KWAME NKRUMAH UNIVERSITY OF SCIENCE AND TECHNOLOGY

COLLEGE OF AGRICULTURE AND NATURAL RESOURCES

FACULTY OF RENEWABLE NATURAL RESOURCES

DEPARTMENT OF AGROFORESTRY

Effect of Jatropha Cake and Inorganic fertilizer on the growth and yield of *Jatropha curcas* (L.)

A thesis submitted to the Board of Graduate Studies, Kwame Nkrumah University of Science and Technology in Partial Fulfillment of the Requirements for the Award of the Degree of Master of Philosophy in Agroforestry

By

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BSc. Natural Resources Management

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DECLARATION

I declare that, this thesis presented to the Department of Agroforestry, Faculty of Renewable Natural Resources – Kwame Nkrumah University of Science and Technology, Kumasi, for the award of Master of Philosophy in Agroforestry is the result of my own investigation except for references to other people's work which have been duly cited and that, it has not been presented elsewhere for another degree.

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DEDICATION

This work is dedicated to my mum, Sylvia Mensah Bonsu.

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ABSTRACT

Since the surge of interest in renewable energy alternatives to liquid fossil fuels, attention has been paid to the possibility of growing *Jatropha curcas*, for the purpose of producing biofuel. The seed of *Jatropha curcas* contains 30% oil that can be used in standard diesel engines. Jatropha biodiesel being a profitable alternative, it has attracted many multinational companies into Ghana with the quest of establishing jatropha plantations. In line with the Bioenergy Policy of Ghana, the government is collaborating with the private sector to develop about one million hectares of jatropha plantation throughout the country. The need therefore arises as to how to improve the yield of jatropha through agronomic techniques such as fertilization to produce enough oil to contribute to the energy requirements of the nation. Few studies on its utilization have proven that jatropha bio-waste (cake) has the potential as a fertilizer. This study was therefore carried out at the Agricultural Research Station at Awomaso, under the College of Agriculture and Natural Resources (CANR), Kwame Nkrumah University of Science and Technology (KNUST), Kumasi, Ghana, to investigate the effect of different levels of jatropha cake and their combinations with NPK 15:15:15 on the growth and yield of *Jatropha curcas* plants. A Randomized Complete Block Design (RCBD) with three replicates was used and twelve treatments applied. Results of a one year study showed a significant ($P < 0.05$) vegetative growth (number of leaves, stem height, stem diameter and number of branches) response of *Jatropha curcas* to all the fertilized treatments except lower levels of NPK (T1= 250 Kg/ha). Early growth responses were observed in plants that received either NPK only or their combinations with jatropha cake. Later, plants that received lower levels of NPK showed similar vegetative growth as controls while their combinations with jatropha cake still performed better. Plants that received jatropha cake only responded late but recorded similar stem heights, stem diameters and number of branches as those that received NPK fertilizers and their combinations with jatropha cake. The combination of both organic and inorganic amendments ensured increased vegetative growth at all stages of the plant's life. Also early flowering as well as fruiting occurred in all fertilized plants but did not translate into higher seed yield. The results of the effects of the various treatments and the plants on the soil's physical and chemical properties showed no significant differences ($p>0.05$) between any of the treatments in soil characteristics after two years. When compared to the initial soil properties however, all the treatments had significantly higher ($p<0.05$) pH values than the initial. The results reported in this work indicate that fertilizer application can induce higher and faster vegetative growth but not seed yields in the first year of the plant's establishment. Also fertilization does not affect the soil's physical and chemical properties. However, the jatropha plant can reduce soil acidity after two years of establishment.

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ABBREVIATIONS

AOAC: Association of Official Analytical Chemists

ARS: Agricultural Research Station

CSIR: Centre for Scientific and Industrial Research

FORIG: Forestry Research Institute of Ghana

FRNR: Faculty of Renewable Natural Resources

GTZ: German Technical Cooperation

NRD: Number of Rainy Days

SOFA: State of Food and Agriculture

TR: Total Rainfall

CHAPTER ONE

1.0 INTRODUCTION

1.1 BACKGROUND

The term global climate change, which was the theme of the Kyoto Protocol signed in 1998 but came into effect in 2005, refers to a lasting statistically significant change in the climate and weather pattern observed on a global scale (Fletcher, 2005). The Kyoto protocol aimed at committing industrialized nations to specified, legally binding, reductions in emissions of six "greenhouse" gases, including carbon dioxide (CO_2). Carbon dioxide is released into the atmosphere through respiration by plants and animals as well as the combustion of fossil fuels. High concentrations of CO_2 in the atmosphere accumulate to form a layer or blanket which prevents the sun's energy from leaving the earth's atmosphere after reflection from the surface of the earth. The trapped solar energy causes an increase in the earth's atmospheric temperature, hence making the earth's climate hotter (Global warming). The need to ameliorate recent increase in global climate change caused by anthropogenic carbon dioxide emissions has driven the world's attention to reduce its dependence on fossil fuels, particularly crude oil (Brittaine and Lutaladio, 2010).

To achieve this goal of reduced CO_2 emissions, it has become imperative to look for more environmentally friendly sources of energy. Bio-energy, including bio-fuels, present a very significant alternative to fossil fuels. Bio-energy is a renewable non-fossil energy, obtained from the combustion of biomass, most often in the form of fuelwood, biogas or liquid bio-fuel. Liquid bio-fuels can be bio-ethanol, biodiesel or straight vegetable oil (Brittaine and Lutaladio, 2010).

Liquid bio-fuels can be used as fuel for vehicle engines, to generate electricity, and also as a fuel for domestic purposes such as cooking and lighting. Replacing fossil fuels with fuel from non-food energy crops will therefore reduce the net addition of CO_2 to the atmosphere. In addition to the net reduction in CO_2 emissions, particulates of hydrocarbons, nitrogen oxides, and sulphur dioxides which are air pollutants are produced in fewer quantities in biodiesels than fossil diesel (Brittaine and Lutaladio, 2010).

The use of bio-diesel has received warm acceptance across the world especially in countries like USA, Brazil, India, Indonesia and Malaysia and production is expected to increase over time. For instance, Indonesia is projected to increase biodiesel production from palm oil from 600 million litres in 2007 to 3 billion litres by 2017, which will make it the world's largest producer of palm oil and the second largest producer of biodiesel (Brittaine and Lutaladio, 2010). A 2008 analysis by the Energy Information Administration found that nearly half of the increase in world biofuel production between now and 2030 will come from the USA (Brittaine and Lutaladio, 2010). Crops that have been used for bio-energy production include soyabeans, rapeseed, oil palm, and recently *Jatropha curcas.*

Since the surge of interest in renewable energy alternatives to liquid fossil fuels, attention has been paid to the possibility of growing *Jatropha curcas,* for the purpose of producing biofuel. The seed of *Jatropha curcas* contains 30% oil that can be used in standard diesel engines and one hectare of the crop can give about 1.6 tonnes of oil under average soil conditions (Gaderkar, 2006). The potential of *Jatropha curcas* to survive on marginal lands offers it a great competitive ability over other bio-energy crops. In addition to its other important roles such as live fencing, improvement of water infiltration, and soil erosion control, is the potential of the jatropha waste after oil extraction to be used as a fertilizer. Chemical analysis of jatropha cake by Ali *et al*. (2010) indicated that the cake has 5.73% nitrogen, and 1.5% phosphorus.

In recent times, the growth of *Jatropha curcas* has become widespread across Africa and Asia. Ghana is projected to be one of the leading producers of jatropha in Africa by 2015. The area planted with jatropha is projected to grow to 4.72 million ha by 2010 and 12.8 million ha by 2011 (Gexsi, 2008). Within the last few years, multinational companies such as Agroils of Italy, Galten from Israel, Scanfuels from Norway and others from Brazil and China have trooped into Ghana requiring huge plots of land to establish jatropha plantations. There is therefore the need to explore areas for improving the nutrition of jatropha to improve and sustain high yields.

1.2 PROBLEM STATEMENT AND JUSTIFICATION

The current global crisis on energy production and the urgency to reduce CO_2 emissions call for identification of other sources of energy such as bio-energy. *Jatropha curcas* being a profitable alternative, has attracted many multinational companies into Ghana with the quest of establishing jatropha plantations. The need therefore arises as to how to improve the yield of jatropha to produce enough oil to contribute to the energy requirements of the nation.

Jatropha is often described as having a low nutrient requirement because it is adapted to growing in poor soils. Growing a productive crop however requires agronomic techniques such as fertilization. Equally, high levels of fertilizer and excessive irrigation can induce increased biomass production at the expense of seed yield (Brady and Weil, 2008).

Current work being done on jatropha in Ghana has centered on germplasm evaluation and there is insufficient data on jatropha responses to fertilizer under different growing conditions. Application of inorganic nitrogenous fertilizers has been reported to increase nitrous oxide (N_2O) emissions which have consequences for global warming. There is therefore the need to explore the use of organic fertilizers either alone or in combination with inorganic amendments which will reduce considerably, the rate of use of inorganic amendments.

Few studies on its utilization have proven that jatropha bio-waste has potential as a fertilizer or for biogas production (Staubmann *et al*., 1997). Agarwal *et al*. (2007), adds that it can be used as manure, as feedstock for biogas production and as animal feed. Envis (2004) also reported that jatropha oil cake as an organic fertilizer is superior to cow-dung manure and is in great demand by agriculturists. This study therefore aims at exploring the potential of jatropha cake and its combination with inorganic fertilizer on the growth and yield of *Jatropha curcas.*

1.3 HYPOTHESES

- Fertilizer application increases the growth and yield of *Jatropha curcas.*
- Combinations of jatropha cake and NPK increase growth and yield of *Jatropha curcas* plants than either jatropha cake or NPK alone.
- Jatropha de-oiled cake can increase the fertility of the soil.
- *Jatropha curcas* plants can maintain soil physical and chemical properties after two years of establishment.

To test these hypotheses, the following objectives below were set.

1.4 OBJECTIVES

- To determine the effect of inorganic fertilizer (NPK 15: 15: 15), jatropha de-oiled cake and their combinations on the growth, fruit and seed yield of *Jatropha curcas.*
- To determine the effect of *Jatropha curcas* and its cake on soil physical and chemical properties.

It was hoped that the achievement of the above objectives would contribute significantly to the country's biodiesel need by providing farmers and companies with key knowledge on the potential of jatropha cake to boost production of *Jatropha curcas*. Furthermore, this knowledge will potentially assist the government in the formulation and implementation of policies with regards to bio-energy production.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 BIOENERGY AND THE NEED FOR BIOFUEL

Bioenergy is a renewable, non-fossil energy obtained from the combustion of biomass, most often in the form of fuelwood, biogas or liquid biofuel. Liquid biofuels can be bioethanol, biodiesel or straight vegetable oil. While bioethanol (ethyl alcohol) is a chemical compound, biodiesel is a mixture of compounds that vary in physical properties according to the feedstock used to produce it. Liquid biofuels can replace petrol and diesel for transport and can be used in stationary engines to generate electricity, pump water and mill food grains as well as for cooking and lighting (Brittaine and Lutaladio, 2010).

