BIOECOLOGY OF *Indigofera hirsuta* Linn.AND ITS GREEN MANURE POTENTIAL ON PERFORMANCE OF *Amaranthus cruentus* Linn. IN IBADAN, NIGERIA

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CERTIFICATION

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DEDICATION

This work is dedicated to Almighty God for His mercies and loving-kindness and to my beloved mother, Mrs. Grace Mobolaji Adelere.

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ABSTRACT

The performance of crops are generally hindered by weeds, but some Leguminous Weeds (LW) such as *Sesbania* spp. have been reported to serve as Green Manure (GM) in the production of vegetables, including *Amaranthus cruentus* (Ac). While some LW do not nodulate, limiting their potential as GM, *Indigofera hirsuta* (Ih), a LW, nodulates and can serve as GM but its use on Ac has not been adequately documented in Nigeria. Therefore, the aim of this work was to determine the GM potential of Ih on Ac performance, and to study its bioecology in Ibadan, Nigeria.

Floristic enumeration was carried out at Teaching and Research Farm, University of Ibadan, during Wet Season (WS) and Dry Season (DS). Quadrats ($0.5m^2$) were laid 15 times, using X-Y coordinate random sampling technique, to determine Relative Importance Value-RIV (%) and Shannon-Wiener index (H′). Seeds (20 each) of Ih, scarified with concentrated H_2SO_4 (analar grade) for 10 (T1), 20 (T2), 30 (T3), 40 (T4), 50 (T5) and 60 (T6) minutes and un-scarified seeds (T7=control) were placed in Petri dishes. The treatments were arranged in a completely randomised design replicated four times and Germination Percentage (GP-%) was determined at day seven. Seeds from T1 were stored in envelope at room temperature to determine storability after scarification and GP was evaluated monthly for eight months. Field experiment was carried out to evaluate the GM potential of Ih. Seeds from T1 were sown for 4, 6, 8 and 10 weeks in 1 m^2 plots, arranged in randomised complete block design in triplicates. The shoots were cut into pieces, incorporated into the soil and allowed to decompose for three weeks before sowing seeds of Ac. Plant Height-PH (cm), Stem Diameter-SD (cm), Leaf Area-LA (cm^2) and Fresh Weight-FW (kg) of Ac were determined using standard procedures. Data were analysed using descriptive statistics and ANOVA at $\alpha_{0.05}$.

Twenty weed species were encountered in WS and 14 in DS. The RIV was highest for *Tridax procumbens* in WS=19.02 and DS=29.03, lowest for both *Sida acuta* and *Talinum fructicosum* in WS=0.62 and DS=1.67, respectively. *Indigofera hirsuta* had 6.87 (WS) and 13.96 (DS). The H′ of 2.11 (WS) was higher than 1.98 (DS). The GP ranged from 96.3 in T1 to 2.5 in T7. Seeds stored for one to four months had similar GP with range 83.0 to 95.0 and significantly higher than those stored for five to eight months with range 15.0 to 73.5. Incorporation of 8-week GM increased PH, SD, LA and FW of Ac with 59.53±1.33, 0.90±0.00, 88.73±4.35 and 1.73±0.04 compared with 45.87±0.80, 0.67±0.03, 51.28±1.24 and 0.77±0.05 recorded for 4-week GM, respectively. This could be adduced to production of high number of effective nodules by Ih at eight weeks. The control plot had the least PH:40.83±0.54, SD:0.60±0.00, LA:43.95±2.59 and FW:0.55±0.03.

All the weed species, including *Indigofera hirsuta,* were randomly distributed in both seasons. Seeds treated with concentrated H_2SO_4 maintained high germination and short viability duration. Performance of *Amaranthus cruentus* was superior in plots incorporated with *Indigofera hirsuta*.

Keywords: Indigenouslegume weed, diversity indices, *Amaranthus*, seed germination, acid scarification, growth parameters.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF PLATES

CHAPTER ONE

INTRODUCTION

The soils of southwestern Nigeria have been reported to be rapidly degrading (Ande *et al*., 2017). Soil degradationisone of the greatest impedimentsto ensuring the region'slong-term crop production in particular and generally in the tropics (Ande *et al*., 2017).This degradation is caused by a variety of factors, including unfavourable anthropogenic activities such as mining, logging beyond environmentally-safe or regulated limits, bush burning, overgrazing and climate change (Ande *et al*., 2017).Another reason for soil deterioration in regions of Africa south of the Sahara desert is increasing the intensification of agriculture in an attempt to take care of the region's rapidly rising population (Tully *et al*., 2015).

With the aim of dealing with the issue of depleted fertility of the soil and food challenges in Nigeria, the government continues to subsidise mineral fertilisers to farmers every year (Ebewore and Emaziye, 2016).However, in recent times, the continous and heavy applications of mineral fertilisers in fields are causing environmental pollution (Ebewore and Emaziye, 2016). Their continued use may result in nutrient imbalances and soil acidification (Usman *et al*., 2015).Therefore, the need to seek alternative sources ofsoil nutrient replenishment that are less harmful to the soil and ecosystem becomes necessary (Ande *et al*., 2017).

To combat the present state of soil degradation, Chukwu *et al*. (2012) suggested application of organic amendments. The utilization of properly amended organic manures by the farmers was also recommended (Ande*et al*., 2017). To this effect, green manurehas been advocated because there have been reports that crops respond well to their use, which works by releasing nutrients gradually and improving the fertility of degraded soils, thereby sustaining yield under continuous cropping (Ibeawuchi *et al*., 2015).Green manures have been found to amend the chemical, physical and biological

characteristics of soils (Perin *et al*., 2002), and also soil health and quality (Ande *et al*., 2017). The use of green manure guarantees that crops are produced without heavy metal pollution (Asadu and Unagwu, 2012). In tropical and subtropical regions, green manure is still being used extensively in low-input cropping systems (Chen *et al.,* 2014). Some weed plants may be good as green manure.

Weeds have existed 10,000 years ago, when agriculture first began (Zimdahl, 2010).Oerke (2006) reported that weeds cause more yield losses (34%) than animal pests (18%)and pathogens (16%).The control of weeds consumed more agrochemicals as herbicides (46%) than the control of insects by insecticides (26%) and of fungal pathogens by fungicides (23%) (Agrow, 2006).Weeds in agriculture could provide biomass for organic matterrecycling and a supply of plant nutrients but are not given adequate attention (Mogle, 2014). Organic matter management was observed as one of the most essential management practices for reducing the harmful impact of agricultural activities and for sustainability of soil quality (Piotrowska and Wilczewski, 2012).

Despite the numerous detrimental effects of weeds in agricultural production, they provide many benefits to agriculture, most important of which is their use as green manure to enhance soil fertility and improve crop performance. If the green manure plant is a nodulating legume, it may have additional advantage of atmospheric nitrogen fixation in the soil. The legume family (Fabaceae) of weeds has been reported to have potential roles in sustainable agriculture and food security (Das and Ghosh, 2012). Their use as green manure has been considered to be of great importance to agriculture in improving soil quality and crop production (Javanmard, 2015). They are also used as cover crops, which are effective in controlling weeds to reduce the use of herbicides (Uchino *et al*., 2011), conserve soil moisture and ameliorate soil temperature (Awodoyin and Ogunyemi, 2005).Perennial herbs with woody stem as well as herbaceous legumeleft as fallows harness biological nitrogen fixation (Cherr *et al*., 2006).Therefore, the focus of research has been on bringing legumes with woody stems that grow quickly into systems of agriculture over the last two decades (Cherr *et al*., 2006).

Indigofera is a genus of plants thatbelong to the family Fabaceae and sub-family Papilionoideae (Soladoye *et al*., 2010). It is indigenous to Africa and Asia (FAO, 2013).

Sixty species of the genus were identified in Nigeria with 27 species (45%)dispersed throughout the Southwestern region (Soladoye and Lewis, 2003). They occurredabundantly in the savanna ecological zone in the country's northern area,and with a few in the southern rainforest zone (Soladoye and Lewis, 2003). *Indigofera* speciesthat can be found in Southwestern Nigeria include *Indigofera hirsuta*,*I. macrophylla*,*I. nummulariifolia*,*I. spicata*,*I. suffruticosa*, *I. tinctoria,* and *I. trita*(Soladoye *et al*., 2010). Some of the species of *Indigofera*have been reported to be useful as cover crops, forage, green manure, and for dye and ethno-medicine.

Indigofera hirsuta isan annual, herbaceous legume commonly called‘hairy indigo’. It is found to be dominant in the highlands of Northern parts of Nigeria with the local names ‘aniyaa, makoomiyaa’ in Hausa**,** **‘**iwele mmuo’ in Igbo and ‘elu aja’ in Yoruba (Burkill, 1995).It is reported to have been used in Nigerian ethno-medicine for the treatment of diabetes, leprosy, tuberculosis, infections, snake bite, in the management ofmalaria and inflammation of the eyelids (Burkill, 1995), and has been recommended for forage production.Owing to its high protein and crude fibre contents, Nigerian farmers in Benue State used it as fresh forage for rabbits (Carew *et al*., 1989).

Indigofera hirsuta, according to Kalmbacher *et al*. (1980), is a legume that can convert atmospheric nitrogen, capable of supplying126 kg N/ha/yr to grasses that grow together with them and 100 kg N/ha to maize crops when planted as a relay crop. It is commonly used as a crop for soil enrichment as well as to help with erosion prevention. It was utilized as a cover crop and green manure in*Coffea* spp., *Camellia sinensis* and *Hevea brasiliensis* plantations in Asia, and in a citrus orchard in Florida (Kalmbacher *et al*., 1980).

Despite the relevance of *Indigofera* spp. as green manure, only a few researches have been conducted on *Indigofera* species in Southwestern Nigeria on its agricultural-related potentials. There are few studies on distribution, identification, classification and morphology and contents of some phytochemicals (Nwachukwu and Mbagwu, 2007; Soladoye *et al*., 2010). Ability of *Indigofera hirsuta* to nodulate and produce effective nodules within a short period makes it a green manure annual crop of high quality. It has also been reported to be tolerant of soils with low pH and fertility and thus, can be useful

in soil improvement (Kalmbacher *et al*., 1980). As a result of these qualities, it is being considered as a green manure plant for the cultivation of *Amaranthus cruentus*Linn., being an annual crop requiring high fertile soil. Also, there is scarcity of information on the use of *I. hirsuta* for green manure in Southwestern Nigeria.

*Amaranthus cruentus*belongs to the family Amaranthaceae. It requires fertile soils with high organic matter content for good productivity (Alonge *et al*., 2007). One of the challenges of *A. cruentus* production in Nigeria is low soil fertility.Nitrogen is a primary limiting factor in*A. cruentus* cultivation and most ofthe Nigerian soils were reported to be nitrogen-deficient (Pospisil *et al*., 2006).Nitrogen is a crucial component of photosynthesis, chlorophyll formation and stomatal conductance, which are responsible for a reasonable percentage of crop yields and is one of the essential plant nutrients (Ivonyi *et al*., 1997). To get a good fresh leaf yield of *A. cruentus*, 70 kg N/ha, 34 kg P/ha and 26 kg P/hawere recommended by Denton and Olufolaji (2000). There have been reports of increase in performance of *A.cruentus* due to addition of nitrogen fertiliser tothe soil (Makinde, 2012).

The problem of low nitrogen content of soils in Nigeria is usually solved with the addition of synthetic nitrogen fertilisers to increase crop yield. However, synthetic fertilizers have negative effects on the environment. Olowoake and Adeoye (2010) reported that recurring use of synthetic fertilisers may lead todecrease in organic matter content of the soil, acidification of the soil and degradation of its physical properties, hence, increase in soil erosion and pollution of groundwater

The increased usage of legume cover crops as green manures to meet crop nitrogen requirements by organic growers have been reported (Bello, 2008). According to NAS/NRC (1979), legumes are capable of supplying the soil as much as 500 kg N/ha. Therefore, several species can be utilized as fallow or green manure, and each one has unique features that can alter soil properties in different ways. Legumes convert atmospheric nitrogen with the assistance of the bacterium *Rhizobium* spp. present in the nodules of their roots (Mgbenka *et al*., 2015).

At the beginning of the cultivation of vegetables, it was at the household level because much attention was given to cereals, tubers and legume crops.However, as

people became more aware of the importance of leafvegetables in a healthy diet, they are eating more of them and farmers now produce them for commercial purpose (Olowoake and Ojo, 2014). *Amaranthus cruentus*is a leaf vegetable grown in Nigeria and other countries of West Africa(Olaniyi, 2007).In Nigeria, its cultivation at the initial stage was at the subsistence level and as a result, its supply to areas of high demand, especially in the urban centres had been low (Adewole and Dedeke, 2012). The increased demand for *A. cruentus* in the metropolitan areas, where fewpeople are engaged in primary agriculture, has turned its cultivation into a key source of income for rural farmers,and as well, made it an important commodity in the market (Law-Ogbomo and Ajayi, 2009).Law-Ogbomo and Ajayi (2009) reported low productivity of *A. cruentus* (7.60 t/ha) in Nigeria, compared to the yield in the United States of America (77.3 t/ha) and world average (14.3 t/ha) reported by FAO (2007).

Therefore, the potentials of *I. hirsuta* as a green manure plant and its effects on the performance of *A. cruentus* in Ibadan, Nigeria were investigated. The specific objectives of the study were to:

i) carry out a survey of the occurrence, distribution and abundance of *I. hirsuta* in relationto other low-growing plant species in the natural ecosystem inIbadan;
ii) evaluate the germination conditions, phenology and growth/biomass accumulation of *I.hirsuta*;
iii) determine effect of density of *I. hirsuta* on its ability to suppress weeds; and
iv) assess the green manure potentials of *I. hirsuta* and its influence on the growth and performance of *A. cruentus.*

CHAPTER TWO

LITERATURE REVIEW

2.1 Weeds and Agriculture

In accordance withthe Weed Science Society of America (WSSA), weeds are classifiedas plants that are unpleasant or whose existence interferes with man's activities or welfare (Vencill, 2002). They are usually plants that are not sown and their presence not only interferes with man's activities but also with the growth of the crops, causing reduction in the yields and quality of the produce (Ghersa *et al*., 2000). They can also be referred to as a class of crop pests that are ubiquitous and probably ever-present in the agro-ecosystem (Rana and Rana, 2016). Weeds are considered a serious biotic threat because they can cause significant losses in farm produce (Fernandez-Quintanilla *et al*., 2008).

The history of weed is extensive and dates back to the dawn of agriculture. In the early history of weeds, they were considered universally undesirable because they were the main problem of farmers and the means of controlling them were manually by hand, use of hand-tools and animals(Breen and Ogasawara, 2011).Though commonly perceived to be unwanted, weed species are pioneer plants that use their environmental potential to increase diversity in agricultural ecosystems through cropping systems targeted towards maximizing crop production (Bhowmik, 1997).Weeds flourish in disturbed environments and produce large number of seeds, therefore, there isa need to manage them in order to maintain food security by sustaining crop productivity in agro-ecosystems (Manning, 2004).

Weeds may be considered to be valuable; some species have properties and undergo processes that are beneficial toman or his activities (Naylor, 2002). In many many cultures, these non-cultivated plants termed 'weed' provide food fodder and medicine (McMichael, 2000). Weeds also provide shelter for animal. Some species of

of birdwere discovered to be declining in arable crop farmland due to a decrease in the number of weeds (Gibbons *et al*., 2006). Certain characteristics make weeds capable of flourishing in locations where they are not needed and outgrow the desired or planted crops. These characteristics include the ability of weed seedlings to grow rapidly and mature in a short time, ability to reproduce while still young and dual mode of reproduction(by seed and vegetative organs).Many weeds have capacity to producenumerous seeds per plant and some havelong-and short-range seed dispersion methods that are uniquely developed (Zimdahl, 2007).Weeds can withstand environmental stress due to their possession of some vegetative organs, such as rhizomes, stolons, bulbs, corms, tubers and vigorous roots. Their seeds can lie dormant in the soil for long periods, resisting decay (Zimdahl, 2007).Another characteristic that distinguishes weeds from other plants is that they are capable of colonizing disturbed sites successfully(Liebman *et al*., 2001).

Weeds are capable of competing for growth resources, water, light and space with crops. They exhibit this by special means such as aggressive root formation, rosette formation, climbing and allelopathy (Zimdahl, 2007). In Africa, the harmful impacts of weeds on crop yield have been established in numerous studies. Average crop losses were determined for *Zea mays* (73%), *Phaseolus vulgaris* (50%), *Sorghum bicolor* (60%), *Vigna unguiculata* (50%), *Oryza sativa* (75%), *Gossypium arboreum* (80%), *Triticum aestivum* (65%), *Arachis hypogaea* (80%) and *Manihot esculenta* (90%) under unweeded circumstances (Dadari and Mani, 2005; Ishaya *et al.*, 2007).

Weed management in agro-ecosystems relied heavily on soil cultivation, seed cleaning and crop rotation from the beginning of agriculture until the advent of herbicides. In a bid to control weeds in modern agriculture, herbicides were the dominant tool used (Harker and O'Donovan, 2013). Synthetic herbicides were discovered between 1940 and the mid-1980s (Zimdahl, 2007). The use of herbicides was partially successful because in the fields, weeds were still the prevalent plant life. Lately, several weed control methods have been adopted due to the failure of herbicide use, especially with emergence of herbicide-resistant weeds. Recent reports (Powles and Yu, 2010) show that herbicides are not the absolute end to the problems that weeds present to crop

productionbecause of the evolution of herbicide-resistant weeds. Even glyphosate, the world's most frequently used herbicide, has been confirmed to be resisted by some weeds such as *A. hybridus, A. palmeri* and *A. tuberculatus* (Powles and Yu, 2010).

There is now a shift towards ecologically-based weed management systems because many weed species have developed resistance to herbicides while those herbicide-susceptible species have been replaced with more difficult-to-control species. Also, economic factors and increase in consciousness of the consequences of the use of herbicides on the environment resulted to the consideration of alternative control methods (Zimdhal, 2007). Another defect of herbicide use is their negative environmental consequence. The unfriendliness of herbicides to the environment has caused serious concern to environmentalists (Breen and Ogasawara, 2011).

2.2 Weed ecology

Adequate ecological and biological understanding of weeds is required to manage weeds successfully as it will help to identify and establish more sustainable ways to manage them. Weed ecology is a branch of weed science that studies the interactions between weeds and their environment, their characteristics and mechanisms of survival in a disturbed or agricultural ecosystem. It involves understanding the population and distribution of weed species within the limit of an ecosystem (Nkoa*et al*., 2015). The goal of studyingweeds is to get better knowledge of their management and control as well as understanding the relationship between weeds and crops (Moss, 2008). Two of the most difficult ecological problems are the perception and learning of the dispersion of a weed species. To compare the richness of different ecosystems and to represent species diversity patterns across spatial scales, standard sampling procedures for diversity assessments are essential (Dengler *et al*., 2016).

The foundation of the Weed Science discipline was based on the characteristics of weeds and their interactions withhuman activities(Monaco *et al*., 2002). According to Fernandez-Quintanilla *et al*. (2008), weed science encompasses a wide range of topics, from ecological and agronomical research to the development of effectual weed

controlapproaches in the environment, and can be viewed as a framework for the consolidation of multiple branches of knowledge to handle weed problems.

The understanding of the dynamics of weed species population, abundance and distribution are perhaps of most ecological importance. In biological management and conservation, species abundance is important in decision-making and aspects of determining the likelihood of an endangered species becoming extinct (Mace *et al*., 2008).It is also important inthe surveillance of invasive species (Veldtman *et al*., 2010) andmanaging the populations of species, especially threatened ones (Figueiredo and Grelle, 2009).Studying the abundance and distribution of plant species is of great importance in maintaining ecosystem diversity and the functions provided by these species and also to develop appropriate conservation measures (Soliveres *et al*., 2016). The abundance and distributions of species indicate measurement of the relative or the total number of a sampled species,and they are usually used for describing ecological communities. Density, plant cover, biomass and basal area are the measures used to estimate plant abundance (Anderson *et al*., 2012).

To evaluate the ecosystems at different scales, species diversity isamong the most crucial indices used,because biodiversity lays emphasis on the species level. It is possible to investigate it at the local level by using indices such as species richness, or the Shannon index, which is the measure of interaction of same or different species amongst others. To measure species diversity, the relative abundance should also be taken into consideration; it involves measuring the number (or frequency) and variety of location of species of weeds in the ecosystem. Accurate estimations of the population of weed speciesand their distribution will help in establishing the population evolves over time as a result of pressureto take control of land used for agricultural production and biodiversity through agronomic approaches (Nkoa *et al*., 2015).

The two components of species diversity are richness and evenness. Evenness is the abundance of each species in a community (Nkoa *et al*., 2015). Evenness offers data as to whether a community is in abundance of one particular or more species, or whether there are approximately equal numbers of each species within the community (Booth *et al*., 2010).Diversity can be measured using several methods. It can be calculated inside

the limits of a community and also between two or more communities. Estimation within a community is called alpha-diversity while between communities is termed beta-diversity. Biotic similarity is a main notion that underlies the measurement of beta diversity, the turnover between a set of locations in the structure of species (Gotelli and Chao,2013).

2.3 Weed Biology

Weed biology is a branch of weed science that studies weed growth, development, and reproduction. Grasping the principles of weed science and developing appropriate weed control techniques necessitates understanding of weed biology (Zimdahl, 2007). It has to do with plant characteristics like germination of seed, the phenomenon of seed failure to germinate, known as dormancy, phenology, morphology and study of growth, reproductive biology and competitive ability (Bhowmik, 1997). Comprehending the underlying mechanisms of weed adaptation and proliferation in agricultural systems is also covered. Such mechanism includes evolution of herbicides-resistant weeds, gene flow between transgenic crops and weeds, and evolutionary ecological features that may be accountable for 'weediness' (Baucom and Holt, 2009).

The study of weed biology is dated back to 1930s when Pavlychenko (1937) worked on the root growth and development features of weeds and crops grown in competitive and non-competitive associations. There are published works on the life history of various species of weed (Bell *et al*., 1962), weed phenology, competition between weed and crop and reproductive biology (Bhowmik, 1997). Based on the number of total publications per decade as a fraction of total publications, the knowledge of weed biology/ecology has continued to increase (Abernathy and Bridges, 1996). Currently, the study of the biology of weed focuses on weed seedbank dynamics, root reserves, dormancy and evolution of weeds and also modelling of outgrowth of weed seedling (Bhowmik, 1997).

2.3.1 Weed seed germination and dormancy

The study of germination usually explains the genetic make-up and existence of the weed species in their natural habitat (Tejavathi*et al*., 2011).Germination or failure of

viable weed seed to germinate (dormancy)are controlled by the interaction of physiological, factors such as the environment, edaphic and genetics (Radosevich *et al*., 1996).The source, degree and duration of dormancy vary extensively in weed seeds. It was reported that dormancy, with the existence of large weed population, is the foundation for the annual weed problem (Hafiz *et al*., 2011). Seed dormancy is a significant contributor to weed issues that persist because it contributes to the weed seed survival in soil for many years as seed banks offer unusual large collection of seeds with varying levels of dormancy (Hafiz *et al*., 2011).

Seed dormancy is a mechanism used by plants in setting time to prevent germination when the condition is unsuitable and time to initiate germination when the conditions are suitable (Black and Halmer, 2006). Dormant seeds are viable seeds that are notgerminatingin an ideal environment where the criteria for germination are met. Dormancy hinders the prediction of weed emergence timing and extent which are important weed control strategies, thereby making getting rid of weeds in the field difficult (Radosevich *et al*., 1996). Therefore, understanding the mechanisms of dormancy is essential both ecologically and economically, as weed infestations can be predicted and long-term management schemes can be evaluatedwith it (Bhowmik, 1997).Causes of seed dormancy in plants vary. It includes the presence of impermeable integument or hard seed coat as a result of palisade cells layers that are impervious (Baskin and Baskin, 2004), presence of inhibitor, undeveloped embryo and environmental factors (Sadeghi*et al*., 2009).A hard seed coat resists germination because of the inability of radicle to pass through it. This kind of dormancy could be overcome by scarification, soaking in acids or weakening the integument by permitting water passage to initiate germination (Cavalheiro *etal.*, 2007). There are different mechanisms of breaking seed dormancy. Physically, dormancy can be removed by rubbing the seeds with sand paper or sand, in order to reduce the thickness of the seed coat and allow water infiltration and diffusion of gases required for germination (Habila *et al*., 2016). Sulphuric acid was reported to be beneficial in removing seed coat dormancy of leguminous species (Awodoyin and Egberongbe, 2010). It works by removing cuticle and

making the testa less hard, which makes water absorption and gaseous exchange easier (Muhammad and Amuse, 2003).

