixtures in the systems and probably intake of growth resources among crop species. From the result of this study in relations to growth parameters of sole and intercropped, sole cropping produced high growth parameters indicating a high level of sensitivity to shading conditions which varied amongst different systems of intercropping to the other. On the contrary, the reduction in growth parameters of intercrop plots could be as a result of levels of competition for growth resources. This sgrees with the work of Adam et al (2013), who reported that the decrease in plant height at higher plant densities (lower inter-row spacing) might be as a result of plant competition for space, soil moisture, nutrient, light and assimilation. Katung (2003), Ogoke and Nnebue (2018), jointly reported that plant height and number of capsule/plant increased significantly with increasing plant population/inter and intra row spacing.

However, the variation in growth due to seasonal drift influence leaf area expansion and active period, photosynthetic efficiency, relative growth rate resulting in variation in dry matter production, its distribution and translocation to grain, tubers considerably, and therefore the final grain and tubers yield. This is in line with the work of Muoneke and Mbah (2007) and Yildirim and Ekina (2017) on the productivity of cassava/okra intercropping system as influence by okra planting density; cassava plant height, number of leaves and leaf area index of cassava were significantly affected by intercropping systems and that cassava plants were significantly shorter at 6 - 12MAP in sole than intercrop with okra especially at higher okra planting density; and that increased okra plant density in intercropped system progressively increased plant height but decreased the number of leaves and leaf area index per plant.

The reduction in the number of leaves and leaf area in crop mixtures in the systems were observed. This could be attributed to shading and shedding effect probably because of low temperature and low intensity of sunlight into the intercrop system and plant density causing slow growth in the intercrop systems; probably because of competition for light, self-shading and other growth resources; and these factors could have impacted some form of stress on the crop. This agrees with work of Adekunle et al, (2014), Dong et al, (2018), Wu, et al (2017) and Blomme et al, (2020), who jointly stated that under deep shading, respiration may equal photosynthesis and no growth will occur. Since photosynthesis takes place primarily in green leaves, from the results of the study it showed that up to a limit, the greater the area of leaf, the greater the amount of photosynthesis produced and growth. But, when leaf area becomes too large, self-shading might have taken place and growth declines.

The results of the study showed variation in leaf area index which could probably be attributed to the competitive differences for growth factors amongst and within the systems and this might have been as a result of limited resources. This agree with the work of Buckley et al (2019), Blomme et al (2018), who observed that if growth resources are limited in an intercrop system, one species of the mixture may be able to remove the needed resources better or sooner than the other, resulting in the depression of yield of the other species of the mixture than caused by competition.

However, the result indicated reduction in the leaf area index of the intercrop system which implies that tuber yield was positively associated with leaf size in both cropping system which also apply to maize. The significant increase in maize yield and yield components recorded in sole cropping than intercropping systems in the study area could be attributed to the ability of the maize to extract the available growth resources including soil nutrients. More so, the apparently higher competitive ability of the maize might have been enhanced by its short duration in growth as maize established, matured and exploit growth resources much earlier than the cassava and sweet potato in the utilization of soil nutrients during early growth period of an establishment, possibly due to genetic constituent of the crop involved in the cropping systems. Similar observations were made by Adekunle et al (2014), Yang et al (2019), who noted that higher competition for nutrients in cassava + sorghum intercropping systems was the most limiting factor for mixture productivity, and that the genetic constituent of crops does not change in different environments with respect to qualitative traits (Okoli & Ngwuta, 2018).