Biofuel production can contribute to the accomplishment of the Millennium Development Goals (MDG) in areas such as environmental sustainability (Goal 7) and eradication of extreme hunger and poverty (Goal 1). The recent increase of the earth's temperature (global warming) has become an issue of concern to the world. International bodies like the UN, FAO, NGO's and governmental bodies have policies directed towards the mitigation of Global warming and the need to reduce the emission of Green House Gases (GHG) into the environment. It is known that the use of fossil fuels is a major contributing factor to the total GHG released into the environment. It is estimated that, transport accounts for 21% of total greenhouse gas emissions (Watson *et al*. 1996). As early as 1911, Rudolf Diesel, who invented the diesel engine, made the following statement in a letter: "It is generally forgotten, that vegetable and animal oils can be used directly in diesel engines. A small diesel engine run with peanut oil during the world exhibition in Paris in 1900, worked so well that, the change of fuel was realized by only a few visitors" (Kiefer, 1986). Following this, scientific research has gone beyond the potential of vegetable oil only to shrubs and other perennials that produce oily nuts, hence jatropha. Using cultivated and non-domesticated plants for energy needs instead of fossilized plant remains such as mineral oil and coal will reduce the net addition of CO_2 to the atmosphere. In addition, biodiesel produces fewer particulates, hydrocarbons, nitrogen oxides and sulphur dioxides than mineral diesel and therefore reduces combustion and vehicle exhaust pollutants that are harmful to human health (Brittaine and Lutaladio, 2010). In developing countries, biofuel ensures plant and environmental sustainability by substituting traditional biomass which involves unsustainable felling of trees and shrub. Brittaine and Lutaladio (2010) report that, traditional biomass accounts for 90 percent of energy consumption in poor countries but this is often unhealthy, inefficient and environmentally unsustainable.

Environmental sustainability can again be enhanced through the establishment of biofuel plants like *Jatropha curcas* that have the ability to reclaim lands. Brazil, Nepal and Zimbabwe included *Jatropha curcas* in their oil production schemes to improve the environment through land reclamation, erosion control, enhanced soil fertility, a better microclimate and greenhouse gas (GHG) mitigation (Openshaw, 2000)

With regards to rural poverty, poor subsistent farmers can integrate biofuel plants with their crops for additional income and reduce the production of surplus foods. There is also the possibility of creating jobs for small holder farmers if policies are made to involve them in biofuel production schemes. According to Brittaine and Lutaladio (2010), 1.6 billion people of the world's population lack access to electricity and 2.4 billion use traditional biomass (wood fuels, agricultural by-products and dung). The livelihood of these people can therefore be improved if they resort to biofuel for their energy needs. The use of the other parts of biofuel plants coupled with several uses of the waste after oil extraction also offer alternative sources of income for poor farmers. Openshaw (2000), summarizing the goals of using *Jatropha curcas* for biofuel production in countries like Brazil, Nepal and Zimbabwe indicated poverty reduction as one of the goals, especially for women, through the stimulation of economic activities in rural areas by using the products of such plants for the manufacture of soap, medicines, lubricants, chemicals, fertilizers, insecticides.

The production of biofuel can also supplement the world's energy demand, thus providing energy security. Current higher prices of crude oil are the driving forces for countries that depend on foreign supplies to resort to biofuels. There is even the possibility of higher prices for crude oil as fossil fuel reserves diminish over time, coupled with its exponential demand due to population increase and rising economies (Brittaine and Lutaladio, 2010).

Brazil's present status in bioethanol production is a typical example of how bioenergy can enhance a country's security to energy threat. According to Xavier (2007), Brazil's National Alcohol Program, PROALCOOL, was launched in 1975 as a policy to reduce the country's dependence on oil imports. At the time, Brazil was importing 80 percent of its oil and the 1973 OPEC oil embargo and production cutback raised concerns that oil dependency could endanger national security. This necessitated the production of ethanol from sugarcane to substitute for oil. A program which started with subsidies by the government and revenue from tax payers is now financially standing on its own. Now the industry is not only self sustaining, it has been responsible for the savings of more than USD 100 billion, with Brazil using locally produced bioethanol instead of importing oil. Not only has Brazil reduced its oil import significantly, it is also the largest producer of ethanol in the world (Moreira, 2006).

Notwithstanding the contributions of biofuels, Brittaine and Lutaladio (2010) assert that, the huge volume of biofuels required to substitute for fossil fuels globally is beyond the capacity of agriculture with present day technology. For example in 2006/7, the USA used 20 percent of its maize harvest for ethanol production. This replaced only three percent of its petrol consumption (World Bank, 2008). More significant displacement of fossil fuels will be likely with second and third generation biofuels (SOFA, 2008).

Xavier (2007) however cautions that, the low (3%) replacement of petroleum consumption in USA by maize does not set the rule for all countries as he compared it to the large replacement (40%) of petroleum by ethanol from sugarcane in Brazil though both countries produced almost the same quantities of ethanol. He made the following observations:

- Sugarcane is a superior feedstock for ethanol production over corn.
- US has a lot more cars than Brazil, hence quantities of ethanol produced is relatively small as compared to the number of cars.
- US' corn production for ethanol uses twice the land size used by Brazil for sugarcane production.

This then reveals that, appropriate feedstock is a pre-requisite for large volumes of biofuel production and can be cost-effective depending on factors such as the consuming population, land size for production and distance of refinery sites from the production farm.

2.2 JATROPHA IN GHANA

Jatropha is believed to have been spread by Portuguese seafarers from its centre of origin in Central America and Mexico via Cape Verde and Guinea Bissau to other countries in Africa and Asia. It is now widespread throughout the tropics and sub-tropics (Brittaine and Lutaladio, 2010). Ghana is projected to be one of the leading producers of jatropha in Africa by 2015. The area planted to jatropha is projected to grow to 4.72 million ha by 2010 and 12.8 million ha by 2015. By then, Indonesia is expected to be the largest producer in Asia with 5.2 million ha, Ghana and Madagascar together will have the largest area in Africa with 1.1 million ha, and Brazil is projected to be the largest producer in Latin America with 1.3 million ha (Gexsi, 2008).

Within the last few years several multinational companies have trooped into Ghana acquiring vast areas of land to cultivate jatropha for bio-fuel. Dogbevi (2009), in a publication to Ghana Business News revealed that, an Italian bioenergy consultancy company, Agroils is cultivating 10,000 hectares of jatropha in Ghana for the production of biofuels. He continued that, Agroils is one of the about 20 companies cultivating jatropha and other crops to produce biofuels in Ghana. There are companies from Brazil, Norway, Israel, China, Germany, The Netherlands, Belgium and India investing in jatropha in Ghana. An Israeli company, Galten has acquired 100,000 hectares of land and an Indian company is requesting for 50,000 hectares of land from the Ghana Investment Promotion Council (GIPC), to cultivate jatropha. A company from the Netherlands has started a pilot project on 10 acres in the northern region and the Chinese are also doing a pilot project. Gold Star Farms Ltd. is cultivating five million acres of land to plant jatropha for the production of biofuels for export.

A Norwegian company ScanFuel Limited has started operations outside Kumasi in the Ashanti region to produce biofuel. The company aims to start initial cultivation of jatropha seeds on 10,000 hectares of land. The company which has a Ghanaian subsidiary, ScanFuel Ghana Ltd., has contracted about 400,000 hectares of land, of which 60 percent has been reserved for biofuel production. Another Norwegian company, Biofuels Africa Ltd., the only one among the about 20 biofuels companies cultivating jatropha in Volta region to have received an Environmental Impact Assessment (EIA) permit from Ghana's Environmental Protection Agency (EPA), covers 23,762.45 hectares. It operates in the Volta and Northern Regions of Ghana. According to Dogbevi (2009), the government of Japan has signed a $73,948 with Ohayo Ghana Foundation, an NGO, for the construction of a jatropha oil press factory at Puriya in the Yendi District. Part of the grant is expected to be used for the purchase of a generator to power the factory's machines as well as provide electricity to the over 360 inhabitants of the predominantly farming community.

Jatropha curcas has gained research attention in higher institutions in Ghana such as Kwame Nkrumah University of Science and Technology, Kumasi and the Faculty of Forest Resources Technology, Sunyani. For instance Owusu *et al*. (2012), investigated the genetic diversity of *Jatropha curcas* germplasm as revealed by Random Amplification of Polymorphic DNA (RAPD) test and strategies for scaling up *Jatropha curcas* production in Ghana.

2.3 BACKGROUND AND BOTANICAL DESCRIPTION OF *Jatropha curcas*

Jatropha curcas is a perennial poisonous shrub which normally grows up to 5m high. It belongs to the family Euphorbiaceae, subfamily Crotonoideae and tribe Joannesieae. The origin of the plant has been a bit of controversy as its origin is still not well established in literature. Most literature suggests that it originated from Central America. According to the Centre for jatropha Promotion and Biodiesel (CPJ) (2010), it is still uncertain where its centre of origin is but it is believed to be from Central America and had such common names such as Barbados nut, bubble-bush, physic nut, purge nut or purging nut (USDA, 2008) . It has been introduced to Africa and Asia and is now cultivated worldwide. In Ghana, the Akans call it "nkrandededua". It is widely cultivated as an ornamental plant and prefers arid conditions (Begg and Gaskin, 1994) and is reported to be able to thrive on any type of land even on desert and wasteland Gadekar (2006).

Jatropha curcas is a perennial shrub whose stem and branches contain latex. It has large green to pale-green leaves. According to Begg and Gaskin (1994) and Heller (1996), the physic nut has five to seven simple, ovate, shallow lobed leaves arranged alternately with 3-5 indentations and a length and width of 6-15cm. Its petioles are about 10cm long.

Male and female flowers are produced on the same inflorescence and average 10 or 20 male flowers to each female flower. The flowers are yellow to green in colour, borne in the axils of the leaves, are small and mostly hidden by foliage.

The fruits are small capsule-like, round and about 2.5cm - 4cm (1-1.5 inches) in diameter. They are green when immature, change from green to yellow when mature, becoming dark brown and split to release 2 or 3 black seeds, each about 2cm (3/4 inches) long (Begg and

Gaskin, 1994; Heller, 1996).The flesh of the seeds is white and oily in texture and is reported to have an agreeable taste.

2.4 USES OF JATROPHA

Jatropha curcas is a multipurpose shrub and has many beneficial attributes that cut across both service and productive functions. As any agroforestry tree, it provides services like carbon sequestration, nutrient cycling, mulch and increases soil microbial activity. It is widely planted as a living fence and hedgerow to protect food crops from damage by livestock and as a wind break to prevent soil erosion and moisture depletion and for reclamation of degraded lands. In Madagascar, it is used as a support plant for vanilla (Duke and Wain, 1981).