Soil management also has influence on seed dormancy. It was reported that the rate of death of seeds of gigantic foxtail and velvet leaf was greatest in soils where prescribed measure of synthetic fertilizer and pesticide was added, and lowest in soils where nourishing minerals from organic materials was added, and weed managed by growing alone (Davis *et al*., 2006). Franzenburg and Owen (2002) also discovered that seeds that were buried beneath the surface of the ground exhibited less dormancy than seeds that were left on the ground surface.

Large numbers of the species of Fabaceaefamily demonstratetemporary failure to germinate that is originally due toinability of seed coat to allow water passage.Seeds of leguminous weeds are generally known to persist for as long as 20 years (Zimdahl, 2007). As observed in most leguminous plants, seeds of *Indigofera hirsuta* exhibit dormancy and without pre-treatment, the germination percentage at a time is very low and germination is never uniform, thus producing seedlings with varying ages.

2.3.2 Effect of planting depth on seed germination in plants

Among the elements that affect germination of seed is depth of sowing. The ability of planting depth to influence germination of seed and seedling outgrowth of different crop plants has attracted the interest ofresearchers(Opande *et al*., 2017). Depth of sowing helps in establishing good crop stands and thereby, achieving higher yields (Siddig *et al*., 2015).According to reportby Mohammad (2011), diverse species of plant have the potential to spring up in a great variety of planting depth. Sowing seeds at different soil depth affect their germination rate. The seeds may experience varying environmental conditions and nutrients availability required for germination. Such environmental conditions include temperature, moisture, changes in oxygen and carbon dioxide concentrations (Sikuku *et al*., 2018).

Sowing seeds deeply in soil may have effects ontheir germination and the seedlings development. This may increase the length of time required for the seeds to sprout and alsothe interval between seed germination and the appearance of

seedling(Ahirwar, 2015). Also, when sown in shallow hole, owing to insufficient moisture content of the top layer of soil, germination may be limited as well as development of very low quality rooting system, which develops horizontally just below the soil surface (Aikins and Afuakwa, 2008).The depth of sowing seeds for effective germination varies among different plant species. Effects of deep sowing of seeds include seedling growth delay, susceptibility to pests, diseases and drought (Ahirwa, 2015).

2.3.3 Growth and development

Study of growth in plants is a significant procedure that is important in a range of contexts. Growth and development are part of the pre-requisites for a species to reproduce successfully in a given environment. It also forms the foundation of agriculture, making it of fundamental importance. In ecology, the physiological processes of growth are known to have great impact on the biological, chemical and geological cycles that occur in essentially all ecosystems on the earth. These processes are therefore, the focus of significant research efforts (Poorter *et al*., 2013).

Reproductive biology has been known to be important in determining the effect of phenological behaviour on timing for each growth and developmental stages. This is important in breeding programmes (Rout *et al*., 2009). It is useful in determining the factors and processes that influence population genetic structure (Kukade and Tidke, 2013). Phenology helps in understanding the interactions between species and the spatial aspects of the community. To study the phenology of plants, the life-history stages such as germination, leafing, flowering, fruiting and others are usually dealt with separately. Though the stages are interdependent, each occurs in its own slot. Their occurrences are in succession such as fruiting following flowering, fruiting preceding seed dispersal etc. (Fenner, 1998).

Plants require diverse resources for growth and development. These include; water, temperature, light, micro and macro nutrients (Poorter *et al*., 2013). On the land, plants growth is frequently restricted by the accessibility to plant nutrients such as nitrogen or phosphorous (Agren *et al*., 2012).

Temperature, a factor of climate, affects the rate at which plants grow and develop. Specific temperature required by each species varies, ranging from minimum to maximum. One of the developmental stages affected by extreme temperature is pollination, though there are strategies to survive the temperature extremes (Hatfield and Prueger, 2015).Light quality, quantity and duration affect thegrowth of plants. Plants require sunlight for the production of food through photosynthesis. Sunlight affects the biomass production of annual crops.Light is one of the required conditions for germination (Sarrantonio and Gallandt, 2003).

2.4 Weeds of ecological importance (legumes)

With eight hundred genera and twenty thousand species, the Fabaceae family is the third biggest of the flowering plant families (Lewis *et al*., 2005). Legumes may occur as weeds of cereal crops or as grain crops often known as pulses.The excessive use of agrochemicals and chemical fertilisers in modern cropping systems could be reduced by the use oflegumes due to their environmental and socio-economic benefits (FAO, 2011). The use of legumes in agriculture has helped in cutting down on the amount of nitrogen fertilizers used in systems suitable for growing crops,capable of fixing nitrogen in the atmosphere,and ameliorate soil richness, in terms of organic carbon, nitrogen and available phosphorus (Jensen *et al*., 2012).

Legumes provide biomass, organic carbon and nitrogen to the soil, thereby, increasing its organic carbon content (Garrigues *et al*., 2012). It was discovered that legumes showed beneficial effects on sandy soils in terms of rise in organic carbon, following three years of research (Hajduk *et al*., 2015). Growing of soybean with maize simultaneously on the same plot of land, at different rates increased soil organic carbon accumulation (23.6 g C kg^{-1}) compared to cultivating only maize (21.8 g C kg^{-1}) on a piece of land, while amending soil with soybean residues yielded 38.5% soil organic carbon (Bichel *et al*., 2016).

Some leguminous plants fix atmospheric nitrogen biologically. This significantly affects soil nitrogen availability (Yu *et al*., 2014). There have been a lot of studies on the importance of legumes in improving soil nitrogen.One of the significant interactions

between plant and microbe is the fixation of nitrogen by rhizobia, present in legumes, through a process called symbiosis. This interaction is extremely important in the nitrogen cycle (Lupwayi *et al*., 2011). Some researchers have investigated the nitrogen contents of shoot, root and nodules of the legumes. Carranca *et al*. (2015) discovered 7-11% nitrogen from legumes associated with root and nodules. Assessment was carried out on nitrogen and phosphorus cycling in the rhizosphere of *Triticum aestivum* and *Vicia faba* grown in mixtures and monoculture, accumulation of phosphorus in the rhizosphere of legumes was discovered to be significant (Wang *et al*., 2012).

Nitrogen-fixing legumes increase the organic matter content, nitrogen levels, CEC, as a result, agricultural yields (Salako and Tian, 2003a). Planting legumes, in contrast to cereals, increases the grain output of succeeding grain crops (Olesen *et al*., 2007).They also reduce the impacts of pests and diseases when mixed with non-leguminous crops in a rotation (Das and Ghosh, 2012) and have ability to suppress weeds, especially the common weeds in Nigeria like spear grass (*Imperata cylindrica)* or witchweed (*Striga hermonthica*) (Ekeleme *et al*., 2003).

2.5 Use of cover crops for weed suppression

Weeds arewell-known for being amongthe most detrimental threats to crop production especially in agricultural systems that make use of little or no chemicals. Cover crops may be relatively effective in suppressing weeds in such agricultural systems (Uchino *et al*., 2011). There have been some cover crops utilized successfully to suppress weeds: *Secale cereale*, *Hordeum bulbosum*,*Trifolium repens*have been used (Ross *et al*., 2001).Cover crops serve not only the purpose of covering the soil; they are usually grown for various ecological reasons (Sarrantonio and Gallandt, 2003). Cover crops have been used to control weeds for ages (Caamal-Maldonado *et al*., 2001).

Leguminous cover crops also play important roles in suppressing weeds. They provide various benefits to an agricultural system when cultivated as live mulches, including as nutrients recycling, enhancing soil structure, and controlling weeds and pests (Hartwig and Ammon, 2002). The mechanism of suppressing weeds by cover crops is by competing for resources with the cover crops and inhibiting weeds growth through biotic,

physical and allelopathic interactions by their above ground residues. Through competition, cover crops which are vigorous and fast-growing compete strongly with weeds. They compete for resources such as space, light, nutrients, and water, effectively suppressing growth of weed by 80–100% during the cover crop's life cycle. Thecanopy closure created by cover crops prevents the growth of emergent weeds by putting them in the shade(Hartiwig and Ammon, 2002).

Another technique of suppressing weeds by cover crops is the release of chemicalsthat have the potential to harm the growing process of other plants. This is called allelopathy. The substances called allelochemicals may be in the form of living plant roots exudates, leaves and shoot or release from plants decaying residues. The allelochemicals, strong enough to be considered as natural herbicides, can inhibit seeds germination, seedlings growth and young plants growth retardation. It can also cause damage to roots and may even cause death of plants. Allelopathy has been documented to be strong enough to control weed in agricultural systems (Boydston and Hang, 1995).

Cover crops made up of legumes also have a significant consequence on soil conservation and planting them may serve as soil management technique. Cover crops grow rapidly and closely to form very thick canopy which stops drops of rain from dislodging soil particles(Hartwig and Ammon, 2002).Plant density is among the most vital elements of production that have an impact on growth of plant and its yield to the greatest extent (Moria *et al*., 2018).An increase in plant density may result in a reduction in production of individual plants. In order for planting of crops from seed to be economically efficient, establishment of ideal sowing rates is required (Muranyi, 2015).

2.6 Nitrogen fixation by legumes

One of the most crucial biological processes to develop sustainable agriculture is symbiotic fixation of nitrogen. The process of fixing nitrogen involves conversion of atmospheric nitrogen (N_2) to ammonia (NH_3) by an enzyme called nitrogenase (Udvardi and Poole, 2013). The process is achieved by the action of bacteria inside the cells of root organs called nodules in most legumes. It involves a complex interaction which is symbiotic, between nodule-producing legumes and rhizobia. Rhizobia fix nitrogen from

the atmosphere and convert it to readily available form, in the form of ammonia for plants, while the host plants (legumes) serve as sources of carbon energy to the rhizobia for the purpose of their development and functions, thus, making the relationship mutual (Sulieman and Tran, 2014).

Land remediation relies heavily on biological nitrogen fixation and research has focused on the association between rhizobia and leguminous plants due to the biggest impact on the nitrogen cycle in terms of quantity.Nitrogen is an important plant nutrient; however, its deficiency often limits plant growth (Mohammadi *et al*., 2012).Nitrogen fixation by legumes offers eco-friendly means of improving internal resources by reducing external inputs (van Hamerene*t al*., 2013) and protecting the environment.

The nodules produced on the root of legumes are extremely complicated organs. Several processes interact with one another, starting from the nodules formation to carbon metabolism, supply of oxygen, cellular reduction and oxidation, and transmembrane transport (Udvardi and Poole, 2013; van Hameren *et al*., 2013). There have been enormous research on the process of nodule metabolism and regulation (Oldroyd and Dixon, 2014; Rogers and Oldroyd, 2014; Sulieman*et al*., 2014) but more researches are required to provide greater understanding of the technique.

Making nitrogen available for theagricultural production system by legumes can be achieved through a mutually beneficial relationship between legumes root nodules and *Rhizobium* bacteria found in the ground (Pinto *et al*., 2007), and resulting in atmospheric nitrogen fixation(Moreira *et al*., 2010). There have been studies, carried out on nitrogen fixing ability of leguminous plants such as *Crotalaria juncea*, *Mucuna aterrima*, *Canavalia ensiformis* (Ramos *et al*., 2001). Some species of legume have also proved effective in recycling and accumulating both macro nutrients such as nitrogen, potassium, calcium, magnesium and micro nutrients after four years of being utilised as ground cover in a rotational system (Borkert *et al*., 2003).

2.7 Use of leguminous cover crops as green manure

The most substantial component of crop production is known to be soil(Usman, 2013). Its degradation or decline in quality is considered to be one of the most

crucialissues restricting crop productivity around the planet. The degradation is a long-term process which indirectly affects the local population as it resulted to crop failure and famine, anda lack of suitable forage for animals (Subair, 2009).Soil degradation has been a severe issue in the Africa south of Sahara desert as the soil resources are already under great stress (Junge *et al*., 2008).

In Nigeria, the disintegration of soil quality is mainly human-induced and its severity was reported to be Light for 37.5 percent (342,917 square kilometer), moderate for 4.3 percent (39,440 square kilometer), high for 26.3 percent (240,495 square kilometer), and extremely high for 27.9% (255,167 square kilometer) (FAO, 2005). Aruleba (2004) and Senjobi (2007)also reported noticeable evidences of land degradation in all parts of Nigeria and that these vary from place to place.It has been reported that south western Nigeria's soils are quickly deteriorating as a result of unsuitable use of land, low basic soil fertility, nutrient mining and climate change's negative consequences (Ande *et al*., 2017).

However, environmental degradation has affected the majority of Nigeria's agricultural soils (FMEN, 2001). Soil deficiency and poor agricultural output as a result of shortage of fertilisers that are inexpensive and capable of being maintainedare also major complaints of farmers in Nigeria (Usman and Kundiri, 2016).Reports showed that the majority of the soils in southwestern Nigeria are mildly to slightly acidic. The acidity of the soils has influence on availability of micro and macro nutrients (Ande *et al*., 2017).As a result of these, several methods for improving soil fertility have been proposed but little success has been recorded as a result of rising population and poverty (Onweremadu *et al*., 2008). Mulching, mixed cropping, terracing, and ridging are all common soil conservation strategies in Nigeria (Ogbonna *et al*., 2006). But their effectiveness has been reported to have declined (Matthews-Njoku and Onweremadu, 2007).

To address the issue of land degradation and its implications for agricultural productivity, a scientific investigation is required to determine the management practices that will give its highest productivity, enhance soil fertility and environmentally-friendly (Amao *et al*., 2013). Many farmers have forgotten about the importance of using organic

resources as soil amendment in crop production, and their proper usage for soil quality and fertility control has been abandoned (Usman and Kundiri, 2016). However, according to reports, the increased use of inorganic fertilisers has diminished the importance and economic advantages of organic materials during the previous three to four decades (Usman and Kundiri, 2016). The advantages of green manure over inorganic fertilisers include their non-polluting nature, posing less danger to the environment and their biodegradability, leaving no unsafe deposits in the environment (Adekiya *et al*., 2017).

Long stretches of time when agricultural land is left unseeded after plowing in order to recover natural fertility, which were once a part of Nigeria's traditional shifting cropping technique for soil rejuvenation, have been replaced with improved fallow of short periods using herbaceous species (Junge *et al*., 2008). In the earlier times before theera of inorganic fertilisers, farmers frequently use the fallow system to replenish fertility. The length of time for fallow may be as long as 8 to 16 years, and up to 20 years on occasion. But as population keeps on increasing, resulting to increase in demand for food and urbanization, the fallow period unknowingly dropped from 8 to 16 years to 8 to 12 years, and now it's 3 to 4 years, which is often not sufficient to restore soil fertility, causing soil and vegetation degradation (Styger and Fernandes, 2012). Consequently, the utilisation of external components of production like chemical fertilisers, agro-chemicals for controlling pest and weeds had been incorporated into the agricultural system. Although, these chemicals have helped to increase productivity, they have also constituted adverse effects directly on the environment and indirectly on man, thus, making agricultural system unsustainable (Ibeawuchi *et al*., 2015).

The periods of planting and growing of green manurecan be referred to as fallow period. It helps to restore soil fertility quickly and also reduce weeds' competitiveness on farmlands (van Scholl, 1998). Commonly used leguminous crops as fallows and green manure in Nigeria are *Leucaena leucocephala, Mucuna pruriens,*or *Pueraria phaseoloides,Sesbania* spp*,Crotalaria juncea*, *Cajanuscajan*, *Vigna radiata*(Ekeleme *et al*., 2004). These legumes have been reported to raise the proportion of nitrogenand available phosphorus components in the soil (Kolawole *et al*., 2004). Legumes such as dry pea or lentil have been grown as fallow for six to eight weeks to prevent the weed

growth and thereby reduce the requirement of herbicides to control weeds (Anderson, 2005).The advantages of improved fallow system on soil microbiological notable characteristics and weed control have been stated (Hauser *et al*., 2006). Hence, improved fallows, particularly in farming systems, have a great potential for soil conservation without fertiliser input. However, shortening the fallow cycle has led to low content of soil organic components (Aikorie *et al*., 2003).

To recover and conserve degraded soils, green manuring is one of the traditional techniques that can be employed. Green manuring is the process of cultivating high biomass producing plants and their incorporation into the soil.Green manures are plants that have been integrated into the soilso as to promote the performance and outputof next crops (Salahin *et al*., 2013). It is an organic production system that is environmentally-friendly, particularly in the production of food.Researches have revealedthe significant benefits of green manure to soil in particular. Such benefits includeincreasing soil organic matter and enhancing soil chemical characteristics like nitrogen by the activities of *Rhizobium* bacteria in the soil and nodules present in the root. It also increases microbial activitiesof the soil and enhancesits physical properties(Moraes *et al*., 2006; Ziblim *et al*., 2013).

The history of green manure dates back to 300 years BC when *Vicia faba* L. and several varieties of *Lupinos sp*. were planted by the Greek and Roman civilizations to boost soil richness and offer a number of the essential nutritional requirementof food crops (Zaccheo *et al*., 2016). Agricultural productivity during the 18th century and the early half of the 19thwere also entirely reliant on the resources of nature(Pikul *et al*., 1997). Usman and Kundiri (2016) stated that for the last 35 years or more, the use of organic fertiliser in northern Nigeria as the driving force behind healthy and high-yielding crops in the farming systems, and that increasing the concentration of inorganic fertilisers in this part of the countryreduces the value of organic materials and their economic benefits.It was reported by Ebewore and Emaziye (2016) that organic matter and vital living organisms that help produce excellent soil are lost over time in soils treated only with synthetic fertilizers. Therefore, there is need for inclusion of green

manure crops in conservation agriculture so as to preservethe soil physicochemical and biological properties(Alam, 2010).

In African semi-arid environments, there has been evidence of green manure being beneficial when it comes to managingorganic matter of the soil (Ganry *et al*, 2001). The biomass produced by green manure increases organic matter which in turn increases the cation exchange capacity. Cation exchange capacity aids in nutrient retention in soil particles (Ciotta *et al*., 2003). The unavailability of sufficient manures in organic farming necessitates the use of other sources of nitrogen of which green manure is an option (Olesen *et al*., 2009). Application of high concentration of animal manure may lead to soil salinisation (Hao and Chang, 2003) and soil phosphorus loading because the ratios of nitrogen to phosphorus (N:P) in animal manure are frequently significantly smaller than those that plants maintain (Hao *et al*., 2004), while making use of legumes as green manure will help to avoid excess phosphorus build up and soil salinisation (Eigenberg *et al*., 2002).

Green manure has great potential providing nourishing substances to crops (Adediran *et al*., 2004). Olesen *et al*. (2007)observed that as opposed to cereals, legumes have the potential to improve grain yield in succeeding cereal crops.Nitrogen from organic manure is better utilized for plant uptake than that from inorganic fertiliser because of its slow release during decomposition. As nitrogen is gradually let out of green manure as it decomposes, this may possibly reduce nitrogen leaching, run-off, loss due to vaporization and increase nitrogen uptake efficiency, thereby increasingcrop yield (Aulakh *et al*., 2000). After decomposition of green manure, the bound organic phosphorus and potassium may be provided ina form that is readily available to crops that succeed (Eichler-Löbermann *et al*., 2009).

Cultivation of green manure, especially those with root system that is well-developed can reduce the occurrence of compacted layers of soil through breakage and thereby increase water infiltration. Soil compaction is caused by intensive farming equipment, which limits water infiltration into the soil and increase surface run-off and erosion (Rosolem *et al*., 2002). The production of dry matter by green manure increases theproportion of organic matter in the soil, which thereafter enhancesthe physical

properties of the soil by improving the porosity, moisture and plant nutrients retention and decreasing soil density.

Also, green manure has the ability to boost microbial activity, decrease the prevalence of pests and diseases and also to suppress weeds (Fageria *et al*., 2005). Living organisms form part of soil components whose waste products are sources of nourishment and energy to the soil. The population and activities of these organisms are usually promoted by the presence of organic materials (Lavelle and Spain, 2001).Green manure, when utilized in place of fallow, has the potential to prevent erosion and subsequently reduce soil nutrients loss (Gaston *et al*., 2003). The use ofgreen manure as fallow also has the ability to suppress weeds (Burgos and Talbert, 1996) and specific crop pests (Bugg *et al*., 1990).

2.8 *Indigofera hirsuta*

The genus *Indigofera* is a member ofFabaceae family, sub-family Papilionoideae and contains about seven hundred species of flowering plants, making it the third largest genus among legumes (Soladoye *et al*., 2010). It is indigenous to Africa and Asia and commonly known as hairy Indigo. In Nigeria, the local names are 'aniyaa, makoomiyaa' in Hausa**,** **'**iwele mmuo' in Igbo and 'elu aja' in Yoruba (Burkill, 1995).The species *I. tinctoria* and *I. suffruticosa*are grown in many countries for the production of indigo dye and medicinal purpose (Puri *et al*., 2007; Luiz-Ferreira *et al*., 2011).

2.8.1 Distribution of *I. hirsuta*

Indigofera is a plant that originated in Africa and Asia and is currently well-established and acclimatized in south of Australia and parts of tropical America (US Forest Service, 2010). In Africa, it occurs naturally in Senegal, Sudan, Congo, Zambia, Mozambique, Angola and Madagascar. It can also be found in the wild in southern Asia, northern Australia, and Queensland, as well as being extensively grown and acclimatized in tropical America and different places of the globe(FAO, 2013; PIER, 2013).

In Nigeria, sixty species of *Indigofera* were recorded with twenty seven species (45%) distributed across the Southwestern area. They occurred abundantly in the

country's northern regions, with the majority of their species inhabiting the savanna ecological zone (Soladoye and Lewis, 2003). It was originally utilized in Malaysia in 1913, when it was grown as a green manure in Bogor in the 19thcentury. It is now being cultivated throughout the tropics (Faridah and van der Maesen, 1997).

2.8.2 Habitat and ecology of *I. hirsuta*

It is frequently found in agricultural areas, dry and deciduous forests, savannah, grassland, waste areas, on river banks and beaches at altitudes not higher than 1500 m. It requires an annual rainfall, 900-2500 mm,average temperature of 15-28°Celsius and not frost tolerant. Although,it thrives on well-drained soils with a pH of 5-8, but it can endure poor soil conditions and thrives in moderately poor, sandy soils with a low pH. Flowering and seed development is stimulated in the dry season and it is intolerant to waterlogging (PIER, 2013).

In Nigeria, it is prevalent in the savanna ecological zone but sparsely distributed in the rainforest zone (Soladoye and Lewis, 2003) while in Madagascar, it is found in disturbed and cultivated humid areas (Puy *et al*., 2002). The species is found in grassland, roadsides, open slopes, sandy ground near shores in Papua New Guinea, China and Taiwan, and also along roadsides, second-growth forest and open areas in Puerto Rico (PIER, 2013).

2.8.3 Description of *I. hirsuta*

Indigofera hirsuta is a herb that grows upright or spreads out, or sub-shrub which completes its entire lifecycle within the space of a year.It grows as high as 1.5 m or shorter (Plate 2.1). Its stem is cylindrical, densely covered with hairs throughout both vegetative and reproductive parts (FAO, 2013). Stipules are narrowly triangular to linear and setaceous, 10-12 mm long (Faridah and van der Maesen, 1997). Leaves are usually compound, imparipinnate with five to seven, and occasionally nine leaflets, arranged oppositely. The leaflets are oval in shape; grow as long as 40 mm and 25 mm in width, with both surfaces covered with hairs. Petioles are 1–2 cm while petiolules are as long as 1.5-3 mm and heavily covered in hair (Mattapha and Chantaranothai, 2012). Apex is

rounded or obtuse; base is wedge-shaped, while margin is covered with long shaggy hairs.