However, from the result of the study, the increase in crop yields in the systems could be as a result of crop compatibility among the crop mixtures in the systems and probably the intensity of competition for growth resources coincided with the peak of available growth resources for each crop in the intercrop system for germination, active growth and translocation of photosynthesis. This agrees with the work of Brookere (2015), who reported that the intensity of competition for moisture increases when it coincided with the peak of moisture requirement stages of the crops either individually or collectively. The result of the experiment showed that intercrop crops probably depended on low interspecific competition in cassava/maize intercrop indicating that the component crop might have transmit an amount of solar energy to other crops. This agrees with the work of Maclaren (2023), who reported that cassava/maize intercrops appeared to have depended largely on low interspecific competition and the ability of the maize components to transmit sufficient light energy to the lower canopy cassava. The result obtained from the study shows that, there was no lodging and that may have caused reduced diameter in maize intercrop in both cropping seasons. This work agrees with work of Adeniyan et al (2014) on growth and yield performance of cassava/maze intercrop, reported increases in plant population density of maize in maize/cassava intercrop directly increased maize plant height at tasselling, plant height at harvest and plant lodging percentage, but reduced stalk diameter, average cob weight, dry matter yield and grain yield. However, the result of the experiment indicated increases in the grain yield (t/ha) in 2016 cropping season than obtained in 2015 cropping season, which could be attributed to the decomposition of organic matter deposited during first season cropping and the ability of microbes to utilize the available ground cover materials to increase soil fertility status (Table 2 and 3). The increases in the grain yield (t/ha) could also be attributed to accelerated uptake of soil nutrients and other growth resources as well as the ability and capacity of maize plant to adapt to intercropping systems due to its growth habit, which permits complementarity benefits in the intercrop systems. This is in line with the work of Kiri (2023) and Sullivan (2003), who reported that intercropping often result in accelerated harvesting of soil resources as a short – term gain for the farmers with limited resources especially if nurse crops are not harvested from the system where they capture and recycle nutrients for use by primary crops in the system to the farmers' advantage.

Yield increases observed from the study could be attributed to crop diversification in the intercropping systems per the unit area of the experiment. This is in line with the work of Kremen and Miles (2012), Lin (2011) who jointly reported that cropping systems can contribute to increase yield per unit area without increasing the land area, while creating a more resilient production systems. The result further indicated increase in the yield and yield components of maize which could also be attributed to the adaptability of maize to the intercropping systems due to its wide inter-row spacing and erect growth habit which allows for complementary benefits for the intercrops. Moreover, the increase in maize yield when intercropped with sweet potato could be attributed to complementary effect in terms of compatibility with light, space, nutrients and water use efficiencies than those of moringa + cassava + maize + sweet potato. This agrees with the work of Oyeogbe et al (2020), who stated that higher grain yields achieved in the maize sole cropping than those of the intercrops is a function of the growth resources including space, light, nutrients and moisture available to maize sown as sole cropping than when intercropped with cowpea, groundnut, and sweet potato.

Results obtained from the study indicated compatibility of cassava in cassava intercrop which appeared to have been depended largely on low inter-specific competition. Thus, the differences in the yield could be attributed to the ability of crop mixtures' complementarities and compatibilities in the cropping systems in both 2015 and 2016 cropping seasons, possibly due to the fact that cassava is a long seasoned crop while maize is a short duration crop. This work agrees with the work of Amoake et al (2022) and Idoke (2018), who had earlier reported that cassava/maize intercrop has been a productive system and compatible mainly because maize is a short season crop while cassava is a long duration crop which depends on low interspecific competition; and the ability of the maize components to transmit sufficient light energy to the lower canopy of the cassava. Moreover, from the result, intercropping increased the number of storage roots and fresh tuber yield of cassava. This could be attributed to better photosynthetic efficiency by the intercrop, and probably tuber initiation and bulking were not affected by any competition having harvested maize earlier before tuberization fully commenced. This agrees with the work of Ravi (2020) who reported that bigger individual tuber yield obtained in intercropping systems could be attributed to less competition for light and other growth resources. However, the result of the study also indicated increase in the number of leaf and leaf area in cassava sole and crop mixtures. This could be attributed to better use of resources including moisture, which might have been supplied during rainy period. The result of this study also indicated a reduction in leaf number and leaf area in all the crops in the systems at 12 weeks after planting (WAP) which corresponded to the dry period. However, the variation in the decline in the leaf differed from one crop to the other as well as from one treatment to the other, probably due to the quality of sunlight interception by the plant and other growth resources availability. Generally, cassava sole cropping produced more leaves, bigger stems, plant height than the corresponding cassava crop mixtures in the systems. This could be attributed to better use of growth resources available in the systems. This work disagree with the work of Ghaffarzadeh (1997), who reported that higher growth and yield from mixed cropping as compared to sole crops on better utilization of solar radiation quality. However, the decline in the leaf number in intercropping could also be attributed to the occurrence of senescence and of course dead of the older leaves in succession from the base of the stem upward (Table 12 and 14); as well as poor interception and adsorption of light. This might have probably exerted pressure on the cassava growth and yield components such as leaf number, leaf area and dry matter content, respectively in the system even though cassava is known generally to be drought tolerant, period of extended water stress and poor light interception could seriously reduce tuber yield. This is in line with the work of Adeniyan et al, (2014), who jointly stated that competition of cassava with maize for light resulted in the reduction in dry matter formation and the stem to attain greater height.