The productive function of jatropha is very extensive as almost every part of the plant is useful for varying purposes. The seed of *Jatropha curcas* contains oil that can be refined into biodiesel usable in standard diesel engine. The biodiesel is produced from jatropha oil by a process of transesterification. The oil content of jatropha seed can range from 18.4–42.3 percent (Heller, 1996) but generally lies in the range of 30–35 percent. The oil is almost all stored in the seed kernel, which has an oil content of around 50–55 percent (Jongschaap, 2007). This compares well to groundnut kernel (42%), rape seed (37%), soybean seed (14%) and sunflower seed (32%) (Brittaine and Lutaladio, 2010). Like many oil seeds, jatropha oil quality and quantity is a factor of its environment and genetic constituents. One hectare of the crop can give 1.6 tonnes of oil under average soil conditions (Gadekar, 2006). Duke and Wain (1981) add that, any diesel engine, with no modification other than the replacement of natural rubber with synthetic rubber hoses (which late model engines do not have anyway), can run on jatropha fuel once the oil has gone through a process called trans-esterification.

According to Ochse (1980), the young leaves may be safely eaten, steamed or stewed with goat meat, said to counteract the peculiar smell of the goat meat. In India, pounded leaves are applied near horses' eyes to repel flies. The oil has been used for illumination, soap and candle making, adulteration of olive oil and making Turkey red oil. Nuts can be strung on grass and burned like candlenuts (Watt and Breyer-Brandwijk, 1962). Mexicans grow the shrub as a host for the lac insect. Ashes of the burned root are used as a salt substitute (Morton, 1981). Duke and Wain (1981) list it as a pesticide and a raticide as well. The bark can be used as a fish poison (Watt and Breyer-Brandwijk, 1962). In South Sudan, the seed as well as the fruit is used as a contraceptive (List and Horhammer, 1979).

The medicinal value of *Jatropha curcas* cannot be over emphasized as it has been used traditionally in many areas of the world as a folk medicine. Physic nut is a folk remedy for burns, convulsions, cough, dermatitis, diarrhoea, dysentery, fever, gonorrhea, hernia, inflammation, parturition, pneumonia, rheumatism, scabies, sores, stomach ache, syphilis, tetanus, tumors, ulcers, yaws, and yellow fever (Duke and Wain, 1981; List and Horhammer, 1979). The latex is applied topically to bee and wasp stings (Watt and Breyer-Brandwijk, 1962). Mauritians massage ascetic limbs with the oil. Cameroon natives apply the leaf decoction in arthritis (Watt and Breyer-Brandwijk, 1962). Colombians drink the leaf decoction for venereal disease (Morton, 1981). Bahamians drink the leaf decoction for heartburn. Guatemalans place heated leaves on the breast as a lactagogue. Cubans apply the latex for the relief of toothache. Colombians and Costa Ricans apply the latex to burns, hemorrhoids, ringworm, and ulcers. Barbadians use the leaf tea for the treatment of marasmus, Panamanians for jaundice and Venezuelans take the root decoction for the treatment of dysentery (Morton, 1981). Seeds are used also for dropsy, gout, paralysis, and skin ailments (Watt and Breyer-Brandwijk, 1962). The root is used in decoction as a mouthwash for bleeding gums and toothache and for the treatment of eczema, ringworm, and scabies (Duke and Ayensu, 1985).

2.5 ESTABLISHMENT, GROWTH AND YIELD

Jatropha curcas can be planted by sexual (seed) and asexual (cuttings) means. It can either be planted directly in the field or raised in a nursery and the seedlings transplanted. Plants propagated by seeds are generally preferred for the establishment of long-lived plantations for oil production. Direct sowing should only be used in areas with high rainfall and the seeds must be sown after the beginning of the rainy season when sufficient rainfall is certain (Jepsen and Joker, 2003). CPJ (2010) makes the following recommendations for the propagation of jatropha;

- For quick establishment of hedges and plantation for erosion control, directly planted cuttings are best.
- For long-lived plantations, for vegetative oil production, plants propagated by seeds are better.
- Under adequate rainfall conditions, the plantations can also be established by direct seeding.

Generally, seed should be collected when capsules split open. Use of fresh seeds improve germination. According to Openshaw, (2000), the best time for planting is in the warm season before or at the onset of the rains. In the former case, watering of the plants is required. The number of trees per hectare at planting may range from 1100 to 3300. Wider spacing (3m x 3m) is reported to give larger yields of fruit, at least in early years (Heller, 1996). Germination is fast, under good conditions and is complete within 10 days. Germination is epigeal (cotyledons emerge above ground). Soon after the first leaves have formed, the cotyledons wither and fall off. In the nursery, seeds can be sown in germination beds or in containers (Jepsen and Joker, 2003). According to Heller (1996) the germination process involves the seed splitting of the shell, emergence of the radicle and the appearance of four little peripheral roots. Usually, five roots are formed from seedlings; one central and four peripheral (Heller, 1996). A tap root is not usually formed by vegetatively propagated plants (Kumar and Sharma, 2008).

According to Openshaw (2000), growth of the plants is dependent on soil fertility and rainfall, especially the latter. Provided the nutrient level is sufficient, plant growth is a function of water availability, especially in the tropics. Flowers and seed production respond to rainfall and nutrients. Poor nutrient level will lead to increased failure of seed development. Thus, it is important to maintain soil fertility (Openshaw, 2000).

Jatropha curcas is classified as deciduous. It sheds its leaves in the dry season. Its growth is very vigorous at the early stages than at maturity. The plant may reach one metre and flower within five months under good conditions (Heller, 1996). Under such conditions, nursery plants may bear fruits after the first rainy season. However vegetative growth can be excessive at the expense of seed production if too much water is applied, for example with continuous drip irrigation (Brittaine and Lutaladio, 2010). It produces abundant insect pollinated flowers in the wet season. In permanently humid regions flowering occurs throughout the year.

The seeds mature about three months after flowering (Heller, 1996; Openshaw, 2000; Jepsen and Joker, 2003). With one rainy season per year, only one fruiting season can be obtained. With irrigation however, up to three fruitings can occur each year (Openshaw, 2000). Mature plants may reach a height of 5m. Generally, jatropha shows a flowering response to rainfall. After short periods of drought, rain will induce flowering. The cycle of flowering can thus be manipulated with irrigation (FACT, 2007).

According to Heller (1996) *Jatropha curcas* reach economic maturity after 3 to 5 years of establishment. Evidences of low yields within the first year of establishment of *Jatropha curcas* have been variously reported (Matsuno *et al.*, 1985; Heller, 1996 and Patolia *et al.*, 2007). Data on yield of the plant has however not been very consistent. For instance, Heller (1996) reported yields between 0.1 and 8.0 tonnes /ha for different countries and ecological zones. Openshaw (2000) also reported seed yields ranging between 0.4 to 12 tonnes /ha. In a semi arid environment in India, Wani *et al.* (2008) projected a potential yield of 1.0 tonne/ha. According to Jongschaap *et al.* (2007), earlier reported yields used data which were highly variable, and claims of high yields were probably due to extrapolation of values taken from single, high-yielding elderly trees. Also, these popularly reported yields do not show if the seed weights were fresh weights, air dried weights or oven dried weights. For instance, a jatropha project in Mali reported yields of 0.8 to 1.0Kg of seed per metre of live fence (Henning, 1996) which is equivalent to 2.5 and 3.5 tonnes/ha/year based on the assumption that the yields are of air dry tonnes/ha with an average nut moisture of about 10 % (Openshaw, 2000).

2.6 ECOLOGICAL DISTRIBUTION AND CLIMATIC REQUIREMENT

There is a lot of controversy surrounding the ecological distribution and climatic requirements of *Jatropha curcas*. It grows well on well-drained soils with good aeration but is well adapted to marginal soils with low nutrient content except on waterlogged conditions. It is also well adapted to arid and semi-arid conditions (Heller, 1996; Openshaw, 2000 and Gadekar, 2006). Its water requirement is extremely low and will grow under a wide range of rainfall regimes from 200 to over 1500 mm per annum (Heller 1996; Katwal and Soni, 2003). It can stand long periods of drought by shedding most of its leaves to reduce transpiration loss.

Jatropha is also suitable for preventing soil erosion and shifting of sand dunes. On heavy soils, root formation is reduced. Jatropha is a highly adaptable species, but its strength as a crop comes from its ability to grow on very poor and dry sites and its susceptibility to few pests and diseases (Heller, 1996). Kumar and Sharma, (2008) reported that, *Jatropha curcas* likes heat and is therefore found mostly in the tropics and subtropics, although it does well under low temperatures and can withstand a light frost. Most jatropha species occur in the seasonally dry areas: (grassland-savanna or cerrado) and thorn forest scrub. It is however completely lacking from the moist Amazon region (Dehgan and Schutzman, 1994).

The current distribution of physic nut shows that its introduction has been most successful in the drier regions of the tropics with an average annual rainfall of between 300 and 1000 mm. Good examples are Cape Verde and Mali (Heller 1996). The centre of origin from where jatropha materials have been collected for provenance trials shows average annual temperatures well above 20°C and up to 28°C. This shows that, it is well adapted to higher temperatures. Other studies however counter this assertion.

For instance, in a study by Maes *et al.* (2009) on the climatic requirements of *Jatropha curcas* L, some of their findings disagree with the distribution of *Jatropha curcas* based on rainfall requirements. The results of their study showed that jatropha is not common in arid and semi-arid regions but are rather found in tropical savannah and monsoon climates with annual rainfall above 944mm. Ninety-five percent of the specimens collected grew in areas with a mean annual rainfall above 944 mm/year with the average minimum temperature of the coldest month being above 10.5 ˚C. The mean annual temperature range was 19.3–27.2 ˚C. They asserted that plantations in arid and semi-arid areas hold the risk of low productivity or require irrigation for optimum yields. Jatropha production in sites with 900–1200mm rainfall can be up to double (5t dry seed/ha/yr) the production in semi-arid regions (2–3 t dry seed /ha / yr).

Although it has been reported that jatropha is drought resistant and can tolerate low moisture regimes (Heller, 1996; Katwal and Soni, 2003 and Gadekar, 2006), this does not undermine the fact that, healthy growth and better yields of plants are enhanced by adequate moisture and nutrition (Taiz and Zeiger, 2010). According to Boyer (1982), soil moisture deficit is the most limiting environmental factor for plant growth and yield in most parts of the world. Several workers have reported the detrimental effects of moisture stress on soil microbial activity and plant growth (Jenny, 1980; Post *et al.*, 1985 and Gunapala *et al.* (1998). During period of drought, plants suffer from water deficits that lead to inhibition of shoot growth, leaf expansion and photosynthesis (Taiz and Zeiger, 2010). Drought-related reduction of plant growth and yield is largely owed to stomata closure in response to low soil water content, which decreases the intake of carbon dioxide and as a result, decreases photosynthesis (Pompelli *et al.*, 2010).