Plate 2.1: *Indigofera hirsuta* bush showing the imparipinnate compound leaves

Inflorescence is made of dense flowered racemes which are 10-30 cm long and densely hairy. Flowers are vexillary and up to 6 mm long. Bracts are lanceolate or linear-triangular, approximately 4 mm long with the apex, narrowing to a slender point; margin is covered with long hairs, heavily covered with hair outside and hairless inside. The stalks are about 2 mm long, covered with hair. Calyx is about 4 mm long with lanceolate and setaceous lobes, acuminate apex, villous margin, and heavily hairy outside and hairless inside. The flower petals are either pink or red in colour, elliptical in shape, 5 by 3 mm, obtuse apex, cuneate base, villous margin and white pubescent outside and glabrous inside. Wings are 5 mm by 1.5 mm, they possess rounded apex, ciliate margin, densely hairy at outside and hairless inside. Ovary is hairy with 5-9 ovules. Pods are straight, cylindrical, dehiscent, 14-16 mm long, with well-developed suture and long spreading hairs. Seeds are cuboid, 1 by 1 mm, brown and smooth (Faridah and van der Maesen, 1997; Mattapha and Chantaranothai, 2012).

2.8.4 Uses of *Indigofera hirsuta*

Indigofera species are grown as ornamentals, plants for indigo dye, and herbal medicine in many places throughout the world (Ellison, 1999). The two most prevalent species; *I. tinctoria* and *I. suffruticosa* are being utilized in the production of indigo dye. Dyes made naturally are more ecologically friendly and resistant to sun and washing than dyes made of chemicals (Angelini *et al*., 1997).

Indigofera hirsuta is a useful plant used as green manure in*Camellia sinensis*,*Coffea* spp and *Hevea brasiliensis* plantations, among othersin Asia. Hairy indigo used as forage and green manure was discovered to have potential for managing nematodes that affect soybean in Alabama (Rodrı´guez-Ka´bana *et al*., 1989).It can as well serve as cover crop, especially in places prone to erosion. It was utilized as a crop for soilprotection and enrichment in citrus orchards in Florida. Also, as a yearly fodder, it was used as a feed crop in Florida and Brazil, where it was mixed with grasses.

Indigofera hirsuta also has ethno-medicinal effects. It was investigated to be one of the commonly used medicinal plants for the management of inflammatory conditions in African traditional medicine (Musa *et al*., 2012). In Philippines, the leaves are used to make a decoction that is used to treat stomach issues and yaws, backache, sores and for liver complaints, epilepsy and convulsion in infants (Burkill, 1995). *Indigofera hirsuta* has been utilized as dye in some western countries of Africa (Djarwaningsih, 1997).

2.8.5 Growth and development of *Indigofera hirsuta*

Seeds are used in the propagation of*Indigofera hirsuta*. The seeds germinate after 7-9 days unevenly to give percentage germination that is often low. Its sprouting can be aided by soaking the seeds in hot water or exposing them to acids. Seeds thrive when sown at 1 cm depth or when broadcast. Seedling rates of 3-5 kg/ha is recommended for drilling in a closely spaced rows and 6-10 kg/ha for broadcasting in a seed bed that has been fully firmed. The seedlings grow very slowly at early stage, which made weeding necessary only after four to six weeks of planting, when it's possible to tell the difference between plants and weeds (Portillo *et al*., 2009).

Under favourable conditions, the plants reach a height of 30 cm about 50 days after planting, after 65 days, the height reaches 60 cm, and 90 cm after about 80 days. It bloomsas the growing season draws to a close, resulting in a green manure of high quality or food for animals before seed maturity. Insects are responsible for pollination. In a symbiotic relationship with cowpea-type rhizobium, hairy indigo fixes atmospheric nitrogen.

2.9 *Amaranthus cruentus*

*Amaranthus cruentus*L. is a leafy vegetable, indigenous to America but now spreads around the world and popularly cultivated in Nigeria (Olaniyi, 2007; Law-Ogbomo and Ajayi, 2009). It ispart of to theAmaranthaceae family and genus *Amaranthus.*In total, there are roughly 60 species of *Amaranthus* (Grubben and Denton, 2004). The cultivation of *A. cruentus* dates back to 6700 BC and as such, It is one of the oldest nourishment sources on the planet(RSA, 2010).In places like Africa, India, and

Nepal, it has been grown for food consumption as grain or leaves (Olaniyi, 2007;Law-Ogbomo and Ajayi, 2009).

Amaranthus cruentus species are annuals that are either straight or spreadand about 0.3-1 m long. The stem is longitudinally grooved, thick and tough. It is a dicotyledonous plant with green or purple leaves, variable in size. The leaves are simple and alternate, with slender stalks and entire margins. The tips are pointed and the flowering part is feather-like with raceme diameter of 10mm or greater (Schippers, 2000). Flowers are tiny green, white, pink or purplish in colour, densely borne in spikes usually at the tips of the branches. Seeds are usually small,egg-shaped with an arrow end at the base, shiny black or whitish to yellowish in colour (Grubben, 2004).

Growth of *A. cruentus*is influenced by many factors, such as agronomic, climatic and edaphic (Tongos, 2016).*A. cruentus* seeds require soil temperatures of 18 to 25 degrees celsius to sprout, and air temperatures of 25 degrees celsius or higher for maximum growth. When thetemperature is below 18 degrees celsius, growth stops. Compared to most vegetables, *A. cruentus* is reported to be tolerant to drought due to its ability to wilt temporarily during extremely dry conditions and then revive after rainfall occurs. Its exposure to severe drought has been reported to induce early flowering and halt leaves production. Due to the relatively low capacity for water consumption, the crop cannot withstand waterlogging (Department of Agriculture, Forestry and Fisheries, 2010).The ideal soil for an early and high yield of *A. cruentus* is crumbly and loose, having high organic matter content. It may grow in a number of soil types, but it thrives insoils with a high nutrient content and well-drained. For germination and emergence in a short amount of time, *A. cruentus* requires a sufficient amount of soil moisture and good seed-soil contact while for growth; it requires a soil pH of 6.4 to produce high yields (Department of Agriculture, Forestry and Fisheries, 2010).

Amaranthus cruentus is propagated from seeds. For highest germination, it is necessary to plant seeds at a depth not deeper than 1.25 cm. Theseedlings are always fragile at the initial stage, so it is essentialthat the seed bed is topographically firm (Department of Agriculture, Forestry and Fisheries, 2010). The seed rate for the cultivation of *A. cruentus* was reported to be between 2-3 kg per hectare (Rai and Yadav,

2005).However, Sokoto and Johnbosco (2017) reported that the seed rate for *A. cruentus* cultivation for grain purpose is 1.5 kg per hectare area, due to the required wider spacing. Broadcasting method is usually used due to the size of the seeds being very small. The seeds are mixed with sand, broadcast in the seedbed and then lightly covered with soil. Broadcasting ensures even distribution. Seeds can also be sown into the soil directly. In this case, the soil is loosened to the greatest depths, to set up a smooth seedbed. Seeds are sown in shallow rows 1.5 m apart and covered lightly with soil. Another method of planting *A. cruentus* is by planting in seed trays and transplanting after 3-4 weeks. Transplanting is normally done using spacing of 1.5 m by 0.3 m. vegetable planter can also be used (van Rensburg*et al*., 2007).

Amaranthus are divided into four types; vegetable, grain, ornamental and weed.The grains can be popped like popcorn, cooked as cereal or ground into flour for baking (Adewole and Dedeke, 2012). *Amaranthus* species are usually cultivated for grains and green leaves, while few species occur in the wild (Sokoto and Johnbosco,2017). They are considered as a food crop with great potential due to its ability to resist pest and diseases, drought and heat. It was also reported to have high nourishment(Rastogi and Shukla, 2013). Prakash and Pal (1991) reported that vegetable *Amaranthus*is equivalent or even superior to spinach (*Spinacia oleracea*), which is very rich in protein, ascorbic acid, and carotenoids.*Amaranthus* species are cultivated in large amount in Nigeria. Its ability to survive when intercropped with other arable crops and early maturity make it to remain the most preferred vegetable crop by a large number of farmers. The farmers see its cultivation as source of revenue generation and survival while waiting for other arable crops to mature (Makinde, 2012).

There have been several written reports on theutilization of *Amaranthus*species for medicinal intentions in Africa.*Amaranthusgraecizans* was reported to be useful in manufacturing local salt by drying and burning the plants to ashes. This local salt can be used as an alternative for common salt. The leaves are also chewed to treat tonsillitis in Uganda and as an anthelmintic in Senegal (Maundu and Grubben, 2004). AVRDC (2011) reported that in pregnant women and their newborns, folic acid in *Amaranthus*decreases the likelihood of neural abnormalities. The roots are used as a laxative for newborns

when heated with honey in Senegal; the water from macerated plants of *A. cruentus* is used in washing the limbs to treat pains and used in expelling tapeworm from the body and heated leaves were used on tumors and the ash from the stems for dressing wounds (Sokoto and Johnbosco, 2017).The seed of *Amaranthus*is rich in lysine and methionine which are on many occasions not found in other grains. These essential amino acids play important roles in prevention and treatment of osteoporosis, a disease that result to bone having tendency to fracture (Pisarikova *et al.,* 2005). It was also reported that *Amaranthus* decreases blood pressure and cholesterol levels when consumed on a regular basis (Olaniyi, 2007; Olaniyi *et al*., 2008).In persons with hypertension and cardiovascular illness, the usage of *Amaranthus cruentus* as an effective alternative to medication therapy is being investigated Martirosyan *et al*. (2007).

In Africa south of the sahara desert, the average leaf yield of *A.cruentus* was reported to be less than 1.2 tonne/ha while the potential yield reported by Oluoch *et al*.(2009) was 32-40 t/ha.*Amaranthus cruentus*can be grown many times in a year because it has short production cycle.It has a high yield, is nutrient-dense, and has a low production cost.It also requires less moisture than almost other crops and survives in dry and warm habitatowing to its possession of broad root system (Stallknecht *et al*., 1990).

In Nigeria, *A. cruentus* is widely cultivated as leafy vegetable (Smitha, 2010). The grain and vegetable types of *A. cruentus* can not be clearly differentiated (Olaniyi, 2007). Leafy *Amaranthus*are sources of minerals, vitamins, protein (23-25%) and higher grain protein (13-19 %)(Grubben and Denton, 2004).Alegbejo (2013) reported that vegetable *Amaranthus*contains considerably higher amount of calcium, minerals, iron, phosphorus and carotenoids than most vegetables but less attention has been given to it compared to grain *Amaranthus*. In the past, *A. cruentus*was mainly used for its grains (Grubben, 2004) but presently, its leaves serve as vegetable, consumable by both human and animals (Trucco and Tranel, 2011). *Amaranthus cruentus*leaves, with condiments are used in preparing soup in Nigeria and Congo (Dhellot *et al*., 2006; Mepha *et al*., 2007).

One of the major nutrients, limiting the growth of vegetables is nitrogen (Qiang *et al.,* 2014). To obtain highest fresh leaf yield of *Amaranthus*, 70 kilograms Nitrogen, 34 kilograms Phosphorus and 26 kilograms Potassium per hectare was recommended by

Denton and Olufolaji (2000).Nitrogen, unlike other macro nutrients, is accessible to plants in two forms; ammonium or nitrite (Olfati *et al.*, 2012). The form of the available nitrogen as well as the level supplied to plants has substantialmpacts on plantperformance (Sun *et al.,* 2014). Also, the response of plants to a particular nitrogen form deviates from species to species (Zhou *et al.,* 2011).The essential nutrients: nitrogen, phosphorus and potassium help in the maintenance of plants quality and performance (Nakano and Morita, 2009; Hafsi *et al*., 2011). Nitrogen is a vital nutrient that plays a crucial function in chlorophyll formation, photosynthesis and stomatal conductance that are responsible for a reasonable percentage of yields of crops (Ivonyi *et al*., 1997).

Nitrogen has been discovered to be the primary limiting factor of production of *Amaranthus*; therefore, growing*A. cruentus* requires knowledge of the impact of nitrogen fertilisation on its yield (Pospisil *et al*., 2006). The problem of low nitrogen content of soils in Nigeria is usually solved with the addition of synthetic nitrogen fertilisers to increase crop yield. However, the synthetic fertilisers have negative consequencies on the ecosystem. Contamination of groundwater is one of the harmful consequences (Olowoake and Ojo, 2014). They are also expensive and often not accessible to the peasant farmers (Okwu and Ukanwa, 2007).

*Amaranthus cruentus*requires soil organic content and adequate soil nutrient, especially nitrogen for highest growth and yield (Olowoake and Ojo, 2014). As a result of this, organic based fertilisers from green manure, particularly nodulating legumes appear to be dependableowing totheir capability to fix nitrogen from the atmosphere into the soil (Egberongbe *et al*., 2017).

CHAPTER THREE

MATERIALS AND METHODS

3.1 Study Area

3.1.1 Location

Floristic survey was conducted at the University of Ibadan Teaching and Research Farm, Lapite-Akinyele, Ibadan and Ologuneru-Ido, Ibadan. Other studies such as germination test, phenology, effect of planting density and green manure potential of *I. hirsuta*were conducted at the Department of Crop Protection and Environmental Biology, University of Ibadan, Ibadan, Nigeria. Laboratory experiments were conducted at the Ecology Research Laboratory, and the pot experiments were carried out in both the screenhouse and field plots, in theCrop Garden of the Department. Ibadan is positionedonlatitude of 7˚26′ N and longitude of 3˚ 54′ E inthe forest-savanna transition ecology of Southwestern Nigeria (Awodoyin and Ogunyemi, 2005).

3.1.2 Geology

The mainparent rock types in Ibadan are basement complex rocks of pre-Cambrian age (Gbadegesin and Olabode, 2000). In the northwest- southeast direction, ridges of hills run with the largest at the central part of the city. The height above sea level(a.s.l) ranges from 160 to 275 m.

3.1.3 Climate

Ibadan is characterised by the West African monsoon, indicating a noticeable seasonal change in wind patterns. Ibadan has an annual average temperature of 27°C while rainfall ranges from 1270 to 1505 mm with 60-80% relative humidity (Gbadegesin and Olabode, 2000; Raheem and Adeboyejo, 2016).

3.1.4 Soils

The soils of Ibadan are mainly those derived from underlaying complex rocks. The dominant soil types are Egbeda, Iwo, Okemesi with several other soil series (Smyth and Montgomery, 1962).

3.1.5 Vegetation

The vegetation of Ibadan consists of secondary forests and forest-savanna transition,and the land uses include farmlands and bush fallows. Previous areas covered with high forest plant species are now dominated by secondary regrowths and invasive herbaceous species. The invasive weed species include*Andropogon tectorum*(savanna grass), *Imperata cylindrica*in younger fallows and the presence of surviving forest species such as the *Elaeis guineensis* in older fallow regrowth (Egbinola *et al*., 2014).

3.2 Assessment and enumeration of population of *I. hirsuta* in natural ecosystem within Ibadan, Nigeria

The population of *I. hirsuta* and populations of other weed species were assessed by conducting floristic survey in some areas where the species was spotted in Ibadan. The areas are:

1) the Teaching and Research Farm,University of Ibadan, with Latitude 7º 27′ 18.2′′ N, Longitude 3º 53′ 29.2′′ E and elevation of 193 m.
2) Lapite-Akinyele, with Latitude 7º 33′ 21.6′′ N, Longitude 3º 54′ 37.3′′ E and elevation of 194 m.
3) Ologuneru-Ido, with Latitude 7º 29′ 88′′ N, Longitude 3º 42′ 33.7′′ E and elevation 185 m.

Surveys were carried out when vegetation had been well established in the ecosystem in July, 2016 and 2020 (wet season) and in February, 2017 and 2021 (dry season). The sampling technique used to assess the population was x-y ordinate random sampling. A plot of 15 m × 15 m was marked out within each sampled area. Sampling units were identified by using series of random numbers (1 to 15), written in papers. A pair of papers containing random numbers was drawn one after the other, each time returning the paper. The first represented the distance on the x-ordinate baseline while the second represented

the distance on the y-ordinate baseline, which was perpendicular to the first baseline. With these two numbers, the positions of sampling units were fixed within the plot.

A quadrat, measuring 0.5 m × 0.5 m, was laid randomly and all weed species having roots inside each quadrat were identified according to the procedures described byAkobundu *et al*. (2016). Individuals of each plant species were counted and recorded. The results were used to compute the absolute and relative frequency, absolute and relative density and relative importance value.

Absolute Frequency (AF) = Number of quadrats that contained the particular species in relation to the total quadrats sampled.

Relative Frequency (RF) $=\frac{f}{F} \times 100$, where f = frequency of a weed species and F = frequency of all weed species.

Absolute density (AD) = $\frac{\text{Number of individuals of particular weed species}}{Area\ (m^2)}$

Relative density (RD) = $\frac{d}{D} \times 100$, where d = density of individual weed species and D = density of all weed species.

Relative Importance Value (RIV) = $\frac{RF+RD}{2}$ (Wentworth *et al*., 1984; Kent and Coker, 1992; Awodoyin and Olubode, 2009; Awodoyin *et al*., 2013).

3.2.1 Measure of species diversity

Data collected were used to estimate species abundance, richness and evenness, using Shannon-Wiener Index (*H′*) and Equitability Index (J′). Statistical analysis was done by using PAleontological STatistic software Version 3.0 (PAST) of Hammer *et al*.(2011).

3.2.2 Shannon-Wiener Index (*H′*)

This indexblends species richness (S) and relative abundance, calculated as:

$H' = -\sum_{i=1}^{S} p_i \ln p_i$ (Kent and Coker, 1992).

Where $p_i = (n_i/N)$, S = species richness (the total number of species in the plot)

n_i = number of individuals of a species, N = total numberof speciesin the community.

3.2.3 Equitability Index (J′)

This is a measure of species evenness, computed as:

$E = \frac{H'}{\ln S}$(Whittaker, 1975).

where H'= Shannon-Wiener Index, S total number of species in the community.

3.3Experiment 1: Germination of seeds of *I. hirsuta*

Seeds of *I. hirsuta* were obtained from mature plants in the crop garden, Department of Crop Protection and Environmental Biology, University of Ibadan, Nigeria in 2016.A germination study was carried out in 2016 and 2017 at Ecology Laboratory of the department.

3.3.1 Acid scarification of seeds of*I.hirsuta*

The seeds (Plate 3.1) were collected from mature pods. Seeds were removed from their pods as soon as they were collected and kept in sealed paper bags. Seeds were steeped in concentratedtetraoxosulphate (VI) acid (H_2SO_4) for 10, 20, 30, 40, 50 and 60 minutes, representing treatments 1, 2, 3, 4, 5 and 6, respectively, inside glass beakers; the untreated seeds served as control (treatment 7) (Awodoyin and Egberongbe, 2010). The seeds were carefully removed from the beakerat the end of each test duration. They were then rinsed immediately with running tapwater to stop the chemical reactions and to remove every trace of acid from the seeds. After thorough washing, seeds (n = 20)were placed on filter paper in each Petridish, andarrangedon the benchin a completely randomized design (CRD) using four replicates per treatment. Distilled water was used to moisten the filter paper and the Petri dishes inspected daily for radicle protrusion. All seeds that germinated were discarded daily from the Petridishes and recorded for seven days. Mean germination was determined and percentage germination was evaluated as:

$$\text{Germination (\%)} = \frac{\text{Total number of seeds that germinated}}{\text{Total number of seeds placed in Petri dish}} \times 100$$

Plate 3.1: Seeds of *Indigofera hirsuta*

3.3.2 Effect of storage of acid-scarified seeds of*I. hirsuta* on germination

This research was conducted between January 2017 and April 2018. Seeds of *I. hirsuta*were collected and treated with H_2SO_4acid. The seeds were steeped in the acid for 10 minutes (as it was established earlier to be the best duration for highest germination), rinsed with running tap water, air-dried andthen kept in paperenvelopes at room temperaturefor 32 weeks. The viability of the acid-treated seeds was recorded at four-week intervals. Seeds (n = 20) wereseton filter papers in Petridishes. Each treatment was set up in triplicates with fresly-treated serving as the control and arranged in completely randomized design.The filter papers were adequatelymoistened daily with distilled water and germination of seeds recorded daily based on the protrusion of the radicle. Number of seeds that germinated was recorded as a cumulative number at seven days.

3.3.3 Effect of sowing depth on germination of acid-scarified seeds of *I.hirsuta*

The study was carried out in January, 2017. The pot experiment was carried out at the screenhouse of the Department of Crop Protection and Environmental Biology, University of Ibadan, following the method of Awodoyin and Ogunyemi (2005). Seeds of *I. hirsuta* steeped in concentrated H_2SO_4 for 10 minutes were used.Fifteen experimental pots (28-cm surface diameter,30 cm depth) were filled with 5 kg top soil, collected from the crop garden. The pots were arranged in a completely randomized design. Two seeds per hole were sown at varying soil depths: 0, 1, 2, 3 and 4 cm.With the use of a dribbling stick, holes were made through the soil in each pot to the specified depth. The pots were adequately watered to the field capacity. Excess water drained off from the perforations at the bottom of the pots. Germination, taken as emergence of the plumule, was recorded as a cumulative number at seven days after sowing. Mean and percentage germination were calculated.

3.4 Experiment 2: Phenology and growth of *I. hirsuta*

The experiment was carried out between September, 2017 and May, 2018. Acid-scarified seeds (n = 3) of *I. hirsuta* were sown in 21 pots arranged in a completerandomized design.The seedlingswerethinned to one per pot at two weeks after

the seeds were sown.The plants were watered daily. At two-week intervals for 14 weeks, three pots were chosen at randomfor the evaluation of growth and dry matter accumulation by recording the following data:

i) Height, takenfrom the ground surface to its shoot apex, using a meter ruler;

ii) Stem diameter at 2 cm above the groundsurface (using a Vernier caliper);

iii) Number of leaves(by visual counting);

iv) Shoot dry weight (using a weighing balance);

v) Root dry weight (using a weighing balance);

vi)Number of nodules (by visual counting); and

vii) Number of effective nodules (by visual counting).

To determine the stem and root dry weights, the pots were emptied by lifting out each plant into acontainer filled with water to loosen the soil.The plant stem branches were detached from the roots of plants, wrapped, and placedin the oven to dry to a constant weight at 80º C. After oven-drying, the samples wereweighed on a top-loading Mettler balance model P1210to determine the dry matter.

3.5 Experiment 3: Effect of planting density on*I. hirsuta* performanceand weed-suppressing ability

The field study was conducted between June, 2017 and January, 2018. An area of land covering 16.5 m × 10 m was marked out. The land was prepared and five test densities were randomly allocated to plots measuring 2 m × 2 m each. Adjacent plots and blocks were separated by 0.5and 1 m, respectively.The experiment was set upin a randomized complete block designusing three triplicates. Planting densities were generated based on previous study established that the plant density range 4-16 plants/m^2. Seeds (n=2) of *I. hirsuta* were sown manually at 1 cm soil depthand 20 cm inter-row spacing, while intra-row spacings varied, viz. 10, 20, 40, 80 and 160 cm. Planting densities were determined as follows:

D1 = 50 plants/m^2 (500,000 plants/ ha) ---------- 20 cm×10 cm;

D2 = 25 plants/m^2 (250,000 plants/ ha) ---------- 20 cm × 20 cm;

D3 = 12.5 plants/m^2 (125,000 plants/ ha) ---------- 20 cm × 40 cm;

D4 = 6.25 plants/m^2 (62,500 plants/ha) ---------- 20 cm × 80 cm;

D5 = 3.125 plants/m^2 (31, 250 plants/ha) ---------- 20 cm × 160 cm; and
D0 = 0 plants/m^2 (Control).

Plants were thinned to oneat two weeks of planting,whileweeds in all the plots were removed at 4 weeks after planting by manual hand-pulling. At harvest, five plants wereselectedrandomly from each plot for assessment. The height of the plants was assessed by taking measurement of themain stem from ground to the tip, using a meter ruler. The diameter of the stem was determined at 2 cm from the ground surface, using a Vernier caliper. The numbers of branches and leaveswere recorded visually. Shoot dry weight was measured, using weighing balance. Shoot dry weight was estimated by clipping the plants with a secateur at the soil surface and oven-dried at 80°C to a constant weight. The oven-dried shoots were weighed on a top loading mettler balance (model P1210).