Results obtained from the study indicated higher storage tuber root yields (t/ha) in sole cropping than in intercropping systems in both 2015 and 2016 cropping seasons. This significant increase in yields could be attributed to efficient use of resources in the systems.

However, dry matter content (DMC) accumulation was significantly higher in crop combinations than in sole cropping (Table 15) in 2016 as compared to 2015 cropping season. This could have been as a result of rapid senescence of leaf in sole cropping than in crop combinations as well as reduction in photosynthesis due to reduction in leaf number and leaf area. More so, the increase in dry matter content in crop mixtures in 2016 could have been as a result of moisture conservation in the systems due to crop cover, which might have helped to sustain the crops for some period of time and the ability of the crop to trap available solar radiation for the process of photosynthesis during that period. This is in line with the work of Adekunle et al (2014) and Chen et al (2018), who stated that higher yields obtained from mixed cropping as compared to sole crops can be attributed to better utilization of environmental resources, mainly solar radiation quality. Also, Schulz et al (2019) and Bekele et al (2021) reported that some crops can tolerate some degrees of shading with some significant improvement in tuber yield with varying degrees of shading in some warm tropical crops.

The result obtained indicated that the performance of cassava was affected by intercropping when compared between cassava sole and cassava intercrops, probably due to differences in utilization of resources and population density. This agrees with the work of Mbah and Ogidi (2012), who stated that intercropping cassava with varying soybean plant population may influence not only the performance of the component crops but also the residual nitrogen contributions in the cropping systems. According to Dasgupta et al (2017) and Evans (2020), the architecture and height of crop canopy as well as days to utilization of soil and aerial environment of the plant properly contribute to the competitiveness and performance of the component crops in intercropping.

The results of the study also showed that intercropping increased the number of storage root tubers and fresh tuber yield of cassava. This could be due to better photosynthetic efficiency by intercrops than sole cassava. Also, cassava root tuber initiation and bulking were not subjected to any intercrop competition, having harvested maize earlier before tuberization process commenced in cassava in the two cropping seasons. Mbah and Ogidi (2012); Mbah and Muoneke (2007), and Mbah et al, (2009) had earlier stated that fresh tuber yield of cassava was not significantly affected by soybean plant populations, though there were bigger individual sizes of root tubers in the intercrop as soybean populations increased. The big individual storage roots obtained could be attributed to less competition for light and other growth resources as maize plant population increased under the additive mixtures.