Works by Van Dam *et al*. (1997), Ye *et al*. (2009) and Gerbens-Leenesa *et al*. (2009) show that *Jatropha curcas* is not more tolerant to drought when compared to annuals such as wheat, soy bean and maize. Maes *et al.* (2009) in studying the effects of drought on plant growth reported that, drought significantly reduced relative growth rates of the *Jatropha curcas* species. In addition to lower nutrient levels, drought stress in marginal soils may account for low yield of *Jatropha curcas* (Fujimaki and Kikuchi, 2010). Lower yields as a result of low moisture and pest infestation on *Jatropha curcas* plants have been reported by other workers (Maes *et al.*, 2009 and Sharma and Srivastava, 2010).

2.7 EFFECT OF JATROPHA PLANT ON SOIL QUALITY

Soil quality has been defined as the capacity of the soil to function within the boundary of an ecosystem while sustaining biological productivity, maintaining environmental quality, and promoting plant and animal health (Doran et al., 1994). Soil quality is determined by the physical, chemical and biological properties of the soil. These properties are controlled by human management practices such as tillage, crop rotation, inorganic and crop residues addition (Fuentes et al., 2009). For instance, the application of fertilizer can maintain, increase or decrease soil pH and microbial activity depending on factors such as type of fertilizer, the time scale, the fertilizer rate and the productivity of the forest involved (Will *et al*., 1984; Titus and Malcolm, 1987; Prescott *et al*., 1992 and Thirukkumaran and Parkinson, 2000). Natural processes such as nutrient cycling and soil erosion also affect the quality of soil. *Jatropha curcas* is a plant that plays an important role in maintaining soil physical and chemical properties (Ogunwole *et al*. 2008)

2.7.1 Effect on Soil Chemical Properties

Soil chemical properties such as percentages of N, P, K, Ca, pH, organic matter and other trace elements constitute the fertility of the soil. The amount of nutrients that is recycled and remains in the mineral soil pool depends on factors such as quantity and rate of decomposition of litter, nutrients release from dying roots, nutrient losses by leaching, surface runoffs and uptake by plants (Campbell *et al*., 1967, Berendse and Aerts, 1987 and Ingestad, 1981). Nutrient loss by leaching and runoff depends on soil properties such as water holding capacity, bulk density and organic matter content of the soil (Ingestad, 1981).

Several studies have reported the effect of jatropha on the chemical properties of soil. For instance, Ogunwole *et al*. (2008) reported the maintenance of organic carbon and nitrogen content of entisols on which *Jatropha curcas* was grown with and without fertilization for one year. Increased carbon content was however recorded in wastelands grown with jatropha in India by Garg *et al*. (2011). Other works by Rao and Korwar (2003), Chaudhary *et al*. (2007) and Ayele (2011) indicated significant increases in nitrogen, carbon and phosphorus contents of soils planted with *Jatropha curcas*.

Higher concentrations of Ca^{2+}, Mg^{2+}, Na^{+} and K^{+} in soils where leaching is less reduce the acidity of soils whose pH is less than 7. Some of these cations are released by decomposition of organic residues such as plant litter and animal manure (Ano and Ubochi, 2007 and Brady and Weil, 2008). By this, there is an indication that jatropha litter can reduce the acidity of soils. In a spacing trial in India, Chaudhary *et al*. (2007) recorded percentages of 2 Mg and 2-4 Ca in leaves of jatropha which were higher than nitrogen percentages. Ayele (2011) reported of significant levels of Ca and Na in soils under stands of jatropha than soils away from the stands. He proposed that, the *Jatropha curcas* plants could improve the availability of these base cations. Ayele (2011) however reported of no significant differences in the pH of basic soils (pH of 8.9) under jatropha stands and those away from the stands.

2.7.2 Organic Matter and Soil Physical properties

Soil organic matter plays an important role in maintaining soil physical properties and processes such as soil structure, water holding capacity, cation exchange capacity, nutrient supply to plants and the ability of a soil to recover after tillage and cropping (Gregorich *et al*., 2001; Matson *et al*., 1997; Studdert and Echeverria, 2000). Factors such as old and new land use types, the soil type, management and climate cause changes in soil organic matter and these changes typically result in differing rates of soil erosion, aggregate formation, biological activity, and drainage (Lantz *et al*., 2001 and Lettens *et al*., 2004). Several studies have shown that organic residues act as binding agents that contribute to soil water and aggregate stabilities (Edwards and Bremner, 1967; Hamblin, 1977; Turchenek and Oades, 1978 and Tisdall and Oades, 1980). According to Haynes and Beare (1997), deposition of organic material from tree canopies result in a large active microbial biomass beneath the canopy, which in turn exudes microbial products that act as binding and gluing agents, thus improving aggregation. Work by Sreedevi *et al.* (2009) indicated that bacterial populations within the rhizosphere of jatropha plants doubled after a year confirms this assertion.

2.8 NUTRITIONAL REQUIREMENTS OF JATROPHA

The ability of *Jatropha curcas* to grow in poor soils does not undermine the necessity of fertilization for increased yield. Like all plants, jatropha responds well to increased soil fertility. Unfortunately enough data is not available on the response of jatropha to fertilizer under different growing regimes; hence there is difficulty in establishing specific recommendations for optimum crop production (Brittaine and Lutaladio, 2010).

Few studies however, have proven that fertilization can increase growth and fruit yield as much as 100% to 120% though over application could lead to increased vegetative growth at the expense of fruit production. For instance, on a wasteland in India, Ghosh *et al*. (2007) discovered that 3.0 tonnes/ha of jatropha seed cake containing 3.2% N, 1.2% P_2O_5 and 1.4% K_2O significantly increased yields by 120% and 93% when applied to young plants at two different spacings. Juwarkar *et al*. (2007) also reported that, *Jatropha curcas* was able to tolerate high amounts of contaminable metals (Arsenic and Chromium) when the soil was treated with bio-sludge and bio-fertilizer (Broth culture of *Azotobacter chroococcum*).

The combination of bio-sludge and bio-fertilizer resulted in increased plant height and biomass yields of the plant whereas growth was inhibited in untreated soils with contamination of above 250 and 100mg/kg of arsenic and chromium respectively. Yong *et al*. (2010) reported of higher rates of photosynthesis in leaves of *Jatropha curcas* plants if nitrogen is not limiting. They again recorded 50% to 100% flowering for jatropha plants that received different levels of inorganic fertilizer (osmocote) while the controls did not flower throughout the study period. Behera *et al*. (2010) found that jatropha plants that received NPK fertilizer developed significantly larger canopies than controls (no fertilization).

In a study to investigate the performance of *Jatropha curcas* under different agro-practices, Behara *et al*. (2010) reported higher number of lateral branches and larger stems in plants that received jatropha cake only and inorganic fertilizer (NPK) at different levels than controlled plants after one year of establishment. Their work also indicated that, jatropha cake only induced increased stem heights and diameters than NPK. Plants that received jatropha cake only reached heights of 121.46cm after one year of establishment.

Better growth of plants as a result of the combination of organic and inorganic sources of nutrients has been reported by Dhoble (1998) and Surgave *et al*. (1998) and it appears that, growth of *Jatropha curcas* responds similarly. Krishna *et al.* (2008) indicated a higher number of lateral branches and taller stems in unpruned jatropha plants treated with a combination of 46:50:25 kg/ha NPK and 5 kg of farm yard manure than others that received either NPK or farm yard manure only and the controls. Chaturvedi *et al.* (2009) and Behera *et al.* (2010) reported similar responses of height and stem diameters of the plant to organic and inorganic nutrition.

Patolia *et al.* (2007) also observed a significant increase of 23% after 2 years in plant heights of *Jatropha curcas* plants that received a combination of 60kg/ha of inorganic nitrogen, 2.55 tonnes/ha of farm yard manure and 1 tonne/ha of jatropha seed cake over those that did not receive any treatment (control). There was also a 17% increase in stem height of plants treated with a combination of 30kg/ha P_2O_5, 2.55 tonnes/ha of farm yard manure and 1 tonne/ha of jatropha seed cake over the control after 2 years. They reported that the plant responded better to nitrogen than phosphorus with regards to seed yield. Seed yields increased with higher rates of nitrogen to a maximum of 467.2kg/ha for plants treated with a combination of 60kg/ha nitrogen, 2.55 tonnes/ha of farm yard manure and 1 tonne/ha of jatropha seed cake after two years though highest yields of 35.6kg/ha was recorded in the first year by plants that received 45kg/ha of 2.55 tonnes/ha of farm yard manure and 1 tonne/ha of jatropha seed cake. Ghosh *et al.* (2007) also reported of increased seed yields of jatropha plants that received fertilization than controls.

2.9 JATROPHA CAKE AND ITS FERTILIZATION POTENTIAL

According to Gadekar (2006), the seed of *Jatropha curcas* contains 30% oil that can be refined into bio-diesel usable in standard diesel engine and one hectare of the crop can give 1.6 tonnes of oil under average soil conditions. The 70 % waste that is left after the oil extraction is the press cake. The press cake cannot be used in animal feed because of its toxic properties. The presence of phytotoxins such as curcin, a highly toxic protein similar to ricin in castor, and deterpene esters makes it unsuitable for animal feed. However it is valuable as organic manure since its nitrogen content of 3.2 to 3.8% is similar to that of the seed cake of castor bean and chicken manure depending on the source and has potential as fertilizer or for biogas production ((Moreira, 1970; Staubmann *et al.*, 1997; Agarwal *et.al.* 2007). As a fertilizer jatropha cake is superior to cow-dung manure and is in great demand by agriculturists (Envis, 2004).

Openshaw (2000) proposes that, if it can be detoxified cheaply, or the oil extracted from toxic free varieties, it could be used in food preparation and the seed cake used as animal feed. In a study to test the use of defatted *Jatropha curcas* waste as an alternative feed in a biogas plant for bio-methanisation, Ali *et al.* (2010) realized a significant increase in the percentage of nitrogen, phosphorus and potassium. The results showed 5.73% nitrogen, 1.5% phosphorus and about 1% potassium in the waste (Table 2.1).

Table 2.1 Biochemical analysis of cow dung and jatropha oil cake.

substrate	TS %	VS %	C %	N %	P %	K %	C/N ratio	Oil content
CD	22.84	86.77	50.33	0.72	0.07	0.08	70:1	nil
JC	90.89	78.56	45.56	5.73	1.75	0.94	8:1	5.67

TS- Total solids; VS- Volatile solids; N- Nitrogen; P- Phosphorus; K- Potassium; CD- Cow dung; JC-jatropha cake. (Source: Ali *et.al*., 2010)

Delgado and Parado (1989) also compared the N, P and K content of jatropha oil cake, neem oil cake and cow dung. Their results are shown in table 2.2.