3.5.1 Assessment of weed spectrum

Weed spectrum was assessed by layingone 0.5 m^2 quadrat at random within each plot, including the control plots, at 14 weeks after sowing for assessment and enumeration of weeds to species level. All weeds that rooted within the quadrat were identified, counted and clipped at the surface of the soil. The weeds were oven-driedat 80˚C and the weight was measured to determine the dry matter. The frequency, density and relative importance value for each weed species were estimated according to previous procedures (see Section 3.2)

3.6 Experiment 4: Green manure potentials of *I. hirsuta* and effect on performance of *A. cruentus.*

3.6.1 Pot experiment

This research was carried out between January and June, 2018.*A. cruentus* seeds were obtained from the National Horticultural Research Institute (NIHORT), Ibadan, Nigeria.Fifteen pots were filled with 5-kg top soil, collected from the Crop Garden. At two-week intervals, acid-scarified seeds of *I. hirsuta* were sown in three pots. This was

done for six weeks and the plants were left for four weeks using the following treatments which were arranged in a completely randomized design:

0 treatment(Control);

4weeks treatment(Planting done at week 6);

6 weeks treatment (Planting done at week 4);

8 weeks treatment (Planting done at week 2); and

10 weeks treatment(Planting done at the onset of experimentation).

At week 10, all the plant shoots were choppedand incorporated within the topsoil into the soil to decompose for three weeks. After three weeks of green manure decomposition, soil samples were collected from each treatment for laboratory analysis and *A. cruentus* seeds were sown into soil medium.At week 2, three plants of *A. cruentus* were selected and marked from each pot and the growthparameters listed belowwere recorded at two-week intervals thereafter for six weeks. The main trial was followed up by a residue trial.

Plant height

With the use of a meter ruler, the height of each of the three plant samplesin each pot was determined by recording the length of *A. cruentus* stem from the ground surface to the terminal bud.

Stem diameter

The stem diameter of the plant samples from each pot was determined by using digital vernier caliper at 2 cm from the ground level and,their average was recorded.

Number of leaves

The number of leaves on plant samples was enumerated visually, andtheir average was recorded.

Leaf area

The leaf area was calculated by multiplying the length and width of each individual leaf of the plant samplesby a factor of 0.64 (Kolawole and Sarah, 2009).

Fresh weight

At harvest(week 6), fresh weight of the plant samples were determined by weighing with top-loading mettlar balance.

3.6.2 Field experiment

This research was carried out between January and June, 2018. An area of land covering 7 m × 9 m was cleared and 15 vegetable beds, measuring 1 m × 1 m were made. The beds were laid out in a randomized complete block design with five treatments using three replicates. The distance between adjoining beds and blocks were 0.5 and 1 m, respectively (Figure 3.1). At two-week intervals, three beds were selected and acid-scarified seeds of *I. hirsuta* were planted at 20 cm × 40 cm spacing. This was done for six weeks and the plants were left for four weeks, to give the following treatments:

0 treatment (Control);

4weeks treatment (Planting done at week 6);

6 weeks treatment (Planting done at week 4);

8 weeks treatment (Planting done at week); and

10 weekstreatment(Planting done at the onset of experimentation).

At week 10, all the plant shoots were cut and buried within 0-10 cm depth in the soil to decompose. At week 3, each treatment had soil samples taken for routine analysis in the laboratory and seeds of *A. cruentus* were sown at 30 cm × 40 cm spacingin each plot (plate 3.2). At week 2, four plants were selected from each bed and growth parameters were recorded at two-week intervals thereafter as above (see Section 3.6).

3.7 Soil analysis

Soil samples wereair-dried, sieved through a 2-mm meshand used for thefollowing analyses at the Department of Agronomy, University of Ibadan, Nigeria:

3.7.1 Particle size distribution

Fifty grammes (50 g) of air-dried soil was measured and put into metal dispersing cup and 20 ml of 2.5 N sodium hexametaphosphate $(NaPO_3)_6$ was poured to the dispersing cup, which was then filled to two inches of the brim with distilled water and

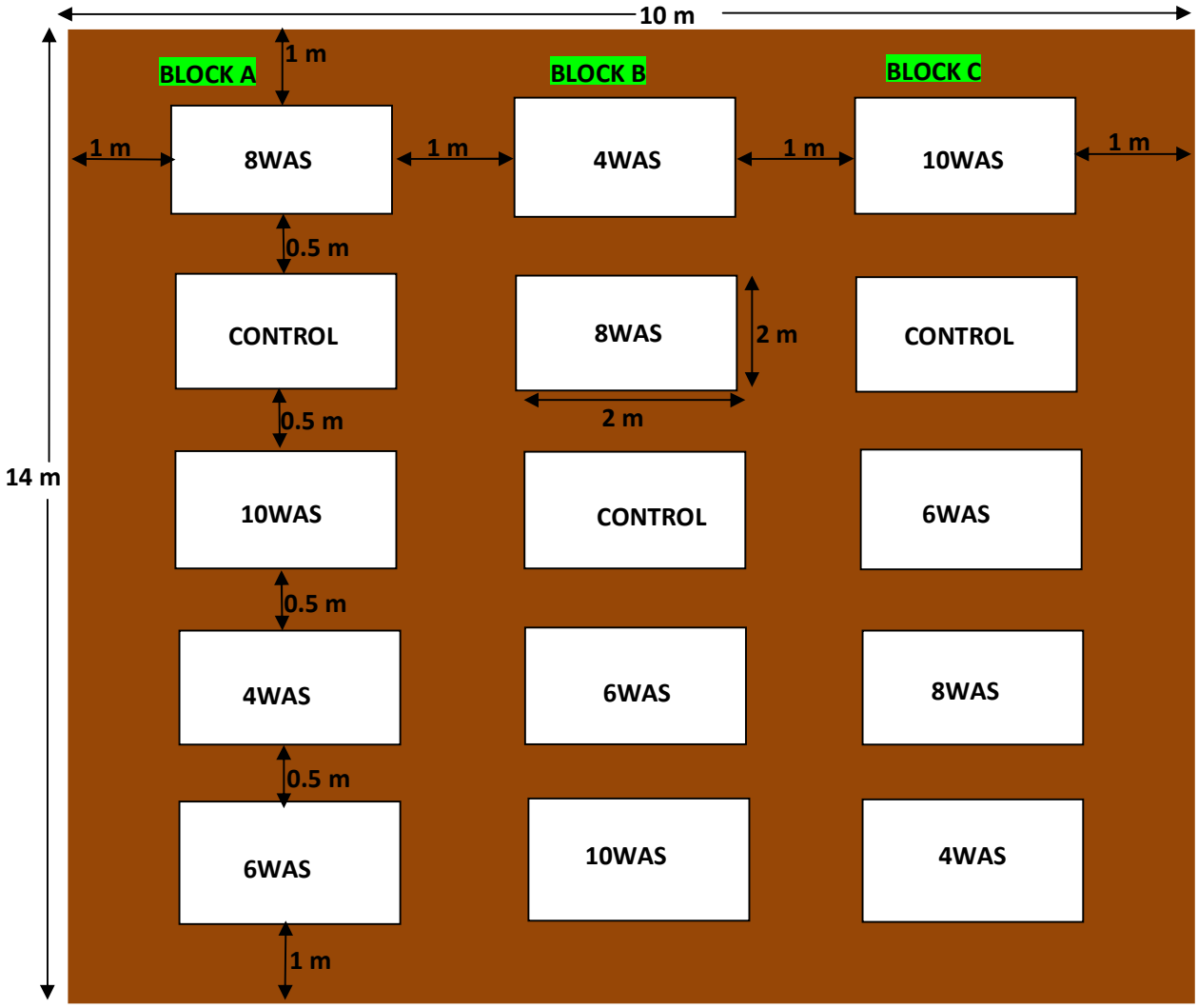

Figure 3.1: Experimental layout of the effect of *Indigofera hirsuta*manure on growth and yield of*Amaranthus cruentus*.WAS = weeks after sowing

Plate 3.2: Effect of green manure of *Indigofera hirsuta*on *Amaranthus cruentus* in a field study at the crop garden, Department of Crop Protection and Environmental Biology, University of Ibadan.

set aside for ten minutes. The dispersing cup was gently fastened to the mixer and swirled for a period of five minutes. From the dispersing cup, the sample (soil and solution) was conveyed quantitatively into a bouyoucos cylinder (Gee and Bauder, 1986).

The cylinder was filled with distilled water to 1000 ml mark.A rubber stopper was placed at the cylinder's end and vigorously agitated by spinning it end to end.The hydrometer was gently put into the mixture 40 seconds after the cylinder was laid down after all of the soil material had been resuspended.

The reading on the hydrometer was taken.The quantity of silt and clay that remained suspended after the sand particles settled was determined by a 40-second reading. The hydrometer was cautiously put into the suspension when the 2-hour settling period is over, and the reading was recorded. Following both hydrometer readings (40 seconds and 2 hours), the temperature of the suspension was measured and recorded.
Calculations:

Grammes of sand = soil weight - 40 second reading.

Grammes of silt + clay = 40 seconds reading.

Grammes of clay = 2 hours reading.

Grammes of silt = 40 second reading - 2 hours reading.

% sand = (grammes of sand/Weight after drying in the oven) x 100

% clay = (grammes of clay/Weight after drying in the oven) x 100

% silt = 100-(% sand + % clay)

3.7.2 Soil pH

Soil pH in H_2O (1:1)

Ten grammes of soil wereweighed into beakers using the standard digital weighing balance.Distilled water (10 mls) were dispensed into it. It was left standing for 15 minutes. After 5 minutes of vigorous stirring, it was left to stand for another 10

minutes.The pH reading was taken using a pH meter that was made standard with buffer solutions of pH 4.0 and 7.0 (Page *et al*., 1982).

Soil pH in 1N KCl (1:1)

Ten grammes of soil were weighed into beakers using the standard digital weighing balance. One N KCl was dispensed into it. It was left standing for 15 minutes. After 5 minutes of stirring, it was leftto stand for another 10 minutes.The pH reading was taken using a pH meter with a buffer solution of pH 4.0 and 7.0 as a standard (Page *et al*., 1982).

3.7.3 Organic matter

An empty, clean, and dry porcelain dish was weighted and result recorded (M_1). A 5-g soil sample was weighed and transferredinto the porcelain dish and dried for 2 h at 105^{o}C and the dish's masstogether with the dried soil (M_2) was determined and recorded.The dish was put in a muffle furnace, which was gradually heated to 440 degrees Celsius. It was left in the furnace overnight.The tongs were used to delicately remove the porcelain dish, which was then placed in a desiccatorto bring the temperature down to normal. The weight of the ash-filled dish or burnt soil (M_3) was determined and recorded (Brady, 1985).

Mass of dried soil(M_D) =M_2- M_1

Mass of the ashed or burnt soil(M_A) =M_3-M_1

Mass of organic matter(M_O) = M_D – M_A

% Organic matter (OM) = $\frac{M_O}{M_D} \times 100$

3.7.4 Soil organic carbon

Soil samples were pulverized fine enough to pass through a 0.5-mm-mesh sieve and then 2g of each of the sample was transferred to the bottom of a clean and dry conical flask. Ten millilitres of 1N $K_2Cr_2O_7$ was accurately dispensed into the flask using the Custom Laboratory Dispenser. Twenty millilitres of concentrated H_2SO_4 was dispensed

using an automatic pipettor into the suspension and swirled vigorously for one minute. This was done inside a fume hood and the time of addition was recorded. It was left standing for 30 minutes, then distilled water (100 ml) was added with the Custom Laboratory Dispenser and mixed well. Small portions of the solutions were filtered using a Whatman filter paper No. 2 into 50 ml vials. Brinkman probe colorimeter was read using 4 cm probe and 650 nm filter with the blank set at 100% T and converted to % absorbance using the conversion table (Walkley-Black, 1934).

3.7.5 Total nitrogen in soil

Two grammes of air-dried soil was weighed and passed through 0.5 mm sieve into a 250 ml digestion tube. Twenty millilitres digestion mixture (95ml concentrated orthophosphoric acid into 2-litre volumetric flask and made to volume with concentrated H_2SO_4 and one Kjeldahl tablet was added (each tablet contains 1g of Na_2SO_4 and equivalent of 0.05g Se).The rack of tubes was placed in the 20 block digestor and digested at 370°C for 3 hours.

The rack was removed from the digestor and cooled.Distilled water (100 ml) was added and stirred vigorously.It was cooled and diluted with 250 ml distilled water. It was shaken 10 times and when cleared, the liquid was poured into the autoanalyzer sampler cups.The manifold cartridge of the autoanalyser was set up; the sampler IV wash receptacle contained 8% H_2SO_4. The baseline was established with all reagents pumping and set at 0% on the chart. Steady state was run for 3 minutes using a standard of 20µg N/ml.The peak height was set at 40% chart divisions. Sample probe was returned to wash cycle for 3 minutes, 0 baseline was rechecked, the sampler was started and the 20µg N/ml standard and readjusted standard was aspirated 3 times. The sample tray was loaded with the N standards 5, 10, 15, 20 and 25µg N/ml,after that comes three sample cups containing wash solution and then the unknown sample solutions (Technicon Instruments Corporation, 1971).

Calculation

$$\% \text{ Total nitrogen in soil or g N per 100g of soil} = \% \frac{\text{chart reading} \times 0.5 \times 250 \times 100}{2 \times 10^6}$$

= % chart reading × 0.00625

3.7.6 Available phosphorus in soil

A solution of 0.025N HCl and 0.03N NH_4F(Bray-1 extractant) was used to extract the available phosphorus in the soil.One gramme of soil and ten milliliters of extractant were shaken for five minutes before being passed through Whatman filter paper No 2. Threemillilitres of the filterate were pipetted into 10ml test tube, 3ml of ammonium molybdate ($(NH_4)_6\ MO_7O_{24}$), 0.5% Boric acid (H_3BO_3) and 75 ml HCl were added.

Five drops of sodium sulphate (Na_2SO_4), sodium metabisulphite and 1-amino-2-sulfuric acid was also added. It was left to stand for 30-45 minutes. The quantity of phosphorus obtained was determined by quantifying the intensity of the blue color generated in the filtrate after treatment with an ammonium molybdate-hydrochloric acid solution and subsequently an aminonaphthol-sulfonic acid solution. An absorption spectrophotometer set to 640 nm was used to determine the colour (Bray and Kurtz, 1945).

3.7.7 Exchangeable Ca, Mg, K, Na and effective cation exchange capacity in soil determination

Fivegrammes of sample were weighed and transferred into an extraction cup. Thirty millilitres of 1N NH_4OAc was added using a Custom Laboratory Dispenser.It was stirred for 15 minutes on a mechanical stirrer (1550 rpm). The soil suspension was left standing for 15 minutes, before passing through a filter. Each sample was diluted 25 times with 1N NH_4OAc as diluent using the Custom Laboratory Dilutor. Atomic absorption spectrophotometer was used for reading Ca and Mg, while flame photometer was used for Na and K (Uehara and Gillman, 1981).

Calculation:

Effective CEC = Ca +Mg +K + Na + Al + H in me/100g

To convert from µg/g to me/100g/200.4 for Ca; 121.6 for Mg; 391.0 for K; and 229.9 for Na

3.7.8 Exchangeable acidity determination

Tengrammes of soil allowed to dry out naturally with air weremeasured into Erlenmeyer flask and 100 ml of 0.5N $BaCl_2$ –triethanolamine solution was introduced. It was stirred and set aside for 24 hours.The flask's contents were transfered into a Buchner funnel lined with filter paper.It was filtered and rinsed with $BaCl_2$ –triethanolamine solution multiple times till a volume of 190 ml was obtained.Before adding the next component of the solution, each portion was allowed to drain. Two to three drips of indicator wereapplied and leachate was titrated with 0.1N HCl to the endpoint of the indicator.A blank containing an equal volume of $BaCl_2$-triethanolamine solution was also titrated (Mclean, 1965).

Calculation:

$$\text{Exchangeable Acidity: meq/100 g} = (Vb - Vs) \times N \times \frac{100}{\text{sample wt. (g)}}$$

where Vb = ml of HCl required to titrate blank to end point;

Vs = ml of HCl required to titrate soil sample extract to end point; and

N = normality of HCl.

3.8 Data analysis

All data wereanalysed, using descriptive ststistics and one-way analysis of variance (ANOVA). Mean separation were made at 5% level of probability using the Fisher's Least Significant Difference (LSD) test.

CHAPTER FOUR

RESULTS

4.1 Enumeration of the population of *Indigofera hirsuta* in relation to other weed species in selected ecosystem.

4.1.1 Teaching and Research Farm, University of Ibadan

In the first survey, carried out in the wet season (July, 2016), a total number of 438 weed species, belonging to 20 plant taxa were identified. The most important of the species were *Tridax procumbens*, *Leptochloa caerulescens* and*Gomphrena celosioides*, while other weeds encountered were relatively not important(Table 4.1).

Also, from the second survey, which was conducted in the dry season (February, 2017), 209 weeds belonging to 14 plant taxa were enumerated. *Tridax procumbens*, *Leptochloa caerulescens*, *Indigofera hirsuta* and *Cleome viscosa* were the most important weed species while the other weed species were not important (Table 4.1).

Species richness (number of species) varied between the two seasons. During the wet season, there were a total of 20 species (Table 4.1) contrasting the 14 species recorded during the dry season. Shannon-Wiener Indices ($H^{'}$) were 2.11 and 1.98 and Equitability indices ($J^{'}$) were 0.71 and 0.75,for the wet and dry seasons, respectively(Tables 4.1).

4.1.2 Lapite Farmland, Akinyele, Ibadan.

In the first survey, carried out in the wet season (July, 2020), a total of 355 weeds, belonging to 37 plant taxa were counted in the surveyed area. The onlyimportant species was *Euphorbia hirta*. From the second survey, which was conducted inthe dry season (February, 2021), 67 weeds belonging to 14 plant taxa were enumerated. *Tridax procumbens*had the highest RIV which was distinctly superior to the less important *E. hirta*. Other weed species were relatively not important (Table 4.2).

Table 4.1: Relative Frequency, Relative Density and Relative Importance Value of Weed Species at the Teaching and Research Farm, University of Ibadan in July, 2016 and February, 2017.

		WET SEASON			DRY SEASON		
Weed Species	Family	RF*	RD	RIV	RF	RD	RIV
Acalypha ciliata Forsk.	Euphorbiaceae	2.00	0.91	1.48	0.00	0.00	0.00
Andropogon tectorum Schum. & Thonn	Poaceae	0.00	0.00	0.00	4.76	1.91	3.34
Calopogonium mucunoides Desv.	Fabaceae	1.02	0.46	0.74	10.71	9.09	9.90
Cleome viscosa L.	Cleomaceae	0.00	0.00	0.00	10.71	11.48	11.10
Cyperus esculentus Linn.	Cyperaceae	0.00	0.00	0.00	4.76	1.91	3.34
Desmodium scorpiurus (Sw.) Desv.	Fabaceae	11.22	5.71	8.47	0.00	0.00	0.00
Eleusine indica (L) Gaertn.	Poaceae	2.04	0.46	1.25	0.00	0.00	0.00
Gomphrena celosoides Mart.	Amaranthaceae	11.20	16.44	13.83	0.00	0.00	0.00
Imperata cylindrica (Linn.) Raeuschel	Poaceae	0.00	0.00	0.00	7.14	2.87	5.01
Indigofera hirsuta Linn.	Fabaceae	11.22	2.51	6.87	15.48	12.44	13.96
Ipomoea triloba Linn.	Convolvulaceae	1.02	0.23	0.62	0.00	0.00	0.00
Kyllinga erecta Schumach	Cyperaceae	3.06	1.14	2.10	0.00	0.00	0.00
Leptochloa caerulescens Steud.	Poaceae	11.22	25.11	18.17	11.90	9.57	10.74
Leuceana leucocephala (Lam.) de Wit	Fabaceae	1.02	0.23	0.62	0.00	0.00	0.00

Mariscus alternifolius Vahl	Cyperaceae	1.02	2.74	1.88	0.00	0.00	0.00
Merremia aegyptia (Linn.) Urban	Convolvulaceae	0.00	0.00	0.00	3.57	1.44	2.50
Oldenlandia herbacea (Linn.) Roxb.	Rubiaceae	7.14	11.42	9.28	0.00	0.00	0.00
Passiflora foetida Linn.	Passifloraceae	2.04	0.46	1.25	0.00	0.00	0.00
Phyllanthus amarus (Schum. &Thonn.) Learndri	Euphorbiaceae	8.16	2.97	5.57	4.76	3.35	4.06
Rhynchospora corymbosa (Linn.) Britt.	Cyperaceae	4.08	3.20	3.64	0.00	0.00	0.00
Sida acuta Burn.	Malvaceae	1.02	0.23	0.62	2.38	0.96	1.67
Sesamum indicum Linn.	Pedaliaceae	2.04	0.91	1.48	0.00	0.00	0.00
Solanum torvum Swartz.	Solanaceae	0.00	0.00	0.00	3.57	2.87	3.22
Spermacoce ocymoides Burm. F.	Rubiaceae	4.08	0.91	2.50	2.38	0.96	1.67
Talinum fructicosum (Jacq.) Willd	Portulacaceae	1.02	0.23	0.62	2.38	0.96	1.67
Tridax procumbens Linn.	Asteraceae	14.29	23.74	19.02	17.86	40.19	29.03

Community structure	Wet season	Dry season
Number of species (richness)	20	14
Shannon-Wiener Index (*H′*)	2.11	1.98
Equitability (J)	0.70	0.75

*RF= Relative frequency, RD= Relative density, RIV= Relative importance value.

Table 4.2: Relative Frequency, Relative Density and Relative Importance Value of Weed Species at Lapite Farmland, Akinyele, Ibadan in July, 2020 and February, 2021.

		WET SEASON			DRY SEASON		
Weed species	Family	RF*	RD	RIV	RF	RD	RIV
Alternanthera sessillis (Linn.) DC.	Amaranthaceae	4.59	2.82	3.70	0.00	0.00	0.00
Andropogon tectorum Schum. & Thonn.	Poaceae	1.83	1.69	1.76	4.76	2.98	3.87
Axonopus compressus (Sw.) P. Beauv.	Poaceae	5.50	10.99	8.25	9.52	7.45	8.49
Boerhavia erecta Linn.	Nyctaginaceae	0.92	0.28	0.60	0.00	0.00	0.00
Brachiaria falcifera (Trin.) Stapf	Poaceae	0.92	0.56	0.74	4.76	4.47	4.62
Calopogonium mucunoides Desv.	Fabaceae	3.67	2.54	3.10	4.76	2.98	3.87
Centrosema pubescens Benth.	Fabaceae	1.83	0.85	1.34	4.76	2.98	3.87
Corchorus olitorius L.	Tiliaceae	2.75	12.68	7.71	0.00	0.00	0.00
Cyperus rotundus Linn.	Cyperaceae	5.50	2.54	4.02	9.52	7.45	8.49
Dactyloctenium aegyptium (Linn.) P. Beauv.	Poaceae	0.92	0.56	0.74	0.00	0.00	0.00
Desmodium scorpiurus (Sw.) Desv.	Fabaceae	0.92	1.97	1.44	0.00	0.00	0.00
Digitaria horizontalis Willd.	Poaceae	0.92	0.28	0.60	0.00	0.00	0.00
Eragrostis tenella (Linn.) P. Beauv. Ex. Roem & Schult	Poaceae	1.83	1.41	1.62	0.00	0.00	0.00
Euphorbia heterophylla Linn.	Euphorbiaceae	6.42	8.45	7.44	0.00	0.00	0.00
Euphorbia hirta Linn.	Euphorbiaceae	12.84	13.52	13.18	9.52	11.92	10.72
Fimbristylis ferruginea (Linn.) Vahl	Cyperaceae	1.83	1.13	1.48	0.00	0.00	0.00
Gomphrena celosioides Mart.	Amaranthaceae	1.83	2.54	2.18	0.00	0.00	0.00
Hyptis suaveolens Poit	Lamiaceae	0.92	1.41	1.16	0.00	0.00	0.00
Icacina trichanta Oliv.	Icacinaceae	0.92	0.28	0.60	0.00	0.00	0.00
Indigofera hirsuta Linn.	Fabaceae	5.50	1.69	3.60	9.52	5.96	7.74
Ipomoea involucrata P. Beauv.	Convolvulaceae	2.75	3.38	3.07	0.00	0.00	0.00
Mariscus alternifolius Vahl	Cyperaceae	4.59	4.23	4.41	0.00	0.00	0.00

Merremia aegyptia (Linn.) Urban	Convolvulaceae	1.83	0.85	1.34	0.00	0.00	0.00
Mimosa diplotricha C. Wright ex Sauuville	Fabaceae	0.92	0.56	0.74	0.00	0.00	0.00
Oldenlandia lancifolia (Schumah) DC.	Rubiaceae	0.92	0.56	0.74	0.00	0.00	0.00
Pennisetum purpureum (Schumach) Morrone	Poaceae	0.92	0.56	0.74	0.00	0.00	0.00
Phyllantus amarus (Schum. & Thonn.) Learndri	Euphorbiaceae	1.83	0.85	1.34	7.14	8.94	8.04
Pupalia lappacea (Linn.) Juss.	Amaranthaceae	0.92	0.28	0.60	0.00	0.00	0.00
Senna hirsuta (Linn.) Irwin & Barneby	Fabaceae	0.92	0.28	0.60	0.00	0.00	0.00
Sida acuta Burn. f.	Malvaceae	2.75	3.66	3.21	0.00	0.00	0.00
Sida cordifolia Linn.	Malvaceae	1.83	0.85	1.34	7.14	8.94	8.04
Spigelia anthelmia Linn.	Loganiaceae	1.83	0.85	1.34	0.00	0.00	0.00
Sporobolus pyramidalis P. Beauv.	Poaceae	2.75	3.10	2.93	2.38	1.49	1.94
Talinum fruticosum (L.) Juss.	Portulacaceae	4.59	6.76	5.67	7.14	7.45	7.30
Tithonia diversifolia (Hemsl.) A. Gray	Asteraceae	3.67	3.38	3.52	0.00	0.00	0.00
Trianthema portulacastrum Linn.	Aizoaceae	0.92	0.28	0.60	4.76	2.98	3.87
Tridax procumbens Linn.	Asteraceae	3.67	1.41	2.54	14.29	23.84	19.06

Community structure	Wet season	Dry season
Number of species (richness)	37	14
Shannon-Wiener Index (*H´*)	3.03	2.40
Equitability (J)	0.39	0.91

*RF= Relative frequency, RD= Relative density, RIV= Relative importance value.