The results of the study on cassava yield and yield components also showed that number of storage root tubers per plant (marketable and non-marketable) tuberous root yield and dry matter content of cassava were from storage root tuber yield and yield components of sole cassava, which were not significantly affected by the intercropping. Among the intercrops in the two cropping seasons, total number of storage root tubers per plant, and especially, number of non-marketable tubers increased with increase in the number of crop population under the additive mixture series. This is in line with the work of Ogwuche et al (2023), who stated that cassava tubers increase with increase in the number of crop population. However, Adeniyan et al (2011) found out that fresh root tuber yields of sole cassava were significantly higher than the yields under the various mixtures of cassava/maize/cowpea. This study also revealed that cassava responded well to increased competition by diverting more dry matter accumulation to the stem, which would have been used to increase storage root tuber yield and size.

The result obtained from the study showed that top growth was highly significant among treatments and this could be due to available growth resources that would have been made available for storage of root tubers. Top growth - tuber ratios were relatively low probably because of rapid bulking of the tubers at the expense of the shoot despite top growth being significantly difference from the systems. Where the ratio appeared high, it is possible that the tubering is low and the top growth are abundantly more luxuriant. But at maturity, it was also observed that there was a relatively low top growth in the crop mixtures, possibly due to much more materials accumulation in the tuber rather than accumulated in the stem and leaves, hence the increase in the tuber ratio (Table 15). This could also be attributed to the function of growth resources utilization and not the cropping systems. Since the number of storage root tubers per plant was not significantly based on the systems used and crop mixtures, it therefore mean that the differences in storage root yield among the crop mixtures could be attributed to higher bulking capacity of the storage root tubers from the different cropping systems, agronomic practices, soil and environmental factors. This findings is in line with the work of Muoneke and Mbah (2007) and Hossain et al (2022), jointly stated that number of tubers per plant (marketable and non-marketable), weight of fresh tubers per plant, tuberous yield and top growth of cassava were not affected by intercropping systems.

The result of the study showed that, the significant increase on sweet potato growth, yield and yield components in sole cropping than observed in intercropping systems could be attributed to the ability of the sweet potato to extract the available resources in the system during growth period, resulting in significant yields (Table 20). However, from the findings of the study conducted; even though sole sweet potato had the highest storage root yields in both cropping seasons, sweet potato intercrop produced appreciable number of marketable storage roots per plant in both 2015 and 2016 cropping seasons. This could be attributed to compatibility and adaptability of sweet potato in the systems, as well as the ability of the sweet potato to produce more roots that might have developed into storage roots. The differences in yield occurred could be due to the variation in population. This findings agrees with the work of Dewit and habte (2023) and Vimela et al (2012) and Njoku et al, (2007) on the effect of intercropping varieties of sweet potato and okra, reported the interaction of okra and sweet potato cultivars being significantly affected the total number of tubers per plant but not the tuber yield.

However, from the findings, it was also observed from the study that, the number of vines planted might have determined the number of plants per plot where each stem at full establishment might have behave as separate sweet potato plant since each has its own root and shoot systems. This agrees with the work of Takim et al (2020), who stated that maximum yield of sweet potato in the intercrop was obtained when one vine of sweet potato was intercropped with maize from sole sweet potato plot. Result also indicated maximum yield of sweet potato than sole cropping. This could as a result of compatibility of crops in the system. This findings disagree with the work of Islam *et al* (2014) and Ogbologwung et al (2016), who jointly reported that sweet potato plant population above 33,333 plants/ha probably reached the carrying capacity, thus additional seedlings are destroyed through allelopathy, competition (self-thinning), shading effects provided by previously emerged stems, or any combination of the above factor which may lead to low yield of the storage roots.

The results obtained from the study showed reduction in yields of sweet potato in association with moringa and moringa/maize/sweet potato intercrops than in sole cropping. This disagree with the work of Abdullahi (2014) and Emuh and Agboola (2000), who reported that sweet potato in association with maize was significantly higher than in the three crop mixtures. The number of storage roots of sweet potato revealed from the study could have depended on the intensity of growth biomass of the plant at the expense of the storage root as observed in growth parameters; including the largest leaf areas produced which might have promoted its greatest growth biomass yields.