Table 2.2 Nutritional analysis of oil seed cakes, and manure (%)

Properties	Jatropha oil cake	Neem oil cake	Cow dung
Nitrogen	3.2 – 4.44	5.0	0.097
Phosphorus	1.4 – 2.09	1.0	0.69
Potassium	1.2 – 1.68	1.5	1.66

(Source: Delgado and Parado, 1989)

The relative proportion of N, P and K in jatropha cake shows its potential as fertilizer. Trials on the use of the cake as fertilizer have resulted in the cake being used commercially in some parts of Africa. In Zimbabwe, the seed cake is being promoted as a commercial fertilizer (Heller, 1996). A German Technical Cooperation project (GTZ) in Mali carried out a fertilizer trial with pearl millet where the effect of manure (5 t/ha), physic nut press cake (5 t/ha) and mineral fertilizer (100 kg ammonium phosphate and 50 kg urea/ha) on pearl millet was investigated. Pearl millet yields per ha were 630 kg for the control, 815 kg for manure, 1366 kg for press cake and 1135 kg for mineral fertilizer. As the costs for mineral fertilizer were higher than those for the press cake, the expenditure of 30,000 CFA (US$60) was higher for the latter (Henning, 1996).

The cake has been applied as fertilizer to boost growth and yield of plants. For instance, Deewan (1982) reported that the application of a mixture consisting of 20 kg of well rotten cow dung, 200g jatropha cake and 100g bone meal applied after pruning of plants resulted in improved growth and flowering of roses in India. Patolia *et al.* (2007), Krishna *et al.* (2008) and Behera *et al*. (2010) have reported similarly.

Higher rates of application of jatropha cake have been reported to be toxic to plants. Moreira, (1970) reported of reduced germination of tomato seeds when high rates of up to 5 t/ha were applied. Phytotoxicity to tomatoes at transplanting was reduced by increasing the time difference between application and seeding. A general effect of excess levels of fertilizers is mentioned by Brittaine and Lutaladio (2010). They reported that, high levels of fertilizer and excessive irrigation can induce high total biomass production at the expense of seed yield.

Research has shown a higher percentage of N, P, and K in the slurry of the press cake after undergoing biological degradation by a biogas plant. According to Ali *et al*. (2010), the slurry from a jatropha biogas plant contained 5.56% nitrogen, 2.90% phosphorus and 1.24% potassium. It is much higher than fresh jatropha cake, fresh cow dung and its bio-digested slurry. The oil content in the press cake was also reduced from 5.67% to 3.95%.

2.10 PEST AND DISEASES OF *Jatropha curcas*

There is a popular assertion that pest and diseases are not significant threats to jatropha because of its pesticidal and raticidal properties. According to Brittaine and Lutaladio (2010), incidence of pest and diseases is widely reported under monoculture plantations and may be of economic significance. Diseases such as collar rot, leaf spots, root rot and damping-off have been observed. Popular pests of the plant include the scutellera bug (*Scutellera nobilis*) which causes flower fall, fruit abortion and seed malformation, the larvae of the moth *Pempelia morosalis* which damages flowers and young fruits, the bark-eating borer *Indarbela quadrinotata*, the semi-looper *Achaea janata* and the flower beetle *Oxycetonia versiccolor* (Brittaine and Lutaladio, 2010). Young plants are also prone to damage by termites.

According to Heller (1996), millipedes can cause total loss of young seedlings and locusts can also cause considerable damage to leaves and seedlings. Shanker and Dhyani (2006) reported Scutellera bug (*Scutellera nobilis*) and the inflorescence capsule-borer *Pempelia morosalis* as the two major pests of *Jatropha curcas* plants. The nymphs and adults suck the cell sap from leaves, tender parts of the plant, flowers and capsules (Shanker and Dhyani, 2006). In a bionomic study of *Scutellera perplexa*, a major jatropha pest from the same family (scutellaridae) as *scutellera nobilis*, Parveen *et al.* (2010) made a similar observation in India and reported that, the scutellera bug remained active throughout the year and severe damage to foliage and developing fruits was observed between July and March.

Heller (1996) made a collection of diseases and pests reported by various authors and summarized them as reported in Table 2.3.

Table 2.3 Pests and diseases observed on physic nut plants by different authors.

Name	Damage and symptons	Source
Phytophthora spp., Pythium spp., Fusarium spp., etc	damping off, root rot	Heller (1992)
Helminthosporium tetramera	leaf spots	Singh (1983)
Pestalotiopsis paraguarensis	leaf spots	Singh (1983)
Pestalotiopsis versicolor	leaf spots	Phillips (1975)
Cercospora jatrophae-curces	leaf spots	Kar and Das (1987)
Julus sp. (millipede)	total loss of seedlings	Heller (1992)
Oedaleus senegalensis (locust)	leaves, seedlings	Heller (1992)
Lepidopterae larvae	galleries in leaves	Heller (1992)
Pinnaspis strachani (cushion scale)	die-back of branches	van Harten, pers. comm
Ferrisia virgata (wooly aphid)	die-back of branches	van Harten, pers. comm
Calidea dregei (blue bug)	sucking on fruits	van Harten, pers. comm
Nezara viridula (green stink bug)	sucking on fruits	van Harten, pers. comm
Spodoptera litura	larval feeding on leaves	Meshram and Joshi (1994)

Source (Heller, 1996)

2.11 HARVESTING AND POST HARVEST ACTIVITIES

Jatropha curcas fruits reach full maturity three months after flowering. By this time ripen fruits change colour from green to yellow and brown. Mechanized harvesting can be done by moving the harvester between rows of plants to shake the fruits to fall. Manual harvesting is by simply beating the plants with a stick or direct plucking with the hands. Fruits are dried after harvesting and seeds are removed. This is followed by drying of the seeds. Brittaine and Lutaladio (2010) recommend that, the seeds are shade dried for sowing but sun dried for oil production to reduce moisture content to 6–10 percent. If kept dry and ventilated, the seeds may be stored for up to 12 months without loss of germination or oil content, although there may be losses to pests in storage.

2.12 JATROPHA OIL

2.12.1 Extraction

2.12.1.1 Mechanical extraction methods

The extraction of oil from jatropha seeds can be done mechanically, chemically and enzymatically. The mechanical means of extraction can be done using the traditional method of roasting the seed kernels, grinding them into a paste, adding water and boiling followed by skimming and filtering to separate the oil from the mesh or fibre. This requires a lot of labour. Mechanical oil expellers have been developed to extract the oil of jatropha to reduce labour. The Bielenberg ram press is a hand-operated expeller designed for construction and repair by small and simply equipped workshops. It has a low work rate; one litre of oil produced per hour and therefore is only suited to small-scale or demonstration use (Henning, 2004a cited in Brittaine and Lutaladio, 2010). With the help of this method 3 liters of oil can be obtained with 12 kg of seeds (http://www.aumkiipure.com/oil-extraction.html, accessed on 16-01-2011). To improve the oil extraction efficiency of the hand expellers, the seeds should be heated by leaving them in the sun or by roasting them gently for ten minutes. For small-scale production, it is common practice to feed the expeller with whole seeds. In large processing plants, the husk, which constitutes 40 percent of the seed weight, can be removed first and used as a fuel, for burning or as a biogas feedstock (Brittaine and Lutaladio, 2010). Other known expellers are the Komet oil expeller and the Nepal made Sayari oil expeller which use diesel for operation. Engine-driven expellers can have work rates of 55 litres per hour (Henning, 2008b), with about 10 percent of the oil produced, and required to fuel the diesel engine that powers the press.

The Sayari expeller, manufactured in Tanzania, has a work rate of 15–33 litres per hour with a 4-5 kW engine and is capable of extracting 15 litres of oil from 75 kg of seed (Brittaine and Lutaladio, 2010). Hand presses are relatively inefficient, extracting only about 60 percent of the available seed oil. Engine-driven screw presses can extract 75–80 percent of the available oil, producing 1 litre of jatropha oil from every 4 kg of dried seed (Henning, 2000, cited in Achten *et al.*, 2008). To speed up the rate of extraction, hot oil extraction is used. This involves preheating the ground paste and the addition of solvents to reduce the viscosity of the oil.

2.12.1.2 Chemical and enzymatic methods

The chemical and enzymatic methods of extraction are modified methods which involve the addition of chemicals and catalytic enzymes to extract more oil at a fast rate. Tamalampudi *et al.* (2007) used the lipase producing whole cells of *Rhizopus oryzae* immobilized onto biomass support particles and observed it to be a promising biocatalyst for producing biodiesel. It was reported to be a cost effective approach of extracting jatropha oil.

2.12.2 Oil properties and suitability for biofuel production

Jatropha oil generally has some properties comparable to fossil diesel that offer it the potential to be used for biodiesel production. The presence of unsaturated fatty acids (high iodine value) allows it to remain fluid at lower temperatures. It has a high cetane (ignition quality) rating. Its low sulphur content indicates less harmful sulphur dioxide ($S0_2$) exhaust emissions when the oil is used as a fuel. These characteristics make the oil highly suitable for producing biodiesel (Brittaine and Lutaladio, 2010). The only advantage of diesel over jatropha biodiesel is that diesel has a higher ignition quality than jatropha oil. This is due to the higher viscosity of jatropha oil than diesel. Diesel is a hydrocarbon with 8-10 carbon atoms per molecule, but jatropha oil has 16-18. Thus, the nut oil is much more viscous than diesel and has a lower ignition quality (cetane number). Table 2.4 shows a comparison between the properties of fossil diesel and jatropha oil.

Table 2.4 Comparison of the characteristics of fossil diesel oil and diesel oil from *Jatropha curcas* seeds

Property	Diesel Oil	Oil of *Jatropha curcas* seeds
Density kg/l (15/40 ^oC)	0.84 – 0.85	0.91 – 0.92
Cold solidifying point (^oC)	-14.0	2.0
Flash point (^oC)	80	110 - 240
Cetane number	47.8	51.0
Sulphur (%)	1.0 – 1.2	0.13

Source: (GTZ, 2006).

Some properties of jatropha seed and oil offer it some competitive advantage over other oily seeds used for biodiesel production. For example crude jatropha oil is more viscous than rapeseed but it is characteristically low in free fatty acids, which improves its storability, though it's high unsaturated oleic and linoleic acids make it prone to oxidation in storage (Brittaine and Lutaladio, 2010)

2.12.3 Processing of Jatropha Oil into Biodiesel

Despite jatropha oil's low ignition quality as compared to diesel, a process of heating, double transesterification and blend with other less viscous oils improve this property (Brittaine and Lutaladio, 2010 and Tiwari *et al*., 2007). *Jatropha curcas* oil can be converted to biodiesel through a transesterification process. The transesterification involves a chemical process whereby oil molecules (triglycerides) are added to methanol to form the jatropha methyl ester (Brittaine and Lutaladio, 2010). An alkali usually sodium hydroxide which serves as a catalyst is mixed with methanol to form sodium methioxide. The product, sodium methioxide is then mixed with the raw jatropha oil to produce the methyl ester of jatropha with glycerine as a by product. The suspended glycerine is drained whereas the methyl ester (biodiesel) is washed with water to remove any remaining methanol and impurities.