Species richness varied between the two seasons. During the wet season, there were a total of 37 species contrasting the 14 species during the dry season (Table 4.2). Shannon-Wiener Indices ($H^{'}$) were 3.03 and 2.40, and Equitability indices ($J^{'}$) were 0.39 and 0.91, for the wet and dry seasons, respectively (Table 4.2).

4.1.3 Ologuneru-Ido, Ibadan.

In the first survey, carried out in the wet season (July, 2020), a total number of 480 weeds, belonging to 33 plant taxa were identified. The only important species was *E. hirta* while other weed species were relatively not important (Table 4.3).

Also, from the second survey, which was conducted in the dry season (February, 2021), 71 weeds belonging to 15 plant taxa were enumerated. *Tridax procumbens* and *Cyperus esculentus* were relatively most important, while other weed species had relatively low importance(Table 4.3). Species richness varied between the two seasons. During the wet season, there were a total of 33 species contrasting the 15 species in the dry season. Shannon-Wiener Indices (H') were 2.83 and 2.46, and Equitability indices ($J^{'}$), 0.81 and 0.91 for the wet and dry seasons, respectively (Table 4.3).

4.2 Effect of concentrated H_2SO_4 on germination of *I. hirsuta* seeds

Observation showed that germination of acid-scarified seeds of *I. hirsuta* commenced after one day, while in the control (untreated seeds), germination commenced after four days of sowing. At seven days, mean germination of the seeds scarified with the acid increased and reached a peak in the seeds treated for 10 minutes, though not significantly different ($p = 0.05$) from the mean germination under 20 to 30 minutes steeping (Table 4.4). Thereafter, germination decreased rapidly to a distinct minimum under 60 minutes of soaking. The mean germination of the untreated seeds (control) was considerably ($p = 0.05$) less than those of treated seeds. During the second trial, germination was also at a peak under 10 minutes of soaking, but this decreased significantly ($p = 0.05$) with increasing duration of soaking to the lowest under 60 minutes of soaking (Table 4.4).

Table 4.3: Relative Frequency, Relative Density and Relative Importance Value of Weed Species at Ido, Ibadan in July, 2020 and February, 2021.

		WET SEASON			DRY SEASON		
Weed species	Family	RF*	RD	RIV	RF	RD	RIV
Acalypha fimbriata Schum. & Thonn.	Euphorbiaceae	1.83	0.63	1.23	4.08	2.82	3.45
Andropogon tectorum Schum. & Thonn.	Poaceae	3.67	1.25	2.46	8.16	5.63	6.90
Axonopus compressus (Sw.) P. Beauv.	Poaceae	0.92	0.21	0.56	4.08	2.82	3.45
Brachiaria lata (Schumach.) C. E. Hubbard	Poaceae	4.59	3.13	3.86	4.08	2.82	3.45
Calopogonium mucunoides Desv.	Fabaceae	4.59	2.50	3.54	10.20	7.04	8.62
Centrosema pubescens Benth.	Fabaceae	3.67	1.25	2.46	6.12	5.63	5.88
Chrysanthellum indicum (Linn.) Vatke var. afroamericanum Turner	Asteraceae	0.92	0.21	0.56	0.00	0.00	0.00
Commelina erecta L.	Commelinaceae	1.83	1.46	1.65	0.00	0.00	0.00
Cyperus haspan Linn.	Cyperaceae	3.67	6.04	4.86	4.08	2.82	3.45
Cyperus esculentus Linn.	Cyperaceae	0.92	3.13	2.02	8.16	19.72	13.94
Dactyloctenium aegyptium (Linn.) P. Beauv.	Poaceae	3.67	2.08	2.88	0.00	0.00	0.00
Digitaria horizontalis Willd.	Poaceae	3.67	15.42	9.54	0.00	0.00	0.00
Digitaria longiflora (Ret.) Pers.	Poaceae	6.42	8.33	7.38	0.00	0.00	0.00
Euphorbia heterophylla Linn.	Euphorbiaceae	4.59	10.42	7.50	0.00	0.00	0.00
Euphorbia hirta Linn.	Euphorbiaceae	9.17	16.67	12.92	8.16	7.04	7.60
Gomphrena celosioides Mart.	Amaranthaceae	4.59	2.71	3.65	0.00	0.00	0.00
Indigofera hirsuta Linn.	Fabaceae	0.92	0.21	0.56	6.12	4.23	5.17
Ipomoea involucrata P. Beauv.	Convolvulaceae	1.83	0.42	1.13	0.00	0.00	0.00
Ipomoea vagans Bak.	Convolvulaceae	0.92	0.21	0.56	0.00	0.00	0.00
Ipomoea verticillata Forssk.	Convolvulaceae	0.92	0.42	0.67	0.00	0.00	0.00
Mariscus flabelliformis Kunth var.	Cyperaceae	2.75	2.71	2.73	0.00	0.00	0.00

flabelliformis							
Merremia aegyptia (Linn.) Urban	Convolvulaceae	0.92	0.21	0.56	4.08	2.82	3.45
Mimosa diplotricha C. Wright ex Sauuville	Fabaceae	3.67	1.46	2.56	0.00	0.00	0.00
Mimosa pudica Linn.	Fabaceae	2.75	1.04	1.90	0.00	0.00	0.00
Phyllantus amarus (Schum. & Thonn.) Learndri	Euphorbiaceae	3.67	2.92	3.29	6.12	9.86	7.99
Sida acuta Burn. f.	Malvaceae	6.42	6.88	6.65	8.16	5.63	6.90
Solanum torvum Swartz	Solanaceae	2.75	1.04	1.90	0.00	0.00	0.00
Spigelia anthelmia Linn.	Loganiaceae	2.75	0.83	1.79	0.00	0.00	0.00
Sporobolus pyramidalis P. Beauv.	Poaceae	0.92	0.21	0.56	4.08	2.82	3.45
Synedrella nodiflora Gaertn.	Asteraceae	2.75	2.08	2.42	0.00	0.00	0.00
Trianthema portulacastrum Linn.	Aizoaceae	0.92	0.21	0.56	0.00	0.00	0.00
Tridax procumbens Linn.	Asteraceae	4.59	2.92	3.75	14.29	18.31	16.30
Vernonia cinerea (Linn.) Less.	Asteraceae	1.83	0.83	1.33	0.00	0.00	0.00

Community structure	Wet season	Dry season
Number of species (richness)	33	15
Shannon-Wiener Index (*H′*)	2.83	2.46
Equitability (J)	0.81	0.91

*RF= Relative frequency, RD= Relative density, RIV= Relative importance value.

Table 4.4: Response of germination of seeds of *Indigofera hirsuta* to concentrated H_2SO_4 scarification at seven days after sowing in Ibadan, Nigeria in 2017.

Duration (minutes)	First Trial	Second Trial
0	0.50 ± 0.29 (2.5)*	0.75 ± 0.25 (3.8)
10	19.25 ± 0.48 (96.3)	18.25 ± 0.63 (91.3)
20	18.75 ± 0.25 (93.8)	17.50 ± 0.96 (87.5)
30	19.00 ± 0.58 (95.0)	16.50 ± 0.50 (82.5)
40	17.50 ± 0.75 (87.5)	14.75 ± 0.75 (73.8)
50	17.75 ± 0.48 (87.5)	12.25 ± 0.63 (61.3)
60	16.00 ± 0.71 (80.0)	10.00 ± 1.08 (50.0)
LSD (p = 0.05)	1.99	2.18

*Values are mean no. of germinated seeds ± standard error and percentage (in parenthesis). LSD (p = 0.05) is the least significant difference at 5% level of probability.

4.3 Effect of duration of storage of acid-scarified *I. hirsuta*seeds on germination

Acid-scarified seeds of *I. hirsuta* were highly viable for four months of storage. As duration of storage increased, mean germination reduced from a peak to a stable level from 2-4 months, and thereafter decreased distinctly to a minimum under 8 months storage (Table 4.5). A similar pattern was recorded in Trial 2, inspite of the shorter period of uniform germination (3-4 months).In both trials,seeds of *I. hirsuta* freshly treated with concentrated H_2SO_4 had considerably ($p = 0.05$) higher germination (98-100%),while the treated seeds stored for seven (21-25%) and eight (14-16%) months had considerably poor germination (Table 4.5).

4.4 Effect of sowing depth on *I. hirsuta* on emergence

Visual observation showed that radicles of scarified-seeds of *I.hirsuta*sown at 0, 1 and 2 cm depths started emerging two days after sowing. The total number of seeds that emerged from 1 and 2 cm depths was much larger than the number of germinated seeds emerged from other depths. At day seven after sowing, the seeds sown at 1 cm depth had 100% emergence in both the first and second trials but this reduced significantly to the lowest at 4 cm soil depth in both trials. Seedlings emergence decreased by less than 50% at 3 cm soil depth in the first trial, contrasting the second trial in which less than 50% reduction in seedling emergence occurred at 4 cm soil depth. Seedlings emergence from the 4 cm soil depth was distinctly low in both trials (Table 4.6).

4.5 Phenology and growth of *I. hirsuta*

Acid-scarified seeds of *I. hirsuta* germinated after 24 hours of sowing (Plate 4.1). This was evident by the protrusion of radicle through the seed coat. Radicle elongation continued till the third day, after which the plumule emergedwith the first pair of leaves. The second pair of leaves emerged on the sixth day after sowing while the leaflets started to emerge at two weeks after sowing.

Stem elongation occurred within the third and sixth week after sowing. During this period, leaf bases began to clearly separate from each other. This was followed by branching at six weeks after sowing.

Table 4.5: Effect of duration of storage of acid-treated seeds of *Indigofera hirsuta* on its germination at seven days after sowing

Storage Duration (month)	First Trial	Second Trial
0 month	19.50 ± 0.29 (98)*	20.00 ± 0.00 (100)
1month	18.75 ± 0.63 (94)	19.25 ± 0.25 (96)
2 months	16.75 ± 0.48 (84)	17.25 ± 0.48 (86)
3months	17.00 ± 1.47 (85)	15.75 ± 0.95 (79)
4 months	17.00 ± 1.29 (85)	16.25 ± 0.85 (81)
5months	14.75 ± 0.85 (74)	14.50 ± 0.65 (73)
6 months	12.00 ± 0.91 (60)	12.00 ± 0.91 (60)
7months	4.25 ± 1.32 (21)	5.00 ± 1.08 (25)
8 months	2.75 ± 0.85 (14)	3.25 ± 1.11 (16)
LSD ($p<0.05$)	2.83	2.28

*Values are mean no. of germinated seeds ± standard error and percentage (in parenthesis). LSD ($p = 0.05$) is the least significant difference at 5% level of probability.

Table 4.6: Effect of depth of sowing on seedling emergencein*I. hirsuta* at seven days after sowing.

Depth (cm)	First Trial	Second Trial
0	7.00 ± 0.58 (70)*	8.33 ± 0.33 (83)
1	10.00 ± 0.00 (100)	10.00 ± 0.00 (100)
2	9.33 ± 0.33 (93)	9.67 ± 0.33 (97)
3	4.67 ± 0.67 (47)	6.00 ± 0.33 (60)
4	1.67 ± 0.33 (17)	3.00 ± 1.00 (30)
LSD (p = 0.05)	1.41	1.56

*Values are mean no. of germinated seeds ± standard error and percentage (in parenthesis). LSD (p = 0.05) is the least significant difference at 5% level of probability.

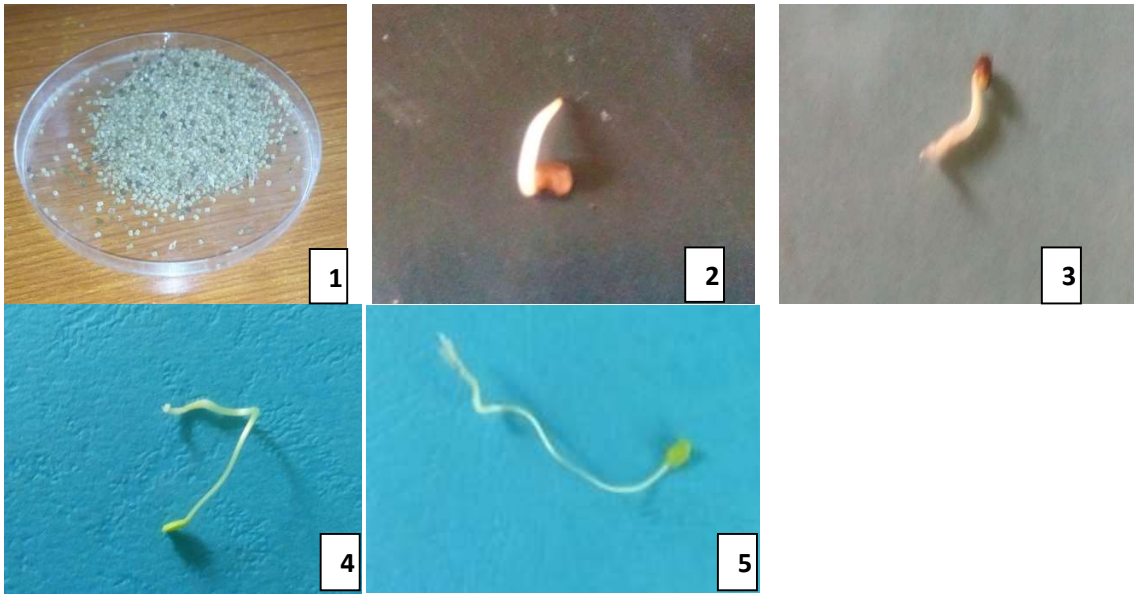

Plate 4.1: Stages of seed germination of *I. hirsuta*(1) seeds in Petri dish; (2) emergence of radicleat day one after sowing; (3) elongation of radicle at day two after sowing; (4) emergence of plumule and cotyledon at day three after sowing; (5) elongation of plumule and cotyledon at day four after sowing.

Flowering commenced at the nineth week aftersowing while fruits emerged at week 12 after sowing (Plate 4.2)and began to mature at week 15 after sowing.

The growth and development of *I. hirsuta* increased as number of weeks increased (Tables 4.7 and 4.8). The growth was slow at the initial stage (the first two weeks) and became rapid between week two and four. The height, stem diameter, leaf number, branch number, root length, nodule number, effective nodule number, shoot and root dry weight, and total dry weight increased while the week advanced after planting (Tables 4.7 and 4.8).

Height

The height increased significantly at two weeks interval till the twelfth week. The heights at week 12 were not significantly different from the height at week 14. At week 14 after sowing, the plant reached the greatest height in first and second trials (Table 4.7).

Stem diameter

The stem diameter increased significantly at two weeks interval till the tenth week. The growth of stem diameter remained the same at weeks 12 and 14. The highest stem diameters were attained at week 12 in the first and second trial (Table 4.7).

Number of leaves

The number of leaves at weeks 2 and 4 were considerably not different in the first and second trials, but differed considerably ($p = 0.05$) from week 6-12 and at week 14, the differences were not significant from week 12. However, the number of leaves recorded at the 14^{th} week was highest (Table 4.7).

Number of branches

The number of branches between week two and four were also not considerably ($p = 0.05$) different in the first and second trials. Number of branches increased significantly between weeks 6 and 10, thereafter, there were no substantial variations. The branch reached the maximum number at week twelve in first and second trials (Tables 4.7).

Plate 4.2: Reproductive stages (a flowering, b fruiting) of development in*Indigofera hirsuta*

Table 4.7: Growthof *I. hirsuta* over a period of 14 weeks in Ibadan, Nigeria.

Week	Height (cm)	Diameter (cm)	Number of leaves	Number of branches	Root length (cm)
			First trial		
2	5.85 ± 0.33*	0.00 ± 0.00	5.50 ± 0.50	0.00 ± 0.00	3.18 ± 0.21
4	16.53 ± 0.94	0.18 ± 0.03	14.00 ± 0.58	0.00 ± 0.00	7.90 ± 0.37
6	20.50 ± 0.72	0.38 ± 0.05	96.25 ± 6.79	8.00 ± 1.80	16.20 ± 0.74
8	26.35 ± 0.60	0.60 ± 0.07	140.25 ± 13.08	16.75 ± 1.38	21.88 ± 0.75
10	34.35 ± 0.49	0.80 ± 0.04	307.25 ± 4.82	27.75 ± 0.85	31.73 ± 0.17
12	42.65 ± 1.24	0.83 ± 0.03	344.50 ± 14.95	29.25 ± 0.25	34.85 ± 0.76
14	43.38 ± 1.73	0.83 ± 0.04	346.25 ± 15.17	28.00 ± 1.68	35.10 ± 0.26
LSD (p = 0.05)	2.64	0.12	29.29	2.87	2.02
			Second trial		
2	5.58 ± 0.26	0.00 ± 0.00	5.75 ± 0.25	0.00 ± 0.00	2.88 ± 0.14
4	16.28 ± 0.25	0.15 ± 0.03	13.50 ± 0.50	0.00 ± 0.00	7.55 ± 0.24
6	21.10 ± 0.51	0.35 ± 0.03	99.00 ± 4.42	8.25 ± 0.75	16.28 ± 0.25
8	25.73 ± 0.41	0.60 ± 0.04	144.00 ± 10.49	16.50 ± 1.26	21.93 ± 0.43
10	33.30 ± 0.30	0.78 ± 0.03	300.50 ± 4.27	27.75 ± 0.85	32.03 ± 0.55
12	41.20 ± 0.92	0.85 ± 0.03	337.50 ± 12.39	28.75 ± 1.85	34.85 ± 0.25
14	42.48 ± 0.66	0.85 ± 0.03	347.50 ± 11.79	28.50 ± 1.85	34.65 ± 0.85
LSD (p = 0.05)	1.54	0.08	23.33	2.87	1.32

*Values are means ± standard error.

Root length

Root length increased significantly (p = 0.05) till week 12. The variation was not considerably (p = 0.05) high between week 12 and 14 (Table 4.7). In the first trial, highest root length was reached at week 14 and in the second trial, the highest was reached at week 12.

Number of nodules and effective nodules

The numbers of nodule and effective nodules number at weeks two and four were not considerably (p = 0.05) different in both trials. The number of nodules were considerably (p = 0.05) higher at week 12. The nodules began to become effective from week 4, though the effectiveness was still low. The number of effective nodules began to increasesignificantly from week six and was highest at week 10 during the trial's first and second phase, respectively. The number of effective nodules reduced significantly at week 12 in the first trial and at week 14 in the second trial (Table 4.8).

Shoot, root and total dry weight

The dry weights of the shoot, root, and total at week two were considerably similar to those at week 4 in both trials. The shoot dry weight varied significantly between weeks 6 and 14. The shoot dry weights at weeks 2 and 4 were significantly lower than other weights. Highest shoot dry weights were obtained at week 12 and week 14 in the first and second trials. The root dry weight varied significantly from week 4-10 but not significantly different from week 10-14, in the first experiment. However in the second experiment, the variation was significant from week 4-14. The highest root dry weights were obtained at week 14 and 12. Highest total dry weight was obtained at the 14th week (Table 4.8).

4.6 Effects of planting densities of *I. hirsuta*on growth and its ability to suppress weeds

The effect of varying densities on the performance of *I. hirsuta* showed that only the plant height was directly related to the density while the stem diameter, number of branches, number of leaves, shoot dry weight and weight of associated weeds were inversely related to the density.

Table 4.8: Growth of *Indigofera hirsuta* over a period of 14 weeks in Ibadan, Nigeria.

Week	Number of nodules	Number of effective nodules	Shoot dry weight (g)	Root dry weight (g)	Total dry weight (g)
First trial					
2	3.25 ± 1.11*	0.00 ± 0.00	0.05 ± 0.01	0.01 ± 0.00	0.06 ± 0.01
4	10.00 ± 1.78	1.75 ± 1.03	0.83 ± 0.13	0.07 ± 0.01	0.90 ± 0.14
6	94.25 ± 5.22	46.00 ± 7.15	8.01 ± 0.48	2.88 ± 0.18	10.89 ± 0.63
8	130.00 ± 7.34	116.75 ± 9.53	17.95 ± 1.39	6.24 ± 0.45	24.19 ± 1.62
10	361.25 ± 19.34	346.50 ± 18.85	33.84 ± 1.38	12.38 ± 0.73	46.22 ± 1.36
12	412.00 ± 25.28	123.00 ± 4.44	60.20 ± 0.63	12.47 ± 0.36	71.72 ± 0.83
14	382.75 ± 4.61	103.25 ± 3.82	57.04 ± 1.10	13.95 ± 1.22	70.99 ± 1.07
LSD ($p<0.05$)	37.19	25.66	2.65	1.72	2.88
Second trial					
2	4.00 ± 1.23	0.00 ± 0.00	0.05 ± 0.00	0.01 ± 0.00	0.06 ± 0.00
4	10.00 ± 1.41	1.50 ± 0.65	0.82 ± 0.12	0.10 ± 0.02	0.91 ± 0.14
6	96.50 ± 3.52	34.00 ± 2.45	7.88 ± 0.44	2.56 ± 0.22	10.41 ± 0.42
8	124.25 ± 2.84	109.00 ± 6.86	17.09 ± 1.12	5.40 ± 0.22	23.00 ± 1.00
10	324.50 ± 11.21	313.50 ± 11.44	31.42 ± 0.54	10.85 ± 0.27	44.16 ± 0.32
12	389.75 ± 4.01	126.50 ± 4.19	59.97 ± 0.55	11.35 ± 0.10	70.82 ± 0.67
14	387.50 ± 2.22	103.00 ± 2.97	60.49 ± 0.24	12.74 ± 0.54	71.84 ± 0.21
LSD ($p<0.05$)	14.52	16.14	1.62	0.77	1.49

*Values are means ± standard error.

Height

The difference among the mean height of plants at the various densities was significant except between densities 3.125 plants/m^2 and 6.25 plants/m^2 where the plants appeared shorter than plants in other densities. At density 50 plants/m^2, plant height was greatest and considerably ($p = 0.05$) greater than plants in other densities. The second trial followed the same trend (Table 4.9).

Stem Diameter

Stem diameter decreased as plant densities increased. The stem diameter of the plants also varied among the densities but variations were only significant ($p = 0.05$) among densities 3.125 plants/m^2, 25 plants/m^2 and 50 plants/m^2. The stem diameter of plants at density 3.125 plants/m^2 was considerably ($p = 0.05$) higher in comparison to the other mean stem diameters except stem diameter at density 6.25 plants/m^2, while those at 25 plants/m^2 and 50 plants/m^2 were significantly lower than other plant diameter. In the second trial, the stem diameter of plants at densities 3.125 plants/m^2 was considerably ($p = 0.05$) higher,compared to those at other densities except plants at density 6.25 plants/m^2. However, the diameter of plants at density 50 plants/m^2 was considerably ($p = 0.05$) lower than plants diameter at other densities.