However, the high growth and total yields of crop obtained generally from the study in 2016 cropping season could be attributed to increase in nutrient through litter falls and decomposition from moringa leaves. This findings agrees with the findings of Zheng et al, (2019), who had earlier reported that detached leaflets from moringa decomposes and release nutrients to the under-storey crops. It was also observed from the study that moringa based cropping systems affect the sweet potato length of both non-marketable and marketable storage roots of sweet potato in the moringa based systems. However, the increase in the sweet potato storage roots obtained from the mixed moringa + sweet potato and moringa + maize + sweet potato in both cropping seasons could be an indication that the neighborhood effect between the crop species was complementary (Table 20). This agrees with the work of Moniruzzaman et al (2007) and Abdullahi et al (2014), who joinly stated the greatest intercrop tuber yield was obtained from sweet potato planted at the same time with okra and cassava when maize was planted at the same time in a cassava maize intercropping systems.

Result obtained from the study showed a significant increase on sweet potato biomass in 2016 than 2015 cropping season. From the findings, sole cropping is significantly higher in 2016 than in 2015 cropping season while crop combinations showed higher biomass in 2015 cropping season than crop combinations in 2016 cropping season. This could be attributed to better use of growth resources, crop compatibility and crop combinations. This agrees with the work of Anyaegbu *et al* (2012), who reported that sweet potato biomass weight was affected by the moringa based systems, where the biomass weight of the stands in the alleys of the fallow species increased significantly compared to those in control plots and those that received chemical fertilizer; an indication that fallow tree species had improved the soil fertility of the area as well as increased the tubers of sweet potato.

Findings from the study showed that there were significant increase in moringa yield and yield components in 2016 cropping season compared to 2015 cropping season. This could be attributed to decomposition of litter falls of moringa oleifera biomass and the incorporation of organic materials from debris of previous crop species into the soil system during tillage operation and the subsequent uptake of nutrients as well as the exploitation of other growth resources by moringa plant. This agrees with the work of Emmanuel et al (2011), who reported that maize yield on the moringa fertilizer plot produced the best result when compared to the control. This is an indication that within the period of tilling, planting and maturity of the plant, the moringa fertilizer had decomposed and made mineral nutrients available for plant use as compared to the control. This present study has shown that moringa oleifera can be used in intercropping systems to give an improved plant yield without any adverse effect on the plant and the environment. The findings of the present study also revealed significant increases in yield and yield components of moringa because, moringa leaves and branches might have decompose thereby releasing nutrients which might have improve soil fertility. This work agrees with the work of Sutarno and Rosyida (2020), who reported that moringa has a soft and deciduous leaflets that detached easily, decompose and release nutrients to the under-storey crops, capable of increasing crop yields especially when worked into the soil.

From the findings of the present study, the increase in leaf production which was obtained in moringa than maize, cassava and sweet potato could be as a result of differences in the type of plant and its adaptation to the environment. The increase in leaf number and leaf area in crop combinations than in sole cropping could be attributed to the number of branches, different levels of nutrients uptake of the crop and ability of the crop to utilize the available environmental resources efficiently in the system; possibly through early establishment, foliation and higher net assimilation rate of the leaves during growth period. The increase in yield and yield components of crop in the mixtures than in sole crop could be as a result of the ability of the crop to utilize available resources, and the increase in moringa fresh and dry leaf yield in moringa intercrop than in sole cropping could be attributed to low evapo-transpiration potential during the growth period and this resulted in high yield of leaves. However, the decrease in fresh and dry leaf yield of moringa at 12 MAP could be due to shedding effect of leaves possibly due to moisture stress and high temperature; and the fact that, the period of leaf senescence coincided with the flowering and fruiting stages with subsequent reduction in vegetative growth. This study agrees with the work of Zheng et al, (2019), Brunetti et al, (2018), Boumenjel et al, (2021) and Fahey (2005), who jointly stated that in drought conditions, moringa may lose its leaves but does not mean that it is dead.