Jatropha biodiesel (methyl ester) is known to contain low amounts of free fatty acids which improve its storability. Tiwari *et al.* (2007) however, have developed a technique to produce biodiesel from jatropha with high free fatty acids contents (15% FFA), in which a two-stage transesterification process was selected to improve methyl ester yield. The first stage involved an acid pre-treatment process to reduce the FFA level of crude jatropha seed oil to less than 1%, the second was the alkali base catalyzed transesterification process which gave a 90% methyl ester yield. Table 2.5 compares some properties of diesel, jatropha oil, methyl ester of jatropha oil and methanol.

2.5 Properties of Diesel, Jatropha oil, Methyl ester of Jatropha oil (Jatropha biodiesel) and Methanol

Properties	**Diesel**	**Jatropha oil**	**Methyl ester of Jatropha oil**	**Methanol**
Density (kgm^{-3})	840	918.6	880	790
Calorific value($kJ\ kg^{-1}$)	42,490	39,774	38,450	19,674
Viscosity (cst)	4.59	49.93	5.65	-
Cetane number	45 - 55	40 - 45	50	3 - 5
Flash point (^{o}C)	50	240	170	-
Carbon residue (%)	0.1	64	0.5	0.0

Source (Vinayak and Kanwarjit 1991)

2.12.4 Suitability of jatropha biodiesel for diesel engines

Van *et al.* (2007) pointed out that, complete replacement of mineral diesel with biodiesel in diesel engines may cause blockage of the fuel system with dislodged residues, damage the hoses and seals in the fuel system, or cause poorer performance due to lower heating value of the biodiesel. Hence, consideration of compatibility of jatropha biodiesel with diesel engines must be made bearing in mind differences in properties between biodiesel and mineral diesel (crude oil). Compatibility techniques may involve engine modification for complete use of only jatropha biodiesel or the use of partial blends of jatropha biodiesel and mineral diesel for engines with existing standards. Blends of up to 5% biodiesel with mineral diesel are generally accepted as not harmful to engines by engine manufactures (Brittaine and

Lutaladio, 2010). A comparison made by Francis *et al.* (2005) between biodiesel and specifications for specifications for European diesel engines shows that jatropha biodiesel has better specifications thanthe European standards (Table 2.6).

Table 2.6: Characteristics of Jatropha Biodiesel compared to European Specifications for Diesel Engines

Characteristic	Jatropha Biodiesel	European Standard	Remarks
Density (g/cm^3 at 20^{0}C)	0.87	0.86 – 0.900	*
Flash point (^{0}C)	191	> 101	*
Cetane No. (ISO 5165)	57 - 62	> 51	***
Viscisity mm^2/s at 40^{0}C	4.20	3.5 – 5.0	*
Net Calorific Value (MJ/J)	34.4	-	-
Iodine No.	95 - 106	< 120	*
Sulphated ash	0.014	< 0.02	*
Carbon residue	0.025	< 0.3	**

* indicates that jatropha performs better than European standard.
Source: (Francis *et al*., 2005).

Brittaine and Lutaladio (2010) suggest that a two-tank system engine modification for efficiently using 100% jatropha biodiesel in engines. One filled with mineral diesel to serve as a starting and stopping unit and the other tank filled with jatropha biodiesel as the running unit. This can avoid the problem of cold starting with more viscous liquid. Senthil *et al.* (2003) also suggested that methyl ester of jatropha oil and dual fuel operation with methanol induction can give better performance and reduced smoke emissions than the blend.

2.13 NUTRIENT SUPPLY TO PLANTS (ORGANIC VERSUS INORGANIC FERTILIZERS)

Organic and inorganic fertilizers have both advantages and disadvantages though they all promote plant growth and ensure increased yields. The major advantage of inorganic over organic fertilizers is that, they are in soluble forms readily available to plants and hence ensure plants' early development. They however cannot influence plant growth over longer periods when compared to organic fertilizers. According to Loomis and Connor (1992), crop plants use typically less than half of the inorganic fertilizer applied to the soils around them. The remaining minerals may leach into surface waters, ground water, become attached to soil particles or contribute to air pollution (Taiz and Zeiger, 2010).

On the other hand, organic fertilizers are slow in releasing nutrients to plants but they influence plant growth over a long span. Organic fertilizers have to undergo processes of decomposition and mineralization before their nutrients are made available to plants. According to Koenig and Cochran (1994), the extent to which plant residues influence soil fertility is partly determined by their biochemical properties, decomposition and concurrent timing of nutrient release and crop demand. Gunapala *et al.* (1998) added that the rate of decomposition of organic material may be used as a measure of biological activity in the soil and of the potential for the soil to provide adequate inorganic N to a crop. This assertion is also confirmed by Clarholm (1984) who stated that availability of nutrients from soil organic matter to plants relies on the mineralization of nutrients from their immobilized forms. It is however imperative to mention that the decomposition process is highly facilitated by soil micro and macro organisms. Nitrogen mineralization in soil is significantly enhanced by the activities of bacterial-feeding nematodes (Anderson *et al.*, 1979, 1983; Ferris *et al.*, 1998;

Ingham *et al.*, 1985). Brady and Weil, (2010) added that higher microbial activity on organic matter accelerates the decay process resulting in a larger net release of humus and nutrients at the end of the process, a condition called the "Priming Effect". Evidence of microbial and nematode activities in accelerating decomposition and mineralization has been proven by several workers. For instance, the Sustainable Agriculture Farming System in Davis, CA observed a significant higher microbial biomass and activity in an organic farming system than in conventional systems after four years (Scow *et al.*, 1994; Temple *et al.*, 1994a, b). Ferris *et al.* (1996) also made a similar observation in the abundance of nematodes involved in decomposition in an organic system than that in a conventional system. In a study to determine the influence of organic *Crotalaria juncea* (Sunn hemp) hay and ammonium nitrate fertilizers on soil nematode communities, Wang *et al.* (2006) reported that sunn hemp fertilizer resulted in a stimulation of nematodes involved in nutrient cycling, while ammonium nitrate supported a soil ecosystem more conducive to plant parasitic nematodes.

The rate of decomposition of organic matter and nutrient release also depends on the quality of the substrate which is determined by its Carbon to Nitrogen ratio (C:N ratio). In general, nitrogen may be easily mineralized when the C:N ratio is < 20:1 (Ferris and Matute, 2003). Abugre *et al*. (2011) reported a C:N ratio ranging between 17:1 and 9:1 for jatropha litter from 30 to 120 days after leaf fall in a closed canopy system. Partey *et al*. (2010) however found Phosphorus and Magnessium concentrations to be the most influential in decomposition and nutrient release in the mulches of *Tithonia diversifolia* , *Senna spectabilis, Gliricidia sepium, Leucaena leucocephala* and *Acacia auriculiformis.*

2.14 PLANTS GROWTH AND NUTRIENT TRANSLOCATION

Plant growth and development are dependent on the genetic constitution and the environment. Since plants are unable to move, their relationship to their physical environment is basically dependent upon adaptation and agronomic impacts by man.

Plants need essential elements or minerals (nitrogen, potassium, phosphorus, calcium, magnesium, sulphur and silicon) and micro (chlorine, iron, boron, manganese, sodium, zinc, copper, nickel and molybdenum) for their healthy growth and development. These elements are obtained from the soil. Although mineral nutrients continually cycle through all organisms, they enter the biosphere predominantly through the root systems of plants, so in a sense, plants act as the "miners" of the earth's crust (Epstein, 1999).

Nitrogen is the most important element required for plant growth. Plants usually pick up nitrogen in the form of inorganic nitrates (NO_3). The reduction and assimilation of NO_3 in higher plants occur in both above and below ground organs and the extent to which these parts participate in N assimilation depends on the plant species, the level of NO_3 and the environmental conditions to which the plant is exposed (Pate, 1971). In a study on nitrogen uptake and assimilation by white lupin plant, Atkins *et al*. (1979) found significant increases in the concentration of total and soluble N in plant parts when the level of NO_3 in the nutrient solution was increased. Plant species with high nitrogen productivity are able to respond rapidly to increased nutrient availability: they have a relatively large photosynthetic apparatus and so can rapidly convert an increased nitrogen uptake into an increased biomass production (Berendse and Aerts, 1987).

Argen (1985a) however reported that nitrogen availability is the most limiting factor in most temperate and tropical forests. Internal conservation of nitrogen could be critical for survival in a nitrogen limited system (Pate 1971, Switzer and Nelson 1972). Trlica and Singh (1979) proposed that with internal nitrogen recycling, the plant would be protected from the negative effects of reduced availability of soil nitrogen under drought conditions. Pate (1971) and Trlica and Singh (1979) discussed the possibility of nitrogen movement out of senescing plant parts and into storage organs for use in the spring.

Although, translocation and cycling of nitrogen may be very different for different species and different life forms (Dickson, 1989), Dalling *et al.* (1976) reported that grain filling period is commonly associated with low level of nitrogen in the soils where they are grown and William (1955) explained that, under such conditions, the nitrogen needed by the developing grains is mostly supplied by mobilization of protein from vegetative organs. In a similar study to that of Dalling *et al.* (1976), Dickson (1989) found that the leaves contributed the largest quantity of the nitrogen supplied for grain development.

In another study on nitrogen translocation in wheat, Simpson *et al.* (1983) found that nitrogen for grain development was obtained entirely by the redistribution of nitrogen from vegetative organs and leaves contributed the highest. Nitrogen translocated into the leaves and glumes through the xylem was not accumulated in these organs but was transferred to the phloem for re-export from the organs. Layzell *et al.* (1971) added that roots and unexpanded regions of the shoot are heavily dependent on photosynthesizing leaves for assimilates but since roots have other mechanisms such as NO_3 reduction, NH_4 assimilation and N_2 fixation for obtaining nitrogen (Schrader, 1978) plant shoots use physiological mechanisms that translocate more rich N to shoot apices than roots (Layzell *et al.*, 1971).

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 STUDY SITE

The study was conducted between May 2010 and June 2012 at the Agricultural Research Station at Awomaso, under the College of Agriculture and Natural Resources (CANR), Kwame Nkrumah University of Science and Technology (KNUST), Kumasi, Ghana. The area falls within the moist semi-deciduous zone of Ghana and experiences a bimodal rainfall pattern. The major wet season is between April and July with a minor wet season between September and December. The period between December and March constitutes the dry season. There is also a short dry spell in August.

The area records an annual rainfall of 1250mm-1500mm and is characterized by a mean annual humidity of 67.6% and an annual temperature of 26.6^{o}C. The characteristic soil type is sandy loam and is classified as a Ferric Acrisol (FAO / UNESCO).

3.2 STUDY 1: Evaluation of Jatropha cake, NPK and their combinations on the growth and seed yield of *Jatropha curcas.*

3.2.1 Experimental Materials

Seed

Jatropha curcas seeds were collected from jatropha stands which had been used for boundary planting at Bamboi in the Brong Ahafo Region.

Jatropha cake

This was obtained from Biofuels Africa, Lotito farms in the Volta Region.

Fertilizer Material

NPK 15:15:15 fertilizer was bought from an Agro-Chemical shop at Kejetia-Kumasi.

Nursery Bags

These were also obtained from an Agro-Chemical shop at Kejetia, Kumasi.