In the second trial, at density 3.125 plants/m^2, the stem appeared greater than other densities but was considerably similar ($p = 0.05$) to density 6.25 plants/m^2. However, the stem diameter of the plants at density 50 plants/m^2 tended to be significantly lower than those of other densities. At lower population density, the plants stem diameter appeared to be significantly high but started to decrease with increase in density, making the plants stem diameter to appear significantly lower (Table 4.9).

Number of branches

For the first and second trials, the branch number varied significantly ($p = 0.05$) among the varying densities except between densities 6.25 plants/m^2 and 12.5 plants/m^2. The highest number of branch was obtained at density 3.125 plants/m^2, while the least were obtained at density 50 plants/m^2(Table 4.9).

Number of leaves

During the trial's first phase, the contrast between thenumberof leaves of *I. hirsuta* among varying densities was not significant except at density 3.125 plants/m^2, where the number of leaves was considerably ($p = 0.05$) greater than others. But in the second trial, the leaf number varied considerably ($p = 0.05$) among the densities. Density 3.125 plants/m^2gave highest number of leaves while density-50 plants/m^2 gave the lowest number of leaves (Table 4.9).

Shoot dry weight

The disparity in the dry weight of the shoot among the densities was significant in both first and second trials. At density-3.125 plants/m^2, the shoot dry weight was considerably ($p = 0.05$) greater than other densities while the shoot dry weight was considerably low at density-50 plants/m^2 for both first and second trials (Table 4.9).

Associated weeds

The planting density of *I. hirsuta*affected the growth of the associated weeds and yield of *I. hirsuta.* The highest density for weed suppression was D5 (50 plants/m^2)(Table 4.9). The dry weight of the weeds decreased as the density of *I. hirsuta* increased. The control plots gave the highest weed dry weight in the both trials which were considerably higher than the dry weight of weeds encountered at the varying densities. In the first trial, the dry weight of weeds at densities D1 (3.125 plants/m^2), D2 (6.25 plants/m^2) and D3 (12.5 plants/m^2) varied widely but they were not significantly different. At D4(25 plants/m^2), the weed dry weight was significantly lower than at other densities, except at D5 (50 plants/m^2) (Table 4.9).

From the survey carried out on associated weeds in the treated and control plots, a total of 16 weed species were enumerated and identified. In all the treated and control plots, the most important weed species were *Chromolaena odorata* and *Ageratum conyzoides* while the least important species were *Meremia aegyptia* and *Spilanthes costata*, as indicated by their relative importance values (RIV) (Table 4.10).

Table 4.9.: Effect of planting density of *I. hirsuta*on growth and dry matter accumulation at 14 weeks after planting in 2018

Density (plants/m^2)	Height (cm)	Stem Diameter (cm)	Number of Branches	Number of Leaves	Shoot Dry Weight (kg)	Weed Dry Weight (kg)
			First trial			
D0 (0)						1.84 ± 0.04
D1 (3.125)	81.17 ± 0.92*	0.97 ± 0.07	21.67 ± 1.20	182.67 ± 13.48	0.38 ± 0.00	1.41 ± 0.01
D2 (6.25)	81.60 ± 1.77	0.87 ± 0.03	18.67 ± 0.33	164.67 ± 9.96	0.31 ± 0.00	1.37 ± 0.01
D3 (12.5)	87.67 ± 1.33	0.80 ± 0.00	17.67 ± 0.33	155.00 ± 4.04	0.26 ± 0.00	1.34 ± 0.01
D4 (25)	93.57 ± 0.30	0.63 ± 0.03	12.67 ± 0.88	149.67 ± 0.88	0.23 ± 0.00	0.98 ± 0.03
D5 (50)	105.00 ± 1.73	0.53 ± 0.03	8.67 ± 1.33	141.67 ± 2.33	0.20 ± 0.00	0.55 ± 0.04
LSD (p = 0.05)	4.19	0.12	2.90	24.55	0.01	0.08
Second trial						
D0 (0)						1.91 ± 0.02
D1 (3.125)	77.30 ± 3.79	0.93 ± 0.03	22.00 ± 0.58	185.33 ± 3.53	0.38 ± 0.00	1.48 ± 0.01
D2 (6.25)	81.77 ± 0.63	0.90 ± 0.00	19.00 ± 0.00	170.33 ± 2.40	0.31 ± 0.00	1.37 ± 0.02
D3 (12.5)	88.00 ± 0.91	0.80 ± 0.00	17.67 ± 0.33	160.67 ± 1.20	0.27 ± 0.00	1.33 ± 0.01
D4 (25)	93.57 ± 0.83	0.67 ±0.03	12.00 ± 0.58	151.00 ± 0.58	0.23 ± 0.00	1.04 ± 0.03
D5 (50)	107.00 ± 3.06	0.57 ± 0.03	7.67 ± 0.88	142.67 ± 1.76	0.20 ± 0.00	0.59 ± 0.01
LSD (p = 0.05)	7.13	0.08	1.78	6.77	0.01	0.06

*Values are means ± standard error.

Table 4.10: Relative Importance Values (%) of associated weeds encountered across *I. hirsuta* planting density

Species	Control	D1*	D2	D3	D4	D5
Ageratum conyzoides	10.92	24.52	17.21	20.59	16.49	12.76
Asystasia gigentica	3.06	0.00	0.00	0.00	0.00	0.00
Alternanthera brasiliana	2.60	0.00	0.00	0.00	0.00	0.00
Celosia leptostachya	4.73	0.00	0.00	4.61	4.16	4.11
Chromolaena odorata	22.95	29.45	14.86	15.37	17.78	16.65
Commelina benghalensis	0.00	1.60	6.61	6.79	4.91	7.36
Ipomoea involucrate	2.89	2.03	16.99	9.42	4.70	4.98
Leptochloa filiformis	10.23	0.00	6.22	6.18	8.80	12.60
Mariscus alternifolius	2.35	6.83	5.48	7.84	5.66	3.66
Merremia aegyptia	2.81	0.00	0.00	2.28	1.50	1.76
Oldenlandia corymbosa	0.00	9.29	16.38	9.78	10.30	5.00
Passiflora foetida	4.90	0.00	0.00	0.71	4.70	5.02
Spilanthes costata	2.81	0.00	0.00	0.00	2.25	4.68
Talinum fructicosum	2.35	10.02	4.89	3.84	4.64	3.08
Tithonia diversifolia	12.39	1.60	2.82	5.11	8.73	13.03
Tridax procumbens	13.92	14.66	8.55	7.49	5.39	5.30

*D1 = 3.125 plants/m^2, D2= 6.25 plant/m^2, D3 = 12.5 plants/m^2, D4= 25 plants/m^2, D5= 50 plants/m^2, and Control = 0 plant/m^2.

Asystasia gigentica and *Alternanthera braziliana* were found only on the control plots. Fifteen out of the total sixteen species of weeds were found on the control plots, contrasting the treated plots in which weed species reduced steadily from a uniform peak from D4 down to the lowest at D1 (Table 4.11).Plots with the lowest *I. hirsuta* density (D1) had the least number of associated weed species and the lowest Shannon-Wiener Index. Plots with the highest density of *I. hirsuta* (D5) and D4, had the same number of weed species. The highest Shannon-Wiener and Equitability Indices were recorded from D5.

4.7: Effect of duration of *I. hirsuta* green manure on growth and yield of *A. cruentus*

4.7.1 Pot experiment

The results indicated that the growth parameters evaluated increased with the age of green manure (Table 4.12).There were considerable variations ($p = 0.05$) among *A. cruentus* grown in pots planted with *I. hirsuta* green manure of varying ages. The *A. cruentus* plants grown in the control pots was significantly ($p = 0.05$) shorter, thinner, with shorter and narrower leaves than those grown in pots where green manure were planted and incorporated. On the other hand, *A. cruentus* plantsgrown in pots where *I. hirsuta* was grown for eight and 10 weeks before incorporation were considerably ($p = 0.05$) taller, thicker, had more leaves which were longer and broader than those in other pots; they also had higher weights.

Height

In the main trial, the greatest height was reached at week six in pots incorporated with the 8 week-old green manure (Table 4.12). There were considerable variations in the height of *A. cruentus* among the treatments, from 2 to 6 weeks after sowing. At week 2 after sowing, the height of *A. cruentus* planted in pots incorporated with 10 week-old green manure was considerably ($p = 0.05$) greater than those planted in other pots. *A. cruentus* heights at weeks four and six in pots incorporated with for 8 and 10 week-old green manure, respectively, were significantly greater than others. The heights of *A. cruentus* on the control plots were considerably ($p = 0.05$) lower than others. The height

Table 4.11: Weed diversity at varying planting densities of *Indigofera hirsuta* in 2018

Planting Density						
	Control	D1*	D2	D3	D4	D5
Species Richness	15	9	10	13	14	14
Shannon-Wiener Index (*H'*)	2.019	1.641	1.976	2.121	2.219	2.270
Equitability Index (J)	0.745	0.747	0.858	0.827	0.840	0.860

*D1 = 3.125 plants/m^2, D2= 6.25 plant/m^2, D3 = 12.5 plants/m^2, D4= 25 plants/m^2,D5= 50 plants/m^2 and Control = 0 plant/m^2.

Table 4.12: Effects of duration of *I. hirsuta* green manure on height (cm) of *A. cruentus* in Ibadan, Nigeria (Pot experiment)

Duration of green manure	Main trial			Residual trial		
	Week 2	Week 4	Week 6	Week 2	Week 4	Week 6
Control	4.17 ± 0.15*	14.63 ± 0.43	28.57 ± 0.27	3.60 ± 0.21	14.83 ± 0.79	23.73 ± 0.23
4-Week	4.83 ± 0.09	17.38 ± 0.44	34.10 ± 0.60	3.87 ± 0.91	18.10 ± 0.06	27.03 ± 0.09
6-Week	5.00 ± 0.06	20.13 ± 0.37	36.07 ± 0.20	4.07 ± 0.07	19.77 ± 0.19	29.00 ± 0.38
8-Week	6.30 ± 0.26	23.90 ± 0.35	39.20 ± 0.32	4.83 ± 0.09	21.27 ± 0.44	30.90 ± 0.29
10-Week	7.13 ± 0.15	22.90 ± 0.32	38.90 ± 0.29	5.10 ± 0.12	20.97 ± 0.23	30.70 ± 0.32
LSD (p = 0.05)	0.49	1.21	1.15	0.45	1.34	0.88

*Values are means ± standard error. LSD = Least significant difference at 5% level of probability

of *A. cruentus* planted for the residual trial to check residual effects were generally reduced compared to main trial but the differences in height among the treatments followed the same trend as first trial.

Stem diameter

The stem diameter at week two after sowing were considerably (p = 0.05) similar across the treatments (Table 4.13). After four weeks of sowing, the stem diameter of *A. cruentus* in the control pots was considerably (p = 0.05) lower compared to those in other treatment pots. The highest stem diameter was reached also at week six in pots planted with 10 week-old green manure and it was considerably (p = 0.05) higher than the stem diameter of *A. cruentus* in control pots (Tables 4.14). In the residual trial, the diameter increased across the treatment at two weeks interval of recording compared to the main trial.

Number of leaves

The numbers of leaves varied considerably (p = 0.05) from week 2-6 after sowing among the treatments and control (Table 4.14). Maximun numberof leaves was obtained at week six in pots planted with 10 week-old green manure. At the second week after sowing, the number of leaves of *A. cruentus* in pots planted with 8 and 10 week-old green manure was considerably (p = 0.05) greater than the number of leaves in remaining treatment pots, while the number of leaves of *A. cruentus* in the control pot was considerably (p = 0.05) lower than in other treatment pots. At 4 WAS, the number of leaves of *A. cruentus* in the control pots planted with 4 week-old green manure pots sown with 6 week-old green manure were not considerably (p = 0.05) similar, but lower than the number of leaves of *A. cruentuus* in pots planted with 8 and 10 week-old green manure. At 6 WAS, the leaf number of *A. cruentus* was considerably (p = 0.05) greater than the leaf number of *A. cruentus* planted in the remaining pots. Residual trial followed the same trend, though there was slight decrease in the leaf number of *A. cruentus*.

Table 4.13:Effects of duration of*I. hirsuta* green manure on stem diameter(cm) of*A. cruentus* in Ibadan, Nigeria (Pot experiment)

	Main trial			Residual trial		
Duration of green manure	Week 2	Week 4	Week 6	Week 2	Week 4	Week 6
Control	0.10 ± 0.00*	0.30 ± 0.00	0.40 ± 0.00	0.10 ± 0.00	0.30 ± 0.00	0.30 ± 0.00
4-Week	0.10 ± 0.00	0.33 ± 0.03	0.43 ± 0.03	0.10 ± 0.00	0.30 ± 0.00	0.30 ± 0.00
6-Week	0.10 ± 0.00	0.40 ± 0.00	0.43 ± 0.03	0.10 ± 0.00	0.30 ± 0.00	0.33 ± 0.03
8-Week	0.10 ± 0.00	0.47 ± 0.03	0.47 ± 0.03	0.10 ± 0.00	0.40 ± 0.00	0.40 ± 0.00
10-Week	0.13 ± 0.03	0.43 ± 0.03	0.50 ± 0.00	0.10 ± 0.00	0.40 ± 0.00	0.40 ± 0.00
LSD (p = 0.05)	NS	0.08	0.08	NS	0.05	0.05

*Values are means ± standard error. NS = no significant difference. LSD = Least significant difference at 5% level of probability

Table 4.14:Effects of duration of *I. hirsuta* green manure on number of leaves of *A. cruentus* in Ibadan, Nigeria (Pot experiment)

	Main trial			Residual trial		
Duration of green manure	Week 2	Week 4	Week 6	Week 2	Week 4	Week 6
Control	5.67 ± 0.33*	9.00 ± 0.00	15.67 ± 0.33	6.00 ± 0.00	8.67 ± 0.33	12.00 ± 0.00
4-Week	6.00 ± 0.00	9.00 ± 0.00	16.33 ± 0.33	6.00 ± 0.00	9.00 ± 0.00	15.00 ± 0.58
6-Week	6.33 ± 0.33	10.00 ± 0.58	16.67 ± 0.33	6.00 ± 0.00	10.33 ± 0.33	15.33 ± 0.33
8-Week	7.00 ± 0.00	12.33 ± 0.33	17.67 ± 0.33	6.67 ± 0.33	12.00 ± 0.00	16.33 ± 0.33
10-Week	7.00 ± 0.00	12.33 ± 0.33	19.67 ± 0.88	6.33 ± 0.33	12.00± 0.00	16.33 ± 0.33
LSD (p = 0.05)	0.66	1.05	1.56	0.66	0.66	1.15

*Values are means ± standard error. LSD = Least significant difference at 5% level of probability

Leaf area

At two weeksafter sowing, the control pots and those planted with 4 week-oldgreen manure produced *A. cruentus* with significantly (p = 0.05) smallest leaf area while the pots planted with 8 week-old and 10 week-old green manure gave *A. cruentus* with significantly (p = 0.05) largest leaf area (Table 4.15). At weeks 4 and 6 after sowing, the leaf area of *A. cruentus* in the pots that contained 8-week green manure andin pots that contained 10 week-oldgreen manure,respectively, remained considerably (p = 0.05) greater than in other treatments.The leaf area of *A. cruentus* in control pots remained considerably (p = 0.05) lower than in other pots.The leaf area of *A. cruentus* planted for the residual trial was reduced compared to main trial. The variations in the leaf area of *A. cruentus*among the treatments followed the same trend.

Fresh weight (Yield)

At harvest (6 weeks after sowing), the fresh weights of *A. cruentus* in pots planted with 8 week and 10 week-oldgreen manure were considerably (p = 0.05) greater than theother treated pots, while the control pots yielded the least fresh weight (Table 4.16). *A. cruentus*planted on the residual green manure had reduced fresh weight compared to first trial.

4.7.2 Effect of duration of *I. hirsuta* green manure on growth and yield of *Amaranthus cruentus*(Field experiment)

The data obtained from the field experiment followed a similar patternto those from the pot experiment. The control plots yielded *A. cruentus*plant that were significantly shorter, thinner, withshorter and narrower leaves than the plots treated with green manure. *A. cruentus* grown in 8 week and 10 week-old green manure were significantly (p = 0.05) taller, thicker, had higher number of leaves,And which were also longer and broader than those on other plots; they also had higher weights (Tables 4.17-4.21).

Table 4.15:Effects of duration of*I. hirsuta* green manure on leaf area(cm^2) of *A. cruentus* in Ibadan, Nigeria (Pot experiment)

	Main trial			Residual trial		
Duration of green manure	Week 2	Week 4	Week 6	Week 2	Week 4	Week 6
Control	2.25 ± 0.04*	10.42 ± 0.23	20.84 ± 0.28	2.11 ± 0.07	10.95 ± 0.19	20.55 ± 0.44
4-Week	2.53 ± 0.04	11.62 ± 0.25	27.60 ± 0.38	2.28 ± 0.04	12.72 ± 0.18	23.23 ± 0.16
6-Week	3.04 ± 0.03	13.73 ± 0.15	28.03 ± 0.21	2.43 ± 0.04	13.44 ± 0.23	24.75 ± 0.26
8-Week	4.11 ± 0.28	16.18 ± 0.15	31.45 ± 0.50	3.07 ± 0.09	15.18 ± 0.12	26.29 ± 0.23
10-Week	4.01 ± 0.14	16.68 ± 0.17	30.30 ± 1.20	3.59 ± 0.16	15.38 ± 0.19	26.41 ± 0.06
LSD (p = 0.05)	0.45	0.61	1.97	0.29	0.58	0.83

*Values are means ± standard error. LSD = Least significant difference at 5% level of probability

Table 4.16:Effects of duration of*I. hirsuta* green manure on fresh weight(kg) of *A. cruentus* in Ibadan, Nigeria (Pot experiment)

	Main trial		Residual trial	
Durationof Green Manure	Week 6	% Increase	Week 6	% Increase
Control	0.70 ±0.02*	0.00	0.57 ± 0.02	0.00
4-week	0.86 ± 0.02	22.86	0.61 ± 0.01	7.02
6-week	0.87 ± 0.02	24.29	0.71 ± 0.02	24.56
8-week	1.05 ± 0.08	50.00	0.83 ± 0.02	45.61
10-week	1.07 ± 0.09	52.86	0.83 ± 0.01	45.61
LSD (p = 0.05)	0.17		0.05	

*Values are means ± standard error. LSD = Least significant difference at 5% level of probability

Height

The height of *A. cruentus* varied from 2 WAS till 6 WAS across the treatments. At 2WAS, the height varied. The height of plants on the control plots were considerably (p = 0.05) lower than the height on other plots while 8 and 10 week-oldgreen manure gave considerably (p = 0.05) higher*A. cruentus*(Table 4.17). At 4 and 6 WAS, the height followed the same trend as observed at 2 WAS. At4 WAS, the control plots wereconsiderably (p = 0.05) lower, compared to others, while plots incorporated with 8 and 10 week-oldgreen manure hadgreatest height, which were considerably (p = 0.05) greater than*A. cruentus*on other plots. At 6 WAS, *A. cruentus*on the control plots were considerably (p = 0.05) lower than others, while those on 8week-old green manure and 10 week-old green manure were considerably (p = 0.05) greater than others. In the residual trial, the same trend was observed, though, the height decreased across the treatment compared to the main trial (Tables 4.17).

Stem diameter

The stem diameter varied significantly (p = 0.05) across the green manure incorporated plots at every two weeks of recording (Table 4.18). At 2 WAS, the stem diameter of *A. cruentus* on the control plots was not significantly different from those on 4 and 6 week-old green manure, but was significantly lower than those on plots 8and 10 week-old. At 4 week after sowing, the stem diameter of *A. cruentus* on control plots, 4 week and 6 week-old green manure plots were also not significantly different from oneanother but those on 8 week and 10 week-old green manure plots were significantly greater. At 6WAS, the stem diameter at the control plot wassignificantly lower than other plots. The stem diameter of *A. cruentus* on 8 week-old green manure was significantly higher than other plots. In the residual trial, the diameter decreased across the treatments at two weeks interval of recording compared to the main trial (Table 4.18).

Table 4.17:Effects of duration of *I. hirsuta* green manure on height (cm) of *A. cruentus* in Ibadan, Nigeria (Field experiment)

	Main trial			Residual trial		
Duration of green manure	Week 2	Week 4	Week 6	Week 2	Week 4	Week 6
Control	5.20 ± 0.12*	21.60 ± 0.60	40.83 ± 0.54	4.67 ± 0.20	14.10 ± 0.38	23.97 ± 0.67
4-Week	7.40 ± 0.23	26.53 ± 0.98	45.87 ± 0.80	6.80 ± 0.21	14.43 ± 0.35	26.07 ± 0.18
6-Week	9.77 ± 0.54	28.53 ± 0.64	47.13 ± 0.90	7.90 ± 0.21	20.23 ± 0.26	32.30 ± 1.88
8-Week	12.73 ± 0.12	31.60 ± 0.91	59.53 ± 1.33	8.97 ± 0.18	21.47 ± 0.41	43.77 ± 1.56
10-Week	12.10 ± 0.15	29.87 ± 1.35	58.07 ± 1.50	8.80 ± 0.21	20.83 ± 0.22	44.03 ± 0.87
LSD (p = 0.05)	0.88	2.95	3.38	0.63	1.04	3.79

*Values are means ± standard error. LSD = Least significant difference at 5% level of probability

Table 4.18:Effects of duration of *I. hirsuta* green manure on stem diameter(cm) of *A. cruentus* in Ibadan, Nigeria (Field experiment)

	Main trial			Residual trial		
Duration of green manure	Week 2	Week 4	Week 6	Week 2	Week 4	Week 6
Control	0.23 ± 0.03*	0.50 ± 0.00	0.60 ± 0.00	0.20 ± 0.00	0.30 ± 0.00	0.53 ± 0.23
4-Week	0.27 ± 0.03	0.50 ± 0.03	0.67 ± 0.03	0.20 ± 0.00	0.30 ± 0.00	0.57 ± 0.03
6-Week	0.30 ± 0.00	0.53 ± 0.10	0.70 ± 0.00	0.27 ± 0.03	0.30 ± 0.00	0.60 ± 0.00
8-Week	0.37 ± 0.03	0.73 ± 0.03	0.90 ± 0.00	0.30 ± 0.00	0.37 ± 0.03	0.80 ± 0.00
10-Week	0.37 ± 0.03	0.70 ± 0.00	0.80 ± 0.00	0.33 ± 0.03	0.37 ± 0.03	0.73 ± 0.03
LSD (p = 0.05)	0.09	0.16	0.05	0.07	0.07	0.08

*Values are means ± standard error. LSD = Least significant difference at 5% level of probability

Number of leaves

The leaf number varied across the treatments at 2 weeks interval. At 2WAS, the leaf number of *A. cruentus* on 8 week and 10 week-old green manure,wereconsiderably higher than on other plots but others were considerably similar. At 4week after sowing, the leaf number varied significantly among the treatments, with 8 week-old green manureplot having the greatest number of leaves, then 10 week-old green manure plot followed. The least number of leaveswas obtained on the control plot. At 6 week after sowing, 8 week-old green manure plot also had significantly highest number of leaves, while 4 week, 6 week and 8 week-old green manure plots were considerably similar but the control plot hadsubstantially lower number of leaves than all other plots. In the residual trial, the leaf number also varied significantly across the treatment at 2 weeks interval (Table 4.19).

Leaf area

Substantial disparity($p = 0.05$) occuredacross the plots (Table 4.20). At 2week after sowing, 8 week and 10 week-old green manure plots produced *A. cruentus* with largest leaf areas, while the control produced *A. cruentus* with lowest leaf area, though not significantly different from those on 4 week-old green manure plot. At 4week after sowing, *A. cruentus* planted on 8 week-old green manure plot had significantly highest leaf area followed by 10week-old green manure plot, while those planted on the control plot had significantly lowest leaf area. The same trend was observed at 6week after sowing, though the leaf area on 8 week-old green manure plot was highest, it was not significantly different from 10week-old green manure plot, while leaf area of *A. cruentus* on the control plot was not significantly different from those on 4 week-old green manure plot. In the residual trial, the leaf area was lower from 2 week after sowing till week 6 but the difference among the treatments followed the same trend as main trial (Table 4.20).