Results obtained from this study of cropping systems indicated that intercropping had an advantage over sole cropping. This is expressed by the land equivalent ratio greater than one which the land equivalent ratio (LER) and yield are critical indices to assess land output. This study on moringa oleifera + cassava + maize + sweet potato intercropping system model indicated that the highest LER exceeded 1.0, with the average (mean) LER of 3.61 and 3.56 for both 2015 and 2016 cropping systems, respectively (Table 28). This implies that the intercrop systems was more efficient in terms of resources use than the sole crops. From the study therefore, an increase in the productivity of these intercrops may be attributed to the cropping system advantage. This is in line with the work of Takim *et al* (2020) on the effect of population density of sweet potato on the yield of maize-sweet potato intercrop for weed suppression reported that LER were highest in intercropping plots, indicating yield advantage over sole cropping which demonstrated a better land utilization and cumulative yield of maize-sweet potato intercropping systems. Also, from the present study, the highest land equivalent ratio (LER) was obtained in the plot when moringa was intercropped with cassava + maize + sweet potato (5.59 and 4.99) in 2015 and 2016 cropping seasons, respectively. This however, implies that intercropping yielded more than sole cropping indicating meaningful output and more beneficial because it is greater than 1.0. This is probably because of the crop that might have been complementary to one another in the utilization of field resources, time and space. This study also agrees with the work of Workayehu (2014), who reported that intercropping was more effective and efficient than sole crops in the use of environmental resources as demonstrated by higher land equivalent ratio. However, the yield advantage obtained from the intercropping system could be attributed to the developmental processes in the complexity of the intercropping system. This is in line with the work of Dong et al, (2018), who reported temporal differentiation of crop growth as one of the drivers of intercropping yield advantage. This present study also suggest that, farmers in the area can adopt intercropping systems with moringa for increased yields and higher farm profits (Table 28).

Result obtained from the study also showed that the highest cost of production in the system was observed from crop combinations of moringa + cassava + maize + sweet potato and moringa/cassava/maize/sweet potato (#111,500) in each treatments, respectively while the least was from sole maize (#82,500) cropping treatments (Table 27). However, the highest cost of production occurred in crops intercrop due to extra cost of planting materials and workmanship. Moringa intercropped with cassava gave the highest economic returns to management (#3,595,600) while the least (#11,000) was when moringa was intercropped with cassava + maize + sweet potato in 2015 and in 2016. Also, the highest economic returns (#4,368,650) was observed in moringa + sweet potato intercrop while the least economic returns (-#8,430) was from all the crop combinations with moringa. This is probably because of extra cost of procuring planting materials and complementary effects of the component crops involved. The high cost of production were however, compensated for higher economic returns to management under these treatments. This agrees with the work of Saad et al (2016), who reported that eventhough the yield of maize varieties was depressed in intercropping compared to sole cropping, that the sweet potato yield compensated for the depression and the higher LER recorded in the intercropping plots indicated yield advantage over sole cropping demonstrating better land utilization and cumulative yield. Similarly, the highest benefit – cost ratio (10.14 and 14.26) was obtained from moringa + cassava + maize + sweet potato crop combinations in both 2015 and 2916 cropping seasons, respectively. This indicating that farmers in the area can adopt this crop combinations for sustainable, profitable and economically feasible production notwithstanding the extra cost of production.

Findings from the study indicated that intercropping moringa with cassava (Mo+Ca), moringa with maize (Mo+Ma), moringa with sweet potato (Mo+Sp), moringa with cassava and sweet potato (Mo+Ca+Sp), moringa with maize and sweet potato (Mo+Ma+Sp) as well as moringa with cassava, maize and sweet potato (Mo+Ca+Ma+Sp) had an advantages over sole cropping. The advantage intercropping had over sole cropping could be attributed to the combination of long season crop (Moringa and Cassava) and relatively short season and low growing crop like maize and seet potato which enables the crops to utilize the potential of the cropping system. Ikeh et al (2012) reported that mixing crops that differ in the requirements for resources reduces competition among the component crops.