3.2.2 Land Preparation

The area selected for the experiment had a slope of 0-5% and was cleared of weeds, trees and shrubs. Tree stumps were uprooted and burnt together with their branches. The land was then ploughed, left for two weeks, ploughed again and harrowed to break the lumps of soil. A second harrowing was done a week later to ensure a fine tilt.

3.2.3 Experimental Design and Layout

A randomized complete block design (RCBD) with three replications was used for the experiment. A rectangular portion of land covering an area of 3500m^2 (35m x 100m) was divided into three blocks, each representing a replicate. Each block was sub-divided into twelve (12) plots and treatments were assigned randomly as shown in Table 3.1

Table 3.1 Experimental Layout

BLOCK 1		BLOCK 2		BLOCK 3	
Treatments	**Treatments**	**Treatments**	**Treatments**	**Treatments**	**Treatments**
T0	T6	T5	T11	T9	T1
T1	T7	T3	T10	T4	T2
T2	T8	T7	T4	T11	T5
T3	T9	T0	T1	T10	T6
T4	T10	T2	T6	T3	T8
T5	T11	T8	T9	T0	T7

Each plot of a block covered an area of $75m^2$. Jatropha seedlings were transplanted at a spacing of 3m x 1m giving a total of 25 plants/plot. A week after transplanting, treatments were applied as follows.

T0 = control (no fertilizer)

T1 = NPK at 250 Kg / ha

T2 = NPK at 300 Kg / ha

T3 = Jatropha cake at 2000 Kg / ha

T4 = Jatropha cake at 3000 Kg / ha

T5 = Jatropha cake at 4000 Kg / ha

T6 = Jatropha cake at 1000 Kg / ha + NPK at 125 Kg / ha

T7 = Jatropha cake at 1500 Kg/ha + NPK at 125 Kg / ha

T8 = Jatropha cake at 2000 Kg / ha + NPK at 125 Kg / ha

T9 = Jatropha cake at 1000 Kg / ha) + NPK at 150 Kg / ha

T10 = Jatropha cake at 1500 Kg /ha + NPK at 150 Kg / ha

T11 = Jatropha cake at 2000 Kg / ha + NPK at 150 Kg / ha

Fertilizer rates were chosen based on recommendations of a similar study by Ghosh *et al* (2007)

3.2.4 Nursery

Loamy soil (top soil) samples was collected from the study site (Agricultural Research Station, Awomaso) and bagged in 1200 sealed nursery bags. Before nursery establishment, 100 seeds were sown in 100 bags and after two weeks, percentage germination was recorded to be 91%. Thereafter, one seed was sown in each of the bags on 12th May, 2010. The bottoms of the bags were perforated to allow for drainage and arranged in a rectangular block under a palm tree that provided partial shade. The bags were watered at three days intervals for 45 days after which they were transplanted into the field.

3.2.5 Transplanting

Transplanting was done on 3rd July, 2010. Nine hundred healthy seedlings of uniform height, diameter and number of leaves were selected from the lot for transplanting in the field. At transplanting, holes were dug in the soil at 3m x 1m and the seedlings together with a bulk of soil around the roots were planted in the holes. Twenty five (25) seedlings were planted in each of the thirty six (36) plots. The plants were rain fed.

3.2.6 Fertilizer Application

A day after transplanting, fertilizer treatments were imposed on the plants. Fertilizer was applied in a ring between 5cm and 8cm diameter and at approximately 5cm deep around each plant and covered.

Plate 1. Weighing of Jatropha cake

Plate 2. Application of NPK fertilizer

3.2.7 Weed and Pest Control

Weeding was done at two months intervals after transplanting until November 2010. Subsequent occurrences of weeds and pests were controlled by the application of glyphosate and cymethoate respectively. Table 3.2 shows when weedicides and pesticides were applied to weeds and pests respectively. The major pest encountered was scutellera bug.

Table 3.2 Periods of Application of Weedicides and Pesticides

Date	Application
15th November, 2010	Pesticide and Weedicide
13th December, 2010	Pesticide
9th April, 2011	Pesticide and Weedicide

3.2.8 Harvesting

The plants were harvested twice within the experimental period. The first harvesting was done between 18th December, 2010 and 26th February, 2011 and the second, between 23rd April, 2011 and 17th June, 2011. Yellowish to brown fruits were harvested by hand-plucking (picking) from the plant. Matured fruits that had fallen from the plants were also picked and put into labeled polythene bags.

3.2.9 Data Collection

Data on growth parameters were collected at two (2) weekly intervals from the time of transplanting to harvesting. After harvesting, data were collected on yield and yield components. Field data were collected from 17th July 2010 to 29th January 2011. The period between July and October constituted the major season after which a dry season set in from November to January. After this period, the plants had shed all their leaves and there was apparently no growth in all parameters being measured. Data collection was then paused till 26th February 2011 when new branches and leaves had started emerging. Data collection resumed from this period to 25th May, 2011. This period constituted the minor season.

Growth parameters (on-field)

Nine (9) plants out of the twenty five (25) plants on each plot were tagged for data collection. These nine (9) plants were chosen from the middle rows of every plot to avoid side effect. Growth parameters measured included, stem height, stem diameter, number of leaves, number of primary branches, time to 50% flowering, time to 50% fruiting and time to maturation of fruits. Stem height was recorded as the distance from the base of the plant to the tip of the tallest vertical branch using a measuring tape attached to a straight edge. A pair of veneer calipers was used to record the stem diameter at the base of the plant, about 2cm above ground level. Number of leaves as well as number of branches was counted. Time to 50 % flowering and fruiting as well as fruit maturation were all recorded by counting the days from the time of transplanting to the time when more than half of the plants within a particular treatment had developed these growth components.

Yield Components

Harvested fruits sealed in labeled bags were transported to the Agroforestry Laboratory of the Faculty of Renewable Natural Resources (FRNR) for analysis. The fruits were air dried for 3 days followed by removal of seeds from the husks by hand cracking. Seeds and husks were oven dried at 60^0C for 2 days using a force draught oven and weighed with an electronic balance calibrated in grams. Their weights were recorded. Fruit dry weight was calculated by summing up seed and husk dry weights.

Percentage seed weight was calculated using the relation;

$$\text{Percentage seed weight} = \frac{\text{Weight of seed}}{\text{Weight of fruit}} \times 100\%$$

Weight per seed from the various treatments was calculated by random sampling 100 seeds from each treatment, weighing the sample and dividing the weight by 100.

That is,

$$\text{Weight per seed (g)} = \frac{\text{Weight of 100 seeds}}{100}$$


Plate 3. Seeds separated from husks **Plate 4. Drying of seeds and husks in oven**

Rainfall Data

Annual rainfall data for the years 2010, 2011 and 2012 were collected from the Forestry Research Institute of Ghana (FORIG) which is very close to the experimental area and considered to be a representation of the site (Appendix 1)

3.2.10 Data Analysis

Growth and yield data obtained from the field and laboratory processing were then subjected to analysis of variance using the Statistical Analysis Software (SAS). Results a presented in the form of tables and graphs.

3.3 STUDY II: Influence of Jatropha plant and its cake on the chemical and physical properties of Soil.

3.3.1 Data Collection

Initial soil and Jatropha cake analysis

After the experimental field had been laid out into blocks, samples of soil were collected both sideways and diagonally from the top, middle and bottom portions of the three blocks into polythene bags. Samples were collected at 15cm and 30cm depths of the land by use of a soil auger and carried to the Agroforestry laboratory for analysis. Samples of jatropha cake from each sac were bulked into three samples and analysed in the FRNR soil laboratory.

Soil analysis at the end of the experiment

A year after the final harvest, soils from the various treatments were taken from each of the thirty (36) plots and bulked for laboratory analysis according to the following criteria.

- Controlled soil (Soils from plots with no fertilizer)
- Inorganic amended soil (Soils from plots where NPK only was applied)
- Organic amended soil (Soils from plots where jatropha cake only was applied)
- Organic and Inorganic amended soil (Soils from plots where both NPK and jatropha cake were applied).

Both initial and final soil samples were tested for their pH and contents of nitrogen, phosphorus, potassium and organic matter contents. Similarly, jatropha cake samples were also analyzed for their pH and nitrogen, phosphorus, potassium and organic matter contents. Also bulk density and moisture contents of the final soil samples were determined.

Nitrogen content was determined by the Kjeldahl's method from AOAC (2005). Organic matter and pH were determined by methods described by Page *et al*. (1982). Bulk density was determined by the core sampling procedure. Bray 1-P one analysis was used to determine the phosphorus content. Contents of potassium and moisture were determined by methods described by AOAC (2005).

3.3.2 Data Analysis

Soil data obtained from the laboratory analysis were subjected to analysis of variance using the Statistical Analysis Software (SAS). Results are presented in the form of tables.

CHAPTER FOUR

4.0 RESULTS

Study 1*: Influence of different levels and combinations of jatropha cake and NPK on the growth and yield of *Jatropha curcas

4.1 Major Season:

Vegetative Growth

4.1.1 Number of Leaves

Number of leaves per plant was recorded for the first six weeks after transplanting and is shown in figure 4.1

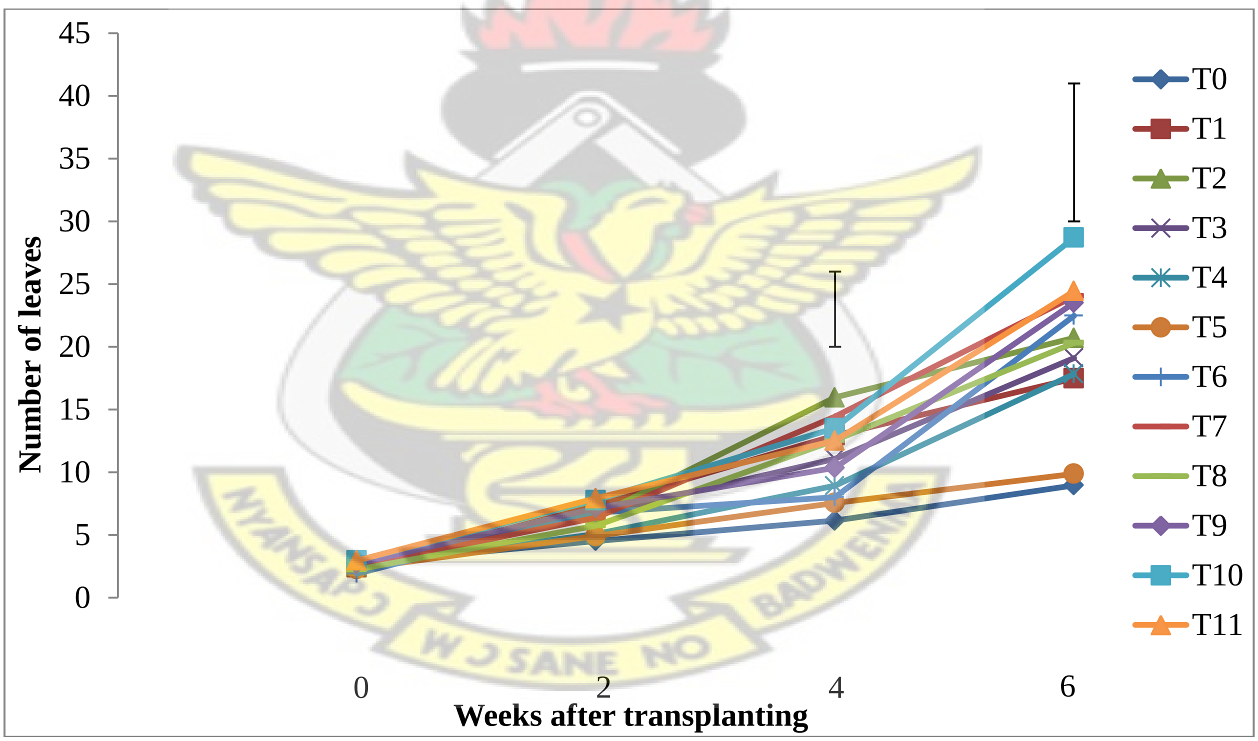

Fig. 4.1 Number of leaves per plant of *Jatropha curcas* plants grown under different levels and combinations of NPK and Jatropha cake for 6 weeks after transplanting (Bars represent LSD's at 5% significance level)