Table 4.19:Effects of duration of *I. hirsuta* green manure on number of leaves of *A. cruentus* in Ibadan, Nigeria (Field experiment)

	Main trial			Residual trial		
Duration of green manure	Week 2	Week 4	Week 6	Week 2	Week 4	Week 6
Control	6.33 ± 0.33*	11.33 ± 0.33	17.00 ± 0.00	6.00 ± 0.00	6.00 ± 0.00	16.67 ± 0.33
4-Week	6.67 ± 0.33	12.00 ± 0.00	17.67 ± 0.33	6.00 ± 0.00	7.00 ± 0.00	18.00 ± 0.00
6-Week	7.33 ± 0.33	12.00 ± 0.00	18.00 ± 0.00	6.67 ± 0.33	7.00 ± 0.00	18.33 ± 0.33
8-Week	7.69 ± 0.33	13.67 ± 0.33	18.67 ± 0.33	7.00 ± 0.00	10.67 ± 0.33	19.33 ± 0.33
10-Week	8.00 ± 0.00	13.00 ± 0.00	18.33 ± 0.33	7.33 ± 0.33	11.00 ± 0.00	19.00 ± 0.00
LSD (p = 0.05)	0.94	0.66	0.81	0.66	0.47	0.81

*Values are means ± standard error. LSD = Least significant difference at 5% level of probability

Table 4.20:Effects of duration of *I. hirsuta* green manure on leaf area(cm^2) of *A. cruentus* in Ibadan, Nigeria (Field experiment)

	Main trial			Residual trial		
Duration of green manure	Week 2	Week 4	Week 6	Week 2	Week 4	Week 6
Control	7.25 ± 0.63*	24.04 ± 0.45	43.95 ± 2.59	6.34 ± 0.25	12.58 ± 1.78	25.63 ± 0.62
4-Week	7.41 ± 0.40	26.75 ± 0.19	51.28 ± 1.24	6.69 ± 0.14	17.44 ± 0.55	36.50 ± 1.02
6-Week	8.93 ± 0.23	31.78 ± 0.73	61.17 ± 1.56	7.10 ± 0.09	19.83 ± 0.20	45.59 ± 0.40
8-Week	13.03 ± 0.44	49.36 ± 0.42	88.73 ± 4.35	8.50 ± 0.33	22.00 ± 0.21	51.01 ± 0.31
10-Week	13.98 ± 0.16	44.22 ± 1.47	81.47 ± 2.44	8.89 ± 0.09	21.58± 0.27	50.50 ± 0.40
LSD (p = 0.05)	1.28	2.49	8.41	0.65	2.68	1.91

*Values are means ± standard error. LSD = Least significant difference at 5% level of probability.

Fresh weight (Yield)

The yield of *A. cruentus* responded positively to green manure incorporation (Table 4.21). The variation was considerable (p = 0.05) among the plots. *A.cruentus*grown on 8 week-old green manure plotgave the highest yield, though not significantly different from 10 week-old green manure plot while control plot produced significantly lower fresh weight than 4 week-old green manure and 6 week-old green manure plots. The same trend was observed on the second trial.

4.8 Effect of*Indigofera hirsuta* green manure on soil chemical properties

The chemical properties of the soil in both experimental pots and field plots varied with the different duration of *I. hirsuta*green manure (Table 4.22). The pots in which green manure crop was planted for 10 weeks before incorporation had the highest soil pH while those in which green manure was planted for 8 weeks before incorporation had the highest soil total nitrogen and available phosphorus. The potsin which green manure was planted for 10 weeks before incorporation also had highest organic carbon and organic matter. The control pots in which green manure was not planted, had the lowest soil pH total nitrogen, organic carbon, organic matter and available phosphorus.

On the field, the control plots had the lowest pH, total nitrogen, available phosphorus, organic carbon and organic matter (Table 4.23). The plots on which green manure was planted for 8 weeks before incorporation had highest soil total nitrogen and available phosphorus while plots on which green manure was planted for 10 weeks before incorporation had highest organic carbon and organic matter.

Table 4.21:Effects of duration of *I. hirsuta* green manure on fresh weight (kg) of *A. cruentus* in Ibadan, Nigeria (Field experiment)

Duration of green manure	Main trial		Residual trial	
	Week 6	% Increase	Week 6	% Increase
Control	0.55 ±0.03*	0.00	0.52 ± 0.02	0.00
4-week	0.77 ± 0.05	40.00	0.68 ± 0.02	30.77
6-week	1.11 ± 0.05	101.83	0.93 ± 0.03	78.85
8-week	1.73 ± 0.04	214.55	1.21 ± 0.05	132.69
10-week	1.62 ± 0.06	194.55	1.19 ± 0.05	128.85
LSD(p = 0.05)	0.15		0.11	

*Values are means ± standard error. LSD = Least significant difference at 5% level of probability

Table 4.22: Effects of*Indigofera hirsuta* green manure on soil chemical properties (Pot Experiment)

Age of Green manure	pH	TN* (g/kg)	AP (mg/kg)	OM (g/kg)	OC (g/kg)	K	Ca	Na	Mg	Mn	Fe	Cu	Zn
						(cmol/kg)					(mg/kg)		
Control	6.9	1.20	4.14	1.78	0.90	0.22	5.42	0.15	1.49	49.10	25.70	0.73	0.34
4-week	7.0	1.90	4.54	1.98	1.42	0.30	5.92	0.19	1.62	52.10	30.46	0.71	0.58
6-week	7.1	2.00	4.60	2.30	2.18	0.34	6.01	0.24	1.84	54.14	30.80	0.80	0.49
8-week	7.0	2.10	5.01	2.38	2.24	0.34	7.34	0.22	1.92	53.80	31.25	0.78	0.53
10-week	7.2	2.10	5.00	2.94	2.94	0.37	7.09	0.26	1.94	55.41	30.24	0.93	0.57

*TN = total nitrogen, AP =available phosphorus, OM = organic matter, OC = organic carbon.

Table 4.23.: Effects of *Indigofera hirsuta*green manure on soil chemical properties (Field Experiment)

Age of Green Manure	pH	TN* (g/kg)	AP (mg/kg)	OM (g/kg)	OC (g/kg)	K	Ca (cmol/kg)	Na	Mg	Mn	Fe (mg/kg)	Cu	Zn
Control	7.4	1.20	4.33	1.99	1.28	0.20	5.58	0.15	1.78	67.9	19.90	0.74	0.35
4-week	7.6	2.00	6.51	2.05	3.02	0.37	5.40	0.23	2.03	105.0	27.10	0.56	0.50
6-week	7.8	2.30	5.84	2.44	3.87	0.32	5.24	0.28	2.32	108.3	32.60	0.60	0.47
8-week	7.7	2.80	9.53	3.38	4.11	0.37	6.89	0.32	2.73	110.8	45.10	0.62	0.59
10-week	7.7	2.40	9.30	3.48	4.23	0.35	7.88	0.26	2.17	135.0	42.40	0.62	0.51

*TN = total nitrogen, AP = available phosphorus, OM = organic matter, OC = organic carbon.

CHAPTER FIVE

DISCUSSION

In order to achieve sustainable cropping, increased productivity and a healthy environment, legumes are considered to have important roles(Storkey *et al*., 2011). *Indigofera hirsuta* is a leguminous plant that is multi-functional in nature. It produces nodules and it istherefore capable of fixing nitrogen from the atmosphere. As a crop for soil protection and enrichment, it also suppresses other unwanted plantsand can therefore be used to control weeds.

The ecology of the plants in the surveyed area was studied by assessing the species diversity usingindices such as species richnessor the Shannon index, amongst others (Eshaghi Rad *et al*.,2009).Gotelli and Colwell (2011) also recommended species richness and evenness as the two components of species diversity in the study of community ecology.

The study of *I. hirsuta* abundance and distribution during both the wet and dry seasons revealed that species richness decreased during the dry season. The decrease in the species diversity during the dry season in all the surveyed areas may be a consequence of moisture stress in the dry season. Species richness has been reported to have significant effects on ecological processes that are significant, such as environmental stability and productivity (Loreau, 2000). The reports of Nkoa *et al*. (2015) are likewise consistent with this principle that studying weed population, abundance and distribution will help in determining changes in their population over time due to agronomic practices. McCollin *et al.* (2000) also reported that the plant species present within a site change through time, which may be due to seasonal changes.

Evaluation of the population of *I. hirsuta* compared to other weedspeciesin the studyareas also indicated no critical dominance by a particular weed species, especially during the wet season. That is, the species were evenly distributed, though some species

appeared to be relatively more important than the other, based on both their relative number and occurrence. Evenness, as reported by Booth *et al.* (2010), provides information on the dominance of a community; whether the species in a community are equally represented or one or more species dominate. However, *Tridax procumbens* was most abundant and dominant in all the study areas in both seasons, especially during the dry season. Its dominance was more exhibited when the weather was dry than when it was wet, which probably indicates that it is more drought-tolerant than most local weed species in the area. This dominance by *T. procumbens, I. hirsuta* and *Cyperus esculentus* in the dry season is shown by the Shannon-Wiener index that is less than that of the wet season.

From the surveys, the weed species encountered during the wet season had greater species evenness than those encountered during the dry season. Nkoa *et al*. (2015) reported that the value of zero for evenness indicates that a particular species has a stronghold on the community, i.e: uneven or plantation, while a value of one implies that the community is the most diverse possible i.e even distribution of all species.

During the dry season, the low weed species diversity encountered in all the surveyed areas indicates that few weed species that tolerate low moisture stress occurred in the habitats and that the environments were quite stressful while high species diversity encountered during the rainy season suggests a more stable ecosystem with a greater number of successful species having access to the growth resources in the habitat. This can be used to indicate the biological health of a particular habitat, as suggested by Yadav and Mishra (2013).The survival of *I. hirsuta* in the dry season may imply that the plant can be introduced as an out-of-season (sown) fallow crop. Also, its low RIV at some study sites may imply that the plant will not become invasive if introduced as fallow crop in farmlands.

The failure of viable seeds of *I. hirsuta* to germinate under favourable conditions (moisture, oxygen, light availability etc) for five days revealed that theyexhibited dormancy. The dormancy appeared to be associated with impervious or hard seed-coat (Das, 2011).Dormancy is a situation when viable seeds do not germinate in favorable conditions, which is known to be peculiar to legume seeds. The hardness of the seed-coat

of most legumeswas attributed to accumulation of lignin (Awodoyin and Ogunyemi, 2003). The strong seed-coat prevents water and gas, which are conditions required for germination, from entering the seed (Taiz and Zeiger,2002). Dormancy keeps seeds and makes them to survivein the soil for an extended period of time. Seeds of some plants such as *Striga* spp., *Senna obtusifolia* and*Eichhornia crassipes* can stay up to 15-20 years in the soil before germination can take place (Cock and Evans, 1984; Kim, 1988).

Dormancy in *I. hirsuta* seeds were broken through scarification with concentrated H_2SO_4 in the laboratory. The acid was able to soften the seed-coat and thereby allow the entry of water and oxygen into the embryo to stimulate germination. The use of concentrated H_2SO_4 to break dormancy in legume seeds has been reported by many researchers and it has been found out that scarification of the seeds with the acid enhanced germination by reducing the number of days required for germination (Awodoyin *et al*., 2000; Sadeghi*et al*., 2009). Application of H_2SO_4 to break dormancy in *Rhynchosia capitata* proved to be best among other methods of scarification (Hafiz *et al*., 2011). The acidwas also used to break dormancy in African locust bean seeds (Aliero, 2004), *Senna obtusifolia*(Awodoyin and Ogunyemi, 2003) and *Sesbania pachycarpa* (Egberongbe and Awodoyin, 2017).

Steeping seeds of *I. hirsuta* in concentrated H_2SO_4 for 10 minutes yielded effective and uniform germination. The decline in germination after 60 minutes of soaking can be primarily attributed to the damage of the seed embryo due toprolonged scorching by the acid. This is consistent with the findings of Sadeghi *et al*.(2009) that prolonged soaking leads to total removal of the seed-coat, causing fast uptake of water by dr seed, fracturing, and endosperm bursting. Aliero (2004) also reported that seeds of*Parkiabiglobosa*got injured with prolonged immersion in H_2SO_4.On the contrary, prolonged acid treatment for up to 120 minutes aided germination in*Sesbania pachycarpa* (Egberongbe and Awodoyin, 2017).

The effective germination of theacid-treated seeds may be ascribed to the reason for germination in acid soils, especially, soils of the tropics (Egberongbe *et al*., 2017). However, the immersion of *I. hirsuta* seeds in concentrated H_2SO_4 for long period of time

(2 hours) had harmful effect and led to burning of the seed-coat and death of the embryo, which was supported in the report bySadeghi*et al*.(2009).

Acid-scarified seeds of *I. hirsuta* can stay viable for a maximum of 6 months when stored at room temperature. The germinability of acid-scarified seeds stored for one month was not different from those freshly treated.The germinability started to decrease after two months of storage till the6thmonth, when the germination was still moderately average,thereafter, germination was poor. The decrease in germinability of stored scarified seeds of *I. hirsuta*agrees with the report of Egberongbe *et al*. (2017) that decrease in germination of stored scarified seeds of*Sesbania pachycarpa* seedsmay be as a result of exposure of the embryo to unfavourable conditions after the removal or reduction of the thickness of seed-coat.

In the current study, planting depth influenced the germination of seeds.This was also affirmed by other researchers (Mohammad, 2011; Opande *et al*., 2017). Sowing *I. hirsuta* seeds at different soil depths affected seedling emergence. The may be as a result of exposure of seeds to varying environmental conditions and nutrients required for germination. Such environmental conditions were reported to include temperature, moisture, change in oxygen and carbon dioxide concentrations (Sikuku *et al*., 2018).

Seeds placed at low soil layershad a delay in their emergence comparedto those planted at shallow soil layers.Sowing seeds of *I. hirsuta*deeper than 3 cm in soils affected germination. Seeds sown in deeper layers, above 3 cm emerged late, compared to those sown shallowerlayers (0-2 cm). This is consistent with the results of Opande *et al*. (2017), who established that seeds of *Crotalaria brevidens* planted in shallow soil layers germinated last, compared to those planted in low depths.Ahirwar (2015) also reported that the interval between seed germination and seedling emergence was lengthened by deep sowing. This trend was also reported in the seeds of *Senna obtusifolia* (Awodoyin and Ogunyemi, 2003) and *Sesbania pachycarpa* (Egberongbe and Awodoyin, 2017).

The failure of some seeds sown on the surface to germinate may be due to direct impacts of climatic factors (such as temperature) or herbivory by rodents and insects, Sikuku *et al*. (2018) reportedsimilar findings. On the contrary, soil surface has been recognized to be favourable for optimal germination in a great number of weeds

(Ebrahimi and Eslami, 2011; Lu *et al*., 2011; De Cauwer *et al*., 2014). Germination of seed of*Echinochloa colona*was found to reduce significantly from 97 percent at the soil surface to 12 percentat a depth of 0.5 cm (Chauhan and Johnson, 2009).Because the seeds gave very low germination at the depth of 4 cm, ploughing them at lower soil depths may prevent germination and be a preventive measure to infestation of *I. hirsuta* in the field. This is in accordance with the studies of Awodoyin and Ogunyemi(2003).

Storage of seeds was described by Pradhan and Badola (2012) as a necessary step in long-term plant genetic resource protection. During storage, seeds often lose viability or become deteriorated due to unsuitable medium of storage, such as room temperature (Nasreen *et al*., 2000).Scarified seeds of *I. hirsuta* remained highly viable when stored for 6 months, thereafter, the viability decreased to 25%. There have been reports on the factors impacting seed lifecycle; temperature, seed moisture content, relative humidity, seed typeas well as others (Butola and Badota, 2004a and b; Yang *et al*., 2005; Pradhan and Badola, 2008).

The ability of seeds of *I. hirsuta* stored up till 4 months after acid scarification to remain as highly viable as the freshly-scarifiedseeds support the findings of Silveira *et al.* (2014), who demonstrated that storage of seeds of *Mimosafoliolosa* for a short length of time does not affect germination.Germination of scarified seeds of *I. hirsuta* started to reduce significantly after 6 months in storage. The reduction might have been attributed to the long-term effect of storage such as drying and eventual death of the seeds, as suggested by Pradhan and Badola (2012). Also, rapid exchange of gases, especially oxygen, may bring about rancidity of seed oil which may affect viability of the seeds.

Plant development and reproduction are frequently linked to growth, measured as increase in height, stem diameter, width, roots, leaf area, leaf fat etc (Brukhin and Morozova, 2011).A mature embryo, surrounded by seed-coat will continue to be in a state of suspended liveliness until germination occurs to bring about active life of the plant. The suspension of the embryo from growth may be due to a physiological phenomenon called dormancy. Viable seeds begin to germinate at the appropriate environmental conditions and when the requirements for germination such as water, air and favourable temperature,

are met while dormant seeds require specific environmental,hormonal, mechanical and otherfactors or conditions, for germination to occur (Raghavan, 2000).

During seed germination, the first obvious development is the growth of radicle, the embryonic root. The radicle emerges by splitting the softened seed coats. The radicle and plumule emerge as a result of mobilization of food reserves in the endosperm and their subsequent metabolism by the growing embryo axis. The radicle extends downward into the soil through positive gravitropism, to form the root while the plumule grows away from the soil into the air through negative gravitropism, to form the shoot system. This occurs through cell division, elongation and differentiation to produce the specialized tissues and organs of the seedling plant. The duration of each phase varies in different plant species and terminated by flowering and fruiting in annual plants.The shoot system is the aerial portion of the seedling; it comprises the stem which is the main axis of the shoot. The stem provides support for leaves; it also bears flowers and fruits (Raghavan, 2000).

At 4 weeks after sowing,*I. hirsuta* showed no apparent variation in the number of branches.This may be linked to growth stage of the plants.According to Babajide and Olayiwola (2014), at such a stage, the plants were still young and not yet ready for branch formation.As the plant growth advanced, stem diameter became consistent. This on stem development was in keeping with Ahmed *et al*. (2010), who suggested that this may be attributed to assimilate translocation to pods to the detriment of stem development. Reduced nodules formation was observed after 12 weeks of sowing while nodule effectiveness was observed after 10 weeks of sowing. The reduced nodulenformation is in accordance withMohammadi *et al*. (2012), who found that nitrogen fixation decreases with legume age due to concomitant increase in soil nitrogen.

One of the most crucial aspects of agronomic management to maximize growth and yield is planting crops at appropriate density (Rasekh *et al*., 2010). Generally, at the mature stage, *I. hirsuta* densities ranged from 4 to 6 plants/m^2 in the natural habitat. Increasing the density to 50 plants/m^2reduced other weed species significantly. However, varying the density of *I. hirsuta* affected its height, stem diameter, number of leaves and branches, shoot dry weight and weight of other weed species encountered. The

development of greater height, weaker stem, fewer leaves and branches by *I. hirsuta* planted at high density indicated sign of etiolation as a result of overcrowding (Etiban and Tiwari, 2015). Etiolation occurs in flowering plants growing under reduced or complete absence of light.

Also, at low densities, the plants were shorter, thicker and produced more leaves. These might have resulted from wider gap among the adjacent plants which could have reduced competition for growth resources such as sunlight and soil nutrients among the plants in addition to reduced canopy expansion from the shoots (Rehman *et al*., 2013). The stronger stem growth in*I. hirsuta* at low population may be ascribed to decreased plant competition, increased light penetration as a result of open canopy and better soil moisture and nutrient-uptake/use (Ahmed *et al*., 2010). The decrease in stem diameter of the plants as the plant density increased was likewise reported by Awodoyin and Ogunyemi (2005) in growth studies on *S. obtusifolia*. Etiban and Tiwari (2015) also reported that *Thysanolaena maxima* had lower height in narrow spacing. Bitew *et al*. (2014) reported similar results in *Pisum sativum*. These results were, however, in contrast with the results of Naim and Eldouma (2011), in the instance of*Arachis hypogaea*.

*Indigoferahirsuta*proved effective in suppressing other weeds. It could be used to cut down on the use of herbicides to manage weeds during the fallow period.To decrease weed development in the spring, some farmers experimented with cultivating legumes like dry pea or lentilsover a period ofapproximately six to eight weeks during fallow (Anderson, 2005). The weed suppressive ability of *I. hirsuta* is attributed to high competitiveness for light due to its spreading nature.As a result of their heavily-shading characteristics, cover crops enhancebiological weed suppression (Lawley *et al*., 2011). Several researches have reported the potential of cover crop cultivation insuppressingweeds(Lawley *et al*., 2011; Lawley *et al*., 2012; Rueda-Ayala *et al*., 2015). They interfere with the life cycle of weeds due to high level of competitionfor nutrients, water, light and space, thereby inhibiting germination, growth and seed production (Awodoyin and Ogunyemi, 2005; Rueda-Ayala *et al*., 2015).

The noticed decrease in weed density as the population of *I. hirsuta* increased may be attributed to rise in inter-specific competition for light and other resources (Hall *et al*., 2014). For effective weed suppression, planting *I.hirsuta*at50 plants/m^2may be required. As cover crops suppress weeds, they also have a number of advantages for agricultural systems, such as nutrient recycling and improved soil structure (Carof *et al*., 2007).

Indigofera hirsuta as green manure planted for 8-10weeks before incorporationhad positive effects on the performances of *A. cruentus*.This supports the findings from previous research that *A. cruentus* reacts to enhanced soil nutrition (Olaniyi, 2006). As a result of the production of highest number of effective nodules at between 8 and 10weeks after sowing, *I. hirsuta planted* between eight and ten weeks was considered to be the best age of incorporation as this was proven by the growth and performance of *A. cruentus* planted after decomposition of the green manure.Egberongbe *et al*.(2017) reported that plots where *Sesbania pachycarpa* planted for a minimum of 45 days before incorporation into the soil gave the best performance of*A. cruentus*.

*Amaranthus cruentus*appeared stunted in the control plots. Height has been reported to be an important growth parameter that has direct link with its productive potential (Law-Ogbomo and Ajayi, 2009). Stunted growth of *A. cruentus* in the control experiment may be due to the plants dependence on the basic soil fertility as shown from the laboratory analysis. This was previously stated by Egharevba and Ogbe (2002). The greatest height recorded from *A. cruentus*in pots and plots of 8 and 10 week-old *I. hirsuta* green manure might be as a result of high primary nutrients (N, P, K) and other nutrients found in the soil (Law-Ogbomo and Ajayi, 2009).

The relatively taller height, thicker stem, more leaf and leaf area, and greater fresh yield of *A. cruentus* planted on plots treated with green manure compared to the control plots could be attributed to high nutrient release from the green manure;green manure increases soil macronutrients such as nitrogen and phosphorus, and organic matter. The residual effect of the manure showed that the *A. cruentus*planted on the treated plots performed better than in the control. This may be attributed to the portion of organic matter and the nitrogen fixed by previous legume being made available for the second crop. The enhanced performance of *A. cruentus* under the influence of green manure

agrees with previous findings on the positive impact ofimproved soil nutrition on *A. cruentus* (Olaniyi, 2006).

The fresh yield of *A. cruentus* increased with the age of green manure incorporated into the soil. Adediran and Banjoko (2003) confirmed that application of manure enhances yield of crops. Also, Olaniyi (2006) reported that *A. cruentus*respond to improved soil nutrition.

The soil in the researchsite was slightly acidic at the onset of the experiment. This was inline withthe results of Ande *et al*. (2017)that the majority of the soils in southwestern Nigeria are mildly to slightly acidic. As the result of the acidic condition of the soils of southwestern Nigeria, the application of fertilizers that increase soil acidity such as ammonium sulphate was reported to be no longer recommendable to farmers. Acidic soils influence availability of both macro and micronutrients. The most available macronutrient in slightly acidic to slightly alkaline soils is phosphorus. With soil becoming more acidic, all essential micronutrients, with the exception of molybdenum, become more available (Ande *et al*., 2017). Maintaining good soil pH is extremely important to soil healthand successful crop production. A few essential bacteria tend to be most active in soils that range from slightly acidic to slightly alkaline during the process of nutrient transformation. Therefore, addition of organic matter will encourage microbial activity and improve the availability of N, P and K significantly (Ande *et al*., 2017).