However, the combination of long season crop (moringa and cassava) and relatively short season crops (maize and sweet potato) enabled the system to utilize the potential of cropping period. By mixing such crops that differs in their requirements for resources (light, water and space), it was likely that their demand for resources was at different times. This is in line with the work of Workayehu (2014), who reported that, intercropping was more effective and efficient than sole crops in the use of environmental resources as demonstrated by higher LER. Efficient utilization of land resources where scarcity of land makes farmers to grow many crops on small piece of land is one of the rationales of intercropping in the traditional farming systems in Southeastern Nigeria.

The result of this study also indicated a better utilization of the land as well as save the land used. This in line with the work of Ijoyah et al (2012), who reported that intercropping okra with maize at the same time not only recorded the lowest competitive pressure but gave the highest LER of 1.75 with 42.9% of land saved; and maize + cassava intercrop gave the highest energy yield and highest LER (Adeniyan et al, 2011). This study however, has shown that LER values for all the intercrop combinations are advantageous to intercrop of moringa + cassava + maize + sweet potato (Mo + Ca + Ma + Sp).

CHAPTER FIVE

5.0 CONCLUSION, RECOMMENDATIONS AND CONTRIBUTION TO KNOWLEDGE

5.1 **Conclusion**

Findings from this study revealed the following:

i. Intercropping system involving moringa, cassava, maize and sweet potato had significant improvement on the growth and yield of the individual crops.
ii. Based on analysis of land equivalent ratio (LER), moringa/cassava/maize/sweet potato intercropping system was superior in the improvement of yield than the sole cropping system.
iii. Moringa/cassava/maize/sweet potato Intercropping ssyetms was effective in the improvement of the organic matter and nitrogen content of the soil. However, other fertility indices declined with intercropping.
iv. Moringa/cassava/maize/sweet potato intercropping systems has proved profitable on the economic returns to management.
v. Moringa/cassava/maize/sweet potato intercropping systems proved beneficial on weed suppression than the sole cropping.

vi. The trend in yield improvement with respect to the different intercropping systems is: Moringa/cassava > moringa/ sweet potato > moringa/cassava/sweet potato > moringa/ maize/ sweet potato > moringa/ cassava/maize/ sweet poato > moringa/ maize.

vii. Summary of yields and land equivalent ratio indicated that moringa/cassava intercropping system consistently had better yield of the component crops in both cropping seasons, and thus recommended in the humid rain forest zone of southeastern Nigeria.

5.2 **Recommendations**

i. Farmers in the South Eastern Nigeria should adopt the practice of moringa based intercropping systems to ensure cost effective weed control.
ii. To improve on the organic matter and nitrogen content of the humid soils, famers should practice moringa based intercropping systems.
iii. For maximum and suitable crop production with regards to land equivalent ratio (LER), farmers should practice moringa based intercropping systems.

5.3 **Contribution to Knowledge**

i. This research work deeply revealed the Potential of Moringa oleifera in the Development of Agricultural-Based Cropping Systems in the humid Rainforest zone of Southeastern Nigeria.
ii. This work proved its effectiveness in the suppression of Weed Growth as well as increased soil organic matter, Nitrogen content of the Soil and a reduction of Soil acidity.
iii. The experiment shown that Intercropping with Moringa improves Growth and yield of Component Crops.
iv. This Research work extensively showed the improvement of Intercropping Systems on Land Equivalent Ratio (LER) and the advantages over sole cropping.
v. The experiment revealed moringa/cassava intercropping system being more Profitable and Beneficial.

vi. This research showed the strength in Diversity by off-setting environmental pressure on the humid rainforest agro-ecosystem.

vii. The integration of moringa in cropping systems can contribute to livelihood enhancement and economic well-being of the poor and marginalized farmers of Southeastern Nigeria.

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