The results of soil examination in the laboratory revealed that green manure of *I.hirsuta* is efficient in improving soil fertility. This is supported byOgunjinmi *et al*. (2017), who made the claim thatthe fertility of the soil can be greatly enhanced by using organic wastes.The observed increase in soil pH concurredwith the results of Opala *et al*. (2012), who discovered that nitrogen transformation and release of cations from decomposition of organic residues leads to increase in soil pH. The earlyupswing in soil pH with the introduction of organic residues can be linked to different mechanisms.Soil pH is known to be generally not affected in short period of time because it is determined by parent material (Bhayal *et al*., 2018).On the contrary, it was reported that soil pH decreases withapplication of green manures in long term (Kumar and Singh, 2010).Some of the mechanisms are ammonification of residue organic nitrogen, oxidation of organic

acid anions found in the decaying residues and adsorption of organic molecule produced during residue decomposition (Haynes and Mokolobate, 2001).Changes in soil pH as a consequence of addition of green manure increased the phosphorus availability (Bhayal *et al*., 2018). Sandy textural class of the soil alsoplays important role in conferring low to highpH while soils with higher pH were reported to resist pH changes due to its greater pH buffering capacity (Anetor and Omueti, 2014).

In the current study, green manure increased the organic carbon, total N and available K contents of the soil. Increased organic carbon levels in the soilas a consequence of incorporation of green manure of *I.hirsuta* is in accordance with the findings ofKanwar *et al*. (2002) thata rise in organic carbon in soil as a consequence of applying organic manure is greater than that resultingfrom adding mineral fertilizer. Total N and soil organic carbon constitute the heterogeneous combinations of organic compounds and are major parameters used in assessing soil fertility (Huang *et al*., 2009).The increase in total Nwas in contrast to the results of Kolawole (2016), who recorded a drop in total N after incorporation of*T. diversifolia* compost.On the other hand, the increase in phosphorusconforms to the findings of Kolawole (2016) on the increase in available P after application of organic residues.Mohammadi *et al*. (2012) demonstrated that nitrogen fixation decreases with legume age due to the concomitant increase in soil N.The increasein Mn, Cu and Zn contents of the soil after incorporation of*I. hirsuta* green manure could be ascribed to mineralization ofthe organic residues. This corroborates the findings of Ihenacho *et al*. (2015) that in the soil system, organic residues are proficient sources of these anions.

CHAPTER SIX

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

6.1 Summary

The need to concentrate on alternate nutrient sources that are less detrimental to soil and environment brought about the introduction of organic fertilisers. In agriculture,weeds provide biomass organic matter sourceand plant nutrients that are easily available. Despite this advantage, the use of these plants has receivednegligible attention; hence this study was conducted to assess the abundance,dispersion and biology of *I. hirsuta* andits potential as green manure in Ibadan.

Indigofera hirsuta seeds exhibited dormancy which was brokenby soaking in concentrated H_2SO_4. Acid-scarified seeds of *I. hirsuta* can be stored in an envelope and stay for 6 months before losing viability. The seeds of *I. hirsuta* germinated uniformly at a depth not higher than 2 cm. Acid-scarified seedsof*I. hirsuta* commenced germination after 24 hours of sowing and seedling growth was slow at the initial stage but became rapid at the branching stage. *Indigofera hirsuta* suppressed other weed species when planted at high density. Lastly, *I. hirsuta* was effective as green manure; it improved soil fertility and subsequently, performance of *A. cruentus*. Other inferences that can be drawn from this study are as follows:

6.2 Conclusions

1. *Indigofera hirsuta* population abundance and distribution in the surveyed areas during the wet and dry seasons indicated that the species was moderately represented in the study areas, though some species appeared to be relatively more important, especially *Tridax procumbens*. However, the species is drought tolerant and can be introduced as fallow plant.

2. Failure of seeds of *I. hirsuta* to germinate under favourable condition for five days, but did after scarification, showed that it exhibits seed dormancy.
3. Concentrated H_2SO_4can be used to break the dormancy exhibited by *I. hirsuta* seeds.This indicates that the dormancy is due to seed-coat that is quite hard and may be impervous to water and gases.
4. Soaking seeds of *I. hirsuta*in concentrated H_2SO_4 for 10minutes was the most effectiveduration of acid-scarificationto break seed-coat dormancy.
5. For effective germination,*I.hirsuta* seedsthey should be sown at 2 cm soil depth. Sowing below 3 cm depth produced poor germination.
6. Acid-scarified seeds of *I. hirsuta* can stay highly viable for a maximum of 6 month when stored at room temperature, before they lose viability.
7. Germination of the scarified seeds kept for 4 months was as viable as the freshly-scarified seeds.
8. *Indigofera hirsuta* showed slow seedling growth at the initial stage but growth increased after four weeks of planting.
9. Generally at the mature stage, *I. hirsuta* densities ranged from 4 to 6 plants/m^2 in the natural habitat. Increasing the density to 50 plants/m^2 reduced other weed species significantly. However, varying the density of *I. hirsuta* affected its height, stem diameter, number of leaves and branches, shoot dry weight and weight of associated weed species.
10. *Indigofera hirsuta* proved effective in suppressing other weeds at density 50 plants/m^2. It could be used to cut down on the use of herbicides to manage weeds during the fallow period.
11. *Indigofera hirsuta* started producing high number of effective nodulesat week eight; therefore, planting *I. hirsuta* for eight weeks was considered to be the best age of incorporation as green manure, judging from the growth and performance of *A. cruentus* planted after decomposition of the green manure.
12. Green manure of *I. hirsuta* has the abilityto increase soil organic matter andnutrients, and subsequently, the performance of *A. cruentus*.
13. The addition of green manure of *I. hirsuta* to the soil increased its carbon content.

14. The residual effect of the manure showed that the *A. cruentus* planted on the treated plots performed better than the control. This may be attributed to the portion of the nitrogen fixed by previous legume being made available for the crop.
15. The green manure of *I. hirsuta* is effective in soil fertility improvement.

6.3 Recommendations

1. In the laboratory, soaking of *I. hirsuta* seeds in concentrated $H_2SO_4$for 10 minutes can be used in breaking the dormancy.
2. Farmers are advised to adopt planting of *I. hirsuta* seeds at depths not higher than 2 cm, for rapid germination.
3. *Indigofera hirsuta* can be used to suppress weeds and reduce the need for herbicides.
4. Farmers and growers of leaf vegetables should be encouraged to use *I. hirsuta* as green manure in *A. cruentus* production, since it is readily accessible, inexpensiveand does not have acidifying effect on the soil.

6.4 Contributions to Knowledge

1. The seeds of *I. hirsuta* soaked in concentrated H_2SO_4 for a maximum duration of 10 minutes gave high germination.
2. Acid-scarified seeds of *I. hirsuta* can be storedunder laboratory conditions for 6 months and still produce 60% germination. However, storage for 4 months (85% germination) is most ideal.
3. When the acid-scarified *I. hirsuta* seeds are planted at a depth not more than 2 cm, guarantees high germination(93-100%).
4. Nodule production in *I. hirsuta* plant begins at two WAS reachesa peak at 10 WAS but decreased markedly thereafter. The nodules became effective at week four after sowing, continued to increase till 10^{th} week, and decreased thereafter.
5. Planting *I. hirsuta* on the field at a density of 50 plants/m^2 suppressed associated weeds up to 70% compared to the control.
6. Planting *I. hirsuta* and incorporating the shoot into the soil as green manure gave *A. cruentus*yield as high as 1.73 kg/m^2.
7. Depending on the duration of green manuring, the yield increase in *A. cruentus* varied from 22.9 to 52.9% in the pot experiment and from 40.0 to 214.6% in the field experiment.
8. The residual effect from green manuring was also better than in the control, and gave yield increase of*A. cruentus* varying from 7.0 to 45.6% in the pot experiment and 30.8 to 132.7% in the field experiment.

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APPENDICES

ANOVA TABLES

Dormancy test 1

EFFECT	SS	DF	MS	F	ProbF	
Duration	1084.714286	6	180.7857	170.6292	1.06E-16	**
Residual	22.25	21	1.059524			
Total	1106.964286	27	40.99868			

C.V. (%): 6.6255835467333
S.E.M.: 0.51466586479089
S.E.D.: 0.727847446077755
LSD (p<0.05): 1.99364162571298
LSD (p<0.01): 2.18079782323492

Second trial

EFFECT	SS	DF	MS	F	ProbF	
Duration	890.4285714	6	148.4048	69.25556	9.57E-13	**
Residual	45	21	2.142857			
Total	935.4285714	27	34.6455			

C.V. (%): 11.3855008510662
S.E.M.: 0.7319250547114
S.E.D.: 1.03509833901353
LSD (p<0.05):
2.18260483646717
LSD (p<0.01):
2.93073557565975

Effect of storage 1

EFFECT	SS	DF	MS	F	ProbF	
Weeks	1213.555556	8	151.6944	39.86131	5.5E-13	**
Residual	102.75	27	3.805556			
Total	1316.305556	35	37.60873			

C.V. (%): 14.303095613914
S.E.M.: 0.975391659226635
S.E.D.: 1.3794121131039
LSD (p<0.05): 2.83031986846915
LSD (p<0.01): 3.82191363262492

Effect of Storage 2

EFFECT	SS	DF	MS	F	ProbF	
Weeks	1128.888889	8	141.1111	57.07865	6.37E-15	**
Residual	66.75	27	2.472222			
Total	1195.638889	35	34.16111			

C.V. (%): 11.4815186191358
S.E.M.: 0.78616509433805
S.E.D.: 1.11180533867719
LSD (p<0.05): 2.28123612228357
LSD (p<0.01): 3.08046010351039

Depth of sowing 1

EFFECT	SS	DF	MS	F	ProbF	
Depth	141.7333333	4	35.43333	59.05556	6.41E-07	**
Residual	6	10	0.6			
Total	147.7333333	14	10.55238			

C.V. (%): 11.8560714679819
S.E.M.: 0.447213595499958
S.E.D.: 0.632455532033676
LSD (p<0.05): 1.40919874307788
LSD (p<0.01): 2.00442403431974

Depth of sowing 2

EFFECT	SS	DF	MS	F	ProbF	
Depth	102.2666667	4	25.56667	34.86364	7.6E-06	**
Residual	7.333333333	10	0.733333			
Total	109.6	14	7.828571			

C.V. (%): 11.5722816024009
S.E.M.: 0.494413232473041
S.E.D.: 0.699205898780096
LSD (p<0.05):1.55792782860991
LSD(p<0.01):2.21597414753633

Green manure (pot)

Height 1

EFFECT	SS	DF	MS	F	ProbF	
Age	226.54	4	56.635	141.8239	9.22E-09	**
Residual	3.993333333	10	0.399333			
Total	230.5333333	14	16.46667			

C.V. (%): 1.78679057296339
S.E.M.: 0.364843954467114
S.E.D.: 0.515967268557224
LSD(p<0.05):1.14964671742559
LSD(p<0.01):1.63524096420322

Height 2

EFFECT	SS	DF	MS	F	ProbF	
Age	106.396	4	26.599	113.0269	2.8E-08	**
Residual	2.353333333	10	0.235333			
Total	108.7493333	14	7.76781			

C.V. (%): 1.7157922812742
S.E.M.: 0.280079353834409
S.E.D.: 0.396092020733314
LSD (p<0.05): 0.882548020357651
LSD (p<0.01):1.25532361715172

Stem diameter 1

EFFECT	SS	DF	MS	F	ProbF
Age	0.017333333	4	0.004333	2.166667	0.146552
Residual	0.02	10	0.002		
Total	0.037333333	14	0.002667		

C.V. (%): 10.0122446753727
S.E.M.: 2.58198889747173E-02
S.E.D.: 3.65148371670128E-02
LSD (p<0.05): 8.13601273657737E-02
LSD (p<0.01): 0.115725475578471

Stem diameter 2

EFFECT	SS	DF	MS	F	ProbF	
Age	0.030666667	4	0.007667	11.5	0.000927	**
Residual	0.006666667	10	0.000667			
Total	0.037333333	14	0.002667			

C.V. (%): 7.44804489655203
S.E.M.: 1.49071198499972E-02
S.E.D.: 2.10818510677872E-02
LSD (p<0.05): 0.046973291435925
LSD (p<0.01): 6.68141344773185E-02

Leaf number 1

EFFECT	SS	DF	MS	F	ProbF	
Age	29.06666667	4	7.266667	9.909091	0.001657	**
Residual	7.333333333	10	0.733333			
Total	36.4	14	2.6			

C.V. (%): 4.97877231731209
S.E.M.: 0.494413232473046
S.E.D.: 0.699205898780104
LSD (p<0.05): 1.55792782860993
LSD (p<0.01): 2.21597414753636

Leaf number 2

EFFECT	SS	DF	MS	F	ProbF	
Age	38	4	9.5	23.75	4.33E-05	**
Residual	4	10	0.4			
Total	42	14	3			

C.V. (%): 4.2163702135576
S.E.M.: 0.36514837167009
S.E.D.: 0.516397779494293
LSD (p<0.05):1.15060595557067
LSD (p<0.01):1.63660537075134

Leaf area 1

EFFECT	SS	DF	MS	F	ProbF	
Age	203.98624	4	50.99656	43.29594	2.78E-06	**
Residual	11.7786	10	1.17786			
Total	215.76484	14	15.41177			

C.V. (%): 3.92539274912311
S.E.M.: 0.626593967414202
S.E.D.: 0.88613768681833
LSD(p<0.05):1.97443780820917
LSD(p<0.01):2.80841195500933

Leaf area 2

EFFECT	SS	DF	MS	F	ProbF	
Age	71.35922667	4	17.83981	86.40526	1.03E-07	**
Residual	2.064666667	10	0.206467			
Total	73.42389333	14	5.244564			

C.V. (%): 1.87396290718969
S.E.M.: 0.262339898266084
S.E.D.: 0.371004642079474
LSD (p<0.05): 0.826649857284537
LSD (p<0.01): 1.17581487355651

Fresh weight 1

EFFECT	SS	DF	MS	F	ProbF	
Age	0.282693333	4	0.070673	7.994721	0.003689	**
Residual	0.0884	10	0.00884			
Total	0.371093333	14	0.026507			

C.V. (%): 10.3244444569925
S.E.M.: 5.42832079621924E-02
S.E.D.: 7.67680489092517E-02
LSD (p<0.05): 0.171049872365886
LSD (p<0.01): 0.243298879538213

Fresh weight 2

EFFECT	SS	DF	MS	F	ProbF	
Age	0.174893333	4	0.043723	54.65417	9.26E-07	**
Residual	0.008	10	0.0008			
Total	0.182893333	14	0.013064			

C.V. (%): 3.98744425481091
S.E.M.: 1.63299316185527E-02
S.E.D.: 2.30940107675824E-02
LSD (p<0.05): 5.14566626394398E-02
LSD (p<0.01): 7.31912172268206E-02

Green manure (field experiment)

Height 1

EFFECT	SS	DF	MS	F	ProbF	
Age	794.624	4	198.656	57.49257	7.28E-07	**
Residual	34.55333333	10	3.455333			
Total	829.1773333	14	59.22695			

C.V. (%): 3.69651204974187
S.E.M.: 1.07320910254126
S.E.D.: 1.51774686807611
LSD (p<0.05):3.38175076424086
LSD (p<0.01):4.81015367294357

Height 2

EFFECT	SS	DF	MS	F	ProbF	
Age	1087.642667	4	271.9107	62.78725	4.78E-07	**
Residual	43.30666667	10	4.330667			
Total	1130.949333	14	80.7821			

C.V. (%): 6.11586614894201
S.E.M.: 1.2014805681139
S.E.D.: 1.69915011435442
LSD (p<0.05): 3.78594238514999
LSD (p<0.01): 5.38507002409742

Stem diameter 1

EFFECT	SS	DF	MS	F	ProbF	
Age	0.166666667	4	0.041667	62.5	4.89E-07	**
Residual	0.006666667	10	0.000667			
Total	0.173333333	14	0.012381			

C.V. (%): 3.52089395109688
S.E.M.: 1.49071198499953E-02
S.E.D.: 2.10818510677846E-02
LSD (p<0.05): 4.69732914359191E-02
LSD (p<0.01): 6.68141344773101E-02

Stem diameter 2

EFFECT	SS	DF	MS	F	ProbF	
Age	0.157333333	4	0.039333	19.66667	9.92E-05	**
Residual	0.02	10	0.002			
Total	0.177333333	14	0.012667			

C.V. (%): 6.915674157215
S.E.M.: 0.025819888974713
S.E.D.: 3.65148371670066E-02
LSD (p<0.05): 8.13601273657598E-02
LSD (p<0.01): 0.115725475578452

Leaf number 1

EFFECT	SS	DF	MS	F	ProbF	
Age	4.933333333	4	1.233333	6.166667	0.009103	**
Residual	2	10	0.2			
Total	6.933333333	14	0.495238			

C.V. (%): 2.49375610873579
S.E.M.: 0.258198889747157
S.E.D.: 0.365148371670105
LSD (p<0.05): 0.813601273657685
LSD (p<0.01):1.15725475578464

Leaf number 2

EFFECT	SS	DF	MS	F	ProbF	
Age	12.93333333	4	3.233333	16.16667	0.00023	**
Residual	2	10	0.2			
Total	14.93333333	14	1.066667			

C.V. (%): 2.44824961040119
S.E.M.: 0.258198889747157
S.E.D.: 0.365148371670104
LSD (p<0.05): 0.813601273657684
LSD (p<0.01): 1.15725475578464

Leaf area 1

EFFECT	SS	DF	MS	F	ProbF	
Age	4440.280893	4	1110.07	51.99894	1.17E-06	**
Residual	213.4794	10	21.34794			
Total	4653.760293	14	332.4114			

C.V. (%): 7.07338632132654
S.E.M.: 2.66757942712115
S.E.D.: 3.77252700454217
LSD(p<0.05):8.40571398898782
LSD (p<0.01): 11.956166742205

Leaf area 2

EFFECT	SS	DF	MS	F	ProbF	
Age	1393.03016	4	348.2575	314.3251	1.82E-10	**
Residual	11.07953333	10	1.107953			
Total	1404.109693	14	100.2935			

C.V. (%): 2.5153182730618
S.E.M.: 0.607715211079659
S.E.D.: 0.859439093569282
LSD (p<0.05): 1.91494963529759
LSD (p<0.01): 2.72379683302781

Fresh weight 1

EFFECT	SS	DF	MS	F	ProbF	
Age	3.19096	4	0.79774	114.0715	2.67E-08	**
Residual	0.069933333	10	0.006993			
Total	3.260893333	14	0.232921			

C.V. (%): 7.22576199965163
S.E.M.: 4.82815814893329E-02
S.E.D.: 6.82804673550363E-02
LSD ($p<0.05$): 0.152138362145537
LSD ($p<0.01$): 0.216399419261831

Fresh weight 2

EFFECT	SS	DF	MS	F	ProbF	
Age	1.115106667	4	0.278777	74.8059	2.07E-07	**
Residual	0.037266667	10	0.003727			
Total	1.152373333	14	0.082312			

C.V. (%): 6.74297832294674
S.E.M.: 3.52451730343656E-02
S.E.D.: 4.98442017133864E-02
LSD ($p<0.05$): 0.111059802383837
LSD ($p<0.01$): 0.157969866378642

Effect of stocking density

Height 1

EFFECT	SS	DF	MS	F	ProbF	
Density	1174.66	4	293.665	55.34583	8.72E-07	**
Residual	53.06	10	5.306			
Total	1227.72	14	87.69429			

C.V. (%): 2.56511763337985
S.E.M.: 1.32991227780915
S.E.D.: 1.8807799800442
LSD($p<0.05$):4.19063894557444
LSD($p<0.01$):5.96070459395912

Height 2

EFFECT	SS	DF	MS	F	ProbF	
Density	1601.036	4	400.259	26.07664	2.85E-05	**
Residual	153.4933333	10	15.34933			
Total	1754.529333	14	125.3235			

C.V. (%): 4.37615145336372
S.E.M.: 2.26195588914653
S.E.D.: 3.19888869592071
LSD (p<0.05): 7.12756818656065
LSD (p<0.01): 10.1381505267248

Stem diameter 1

EFFECT	SS	DF	MS	F	ProbF	
Density	0.369333333	4	0.092333	19.78571	9.66E-05	**
Residual	0.046666667	10	0.004667			
Total	0.416	14	0.029714			

C.V. (%): 8.98855330347299
S.E.M.: 3.94405318873293E-02
S.E.D.: 5.57773351022696E-02
LSD (p<0.05): 0.124279647401625
LSD (p<0.01): 0.176773583891021

Stem diameter 2

EFFECT	SS	DF	MS	F	ProbF	
Density	0.289333333	4	0.072333	36.16667	6.41E-06	**
Residual	0.02	10	0.002			
Total	0.309333333	14	0.022095			

C.V. (%): 5.78293442456789
S.E.M.: 2.58198889747138E-02
S.E.D.: 3.65148371670077E-02
LSD (p<0.05): 8.13601273657624E-02
LSD (p<0.01): 0.115725475578455

Branch number 1

EFFECT	SS	DF	MS	F	ProbF	
Density	320.4	4	80.1	31.61842	1.19E-05	**
Residual	25.33333333	10	2.533333			
Total	345.7333333	14	24.69524			

C.V. (%): 10.031375114549
S.E.M.: 0.91893658347268
S.E.D.: 1.29957257930786
LSD (p<0.05): 2.89562815493186
LSD (p<0.01): 4.11869986168273

Branch number 2

EFFECT	SS	DF	MS	F	ProbF	
Density	398	4	99.5	106.6071	3.72E-08	**
Residual	9.333333333	10	0.933333			
Total	407.3333333	14	29.09524			

C.V. (%): 6.16654329625082
S.E.M.: 0.557773351022717
S.E.D.: 0.788810637746615
LSD (p<0.05): 1.7575796288233
LSD (p<0.01): 2.4999559980799

Leaf number 1

EFFECT	SS	DF	MS	F	ProbF	
Density	2986.266667	4	746.5667	4.100513	0.032008	*
Residual	1820.666667	10	182.0667			
Total	4806.933333	14	343.3524			

C.V. (%): 8.50055113485664
S.E.M.: 7.79030736806251
S.E.D.: 11.0171583349691
LSD (p<0.05): 24.547758524629
LSD (p<0.01): 34.9163788409115

Leaf number 2

EFFECT	SS	DF	MS	F	ProbF	
Density	3331.333333	4	832.8333	60.0601	5.91E-07	**
Residual	138.6666667	10	13.86667			
Total	3470	14	247.8571			

C.V. (%): 2.29864033642303
S.E.M.: 2.14993539954643
S.E.D.: 3.04046780026458
LSD (p<0.05): 6.77458443398276
LSD (p<0.01): 9.63607151135031

Shoot dry weight 1

EFFECT	SS	DF	MS	F	ProbF	
Density	0.058026667	4	0.014507	1088	3.79E-13	**
Residual	0.000133333	10	1.33E-05			
Total	0.05816	14	0.004154			

C.V. (%): 1.32300134663297
S.E.M.: 2.10818510678231E-03
S.E.D.: 2.98142397000452E-03
LSD (p<0.05): 6.64302658181023E-03
LSD (p<0.01): 9.44894551362047E-03

Shoot dry weight 2

EFFECT	SS	DF	MS	F	ProbF	
Density	0.058973333	4	0.014743	552.875	1.1E-11	**
Residual	0.000266667	10	2.67E-05			
Total	0.05924	14	0.004231			

C.V. (%): 1.85754596940406
S.E.M.: 2.98142396999975E-03
S.E.D.: 4.21637021355788E-03
LSD (p<0.05): 9.39465828718598E-03
LSD (p<0.01): 1.33628268954651E-02

Weed weight 1

EFFECT	SS	DF	MS	F	ProbF	
Density	2.8776	5	0.57552	261.6	8.18E-12	**
Residual	0.0264	12	0.0022			
Total	2.904	17	0.170824			

C.V. (%): 3.75233260785992
S.E.M.: 2.70801280154617E-02
S.E.D.: 3.82970843102656E-02
LSD (p<0.05): 8.34421786340542E-02

LSD(p<0.01):0.116979960184024

Weed dry weight 2

EFFECT	SS	DF	MS	F	ProbF	
Density	2.941561111	5	0.588312	588.3122	6.56E-14	**
Residual	0.012	12	0.001			
Total	2.953561111	17	0.173739			

C.V. (%): 2.45666801394223
S.E.M.: 1.82574185835089E-02
S.E.D.: 2.58198889747209E-02
LSD (p<0.05): 5.62567053587053E-02
LSD (p<0.01): 7.88678730670143E-02