T0 = Control (no fertilizer),
T1 = 250 Kg / ha of NPK,
T2 = 300 Kg / ha of NPK,
T3 = 2000 Kg / ha of Jatropha cake,
T4 = 3000 Kg / ha of Jatropha cake
T5 = 4000 Kg / ha of Jatropha cake
T6 = 1000 Kg / ha of Jatropha cake + 125 Kg / ha of NPK
T7 = 1500 Kg /ha of Jatropha cake + 125 Kg / ha of NPK
T8 = 2000 Kg / ha of Jatropha cake + 125 Kg / ha of NPK
T9 = 1000 Kg / ha of Jatropha cake + 150 Kg / ha of NPK
T10 = 1500 Kg /ha of Jatropha cake + 150 Kg / ha of NPK
T11 = 2000 Kg / ha of Jatropha cake + 150 Kg / ha of NPK

Two weeks after transplanting, there were no significant differences ($P > 0.05$) between all twelve treatments. At week 4 however, treatments which received 300 Kg/ha of NPK **(T2)** had significantly higher ($P < 0.05$) number of leaves than plants that received two levels of jatropha cake only at 3000 Kg/ha and 4000 Kg/ha (T3 and T4) and a combination of 1000 Kg/ha of Jatropha cake + 125 Kg/ha of NPK **(T6).**

Leaf numbers in plants that received a combination of Jatropha cake and NPK (T6, T7, T8, T9, T10 and T11) were all significantly higher ($P < 0.05$) than the control **(T0)** at week 6 but plants receiving 4 tonnes / ha of Jatropha cake only **(T5)** had significantly lower number of leaves ($P > 0.05$) than all combined treatments of NPK and Jatropha cake except plants that received a combination of 2000 Kg/ha of Jatropha cake + 125 Kg/ha of NPK (**T8)**. No significant differences existed between the other fertilized treatments.

4.1.2 Stem Height

Increase in stem height in all treatments followed a characteristic growth curve. It was gradual at the early stages of growth, increased rapidly between weeks 10 and 18 and remained steady between weeks 18 and 26.

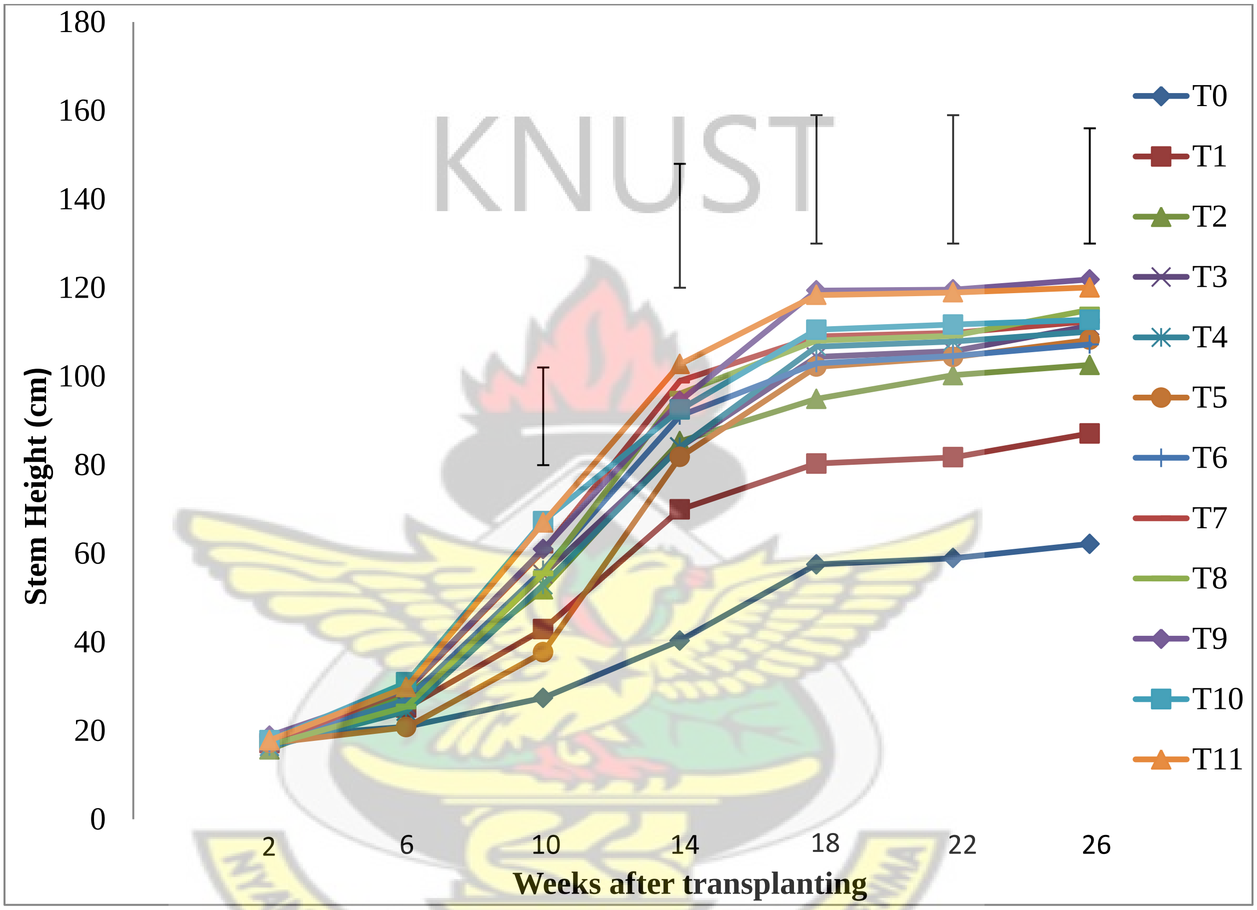

Fig.4.2 Mean stem height (cm) of *Jatropha curcas* plants grown under different levels and combinations of NPK and jatropha cake for 26 weeks after transplanting (Bars represent LSD's at 5% significance level)

T0 = Control (no fertilizer),	T6 = 1000 Kg / ha of Jatropha cake + 125 Kg / ha of NPK
T1 = 250 Kg / ha of NPK,	T7 = 1500 Kg /ha of Jatropha cake + 125 Kg / ha of NPK
T2 = 300 Kg / ha of NPK,	T8 = 2000 Kg / ha of Jatropha cake + 125 Kg / ha of NPK
T3 = 2000 Kg / ha of Jatropha cake,	T9 = 1000 Kg / ha of Jatropha cake + 150 Kg / ha of NPK
T4 = 3000 Kg / ha of Jatropha cake	T10 = 1500 Kg /ha of Jatropha cake + 150 Kg / ha of NPK
T5 = 4000 Kg / ha of Jatropha cake	T11 = 2000 Kg / ha of Jatropha cake + 150 Kg / ha of NPK

No significant differences (P>0.05) were observed in the heights of the plants up to six weeks after transplanting. At week 10 however, all plants that received the fertilized treatments (except the highest level of jatropha cake (T5 4000 Kg/ha)) had significantly higher (P< 0.05) stem heights than controls. Also stem heights of all combinations consisting of the different levels of Jatropha cake and 150 Kg of NPK (T9, T10, T11) in addition to those of T7 (1500 Kg/ha of Jatropha cake + 125 Kg/ha of NPK) were significantly higher (P< 0.05) than those receiving 4000 Kg/ha of Jatropha cake (T5). Between weeks 14 and 22, plant heights in all fertilized treatments were significantly higher (P< 0.05) than the control (T0). In addition, the three treatments T9, T10 and T11 were significantly higher (P< 0.05) than plants receiving 250 Kg/ha of NPK **(T1)** at weeks 18 and 22.

At the final sampling (week 26), plant height in all treatments except the treatment receiving 250 Kg/ha of NPK were significantly higher than control **(T0)**. No differences existed between the other treatments except in the treatment receiving 250 Kg/ha of NPK (T1) which was significantly lower (P > 0.05) than treatments that received combinations of 2000 Kg/ha of Jatropha cake + 125 Kg/ha of NPK (T8**)**, and two other combinations of Jatropha cake and 150 Kg/ha of NPK **(T9, T11)**. Combination of 1000 Kg/ha of Jatropha cake + 150 Kg/ha of NPK **(T9)** recorded the highest stem height of 121.9cm with the control **(T0)** having the least height of 62.2cm

The highest stem height increases for most of the treatments, ranging between 0.46 cm/day and 1.57 cm/day, were observed between weeks 10 and 14 for control plants (T0) and those that received 4000 Kg/ha of Jatropha cake **(T5)** respectively (Table 4.1.).

Table 4.1 Rate of increase in Stem Height (cm/day) of *Jatropha curcas* plants grown under different levels and combinations of Jatropha cake and NPK 26 weeks after transplanting

Treatments	Wk2 – Wk6	Wk6 - Wk 10	Wk10 – Wk14	Wk14 - Wk18	Wk18 – Wk22	Wk22 - Wk26
T0	0.08	0.23	0.46	0.61	0.05	0.12
T1	0.29	0.63	0.97	0.37	0.05	0.19
T2	0.44	0.85	1.20	0.34	0.19	0.08
T3	0.30	1.06	1.03	0.73	0.05	0.20
T4	0.28	1.02	1.11	0.81	0.04	0.08
T5	0.13	0.60	1.57	0.73	0.08	0.14
T6	0.35	1.05	1.24	0.42	0.06	0.09
T7	0.42	1.12	1.37	0.36	0.03	0.09
T8	0.31	1.07	1.45	0.43	0.04	0.21
T9	0.38	1.13	1.20	0.89	0.01	0.08
T10	0.47	1.30	0.90	0.64	0.04	0.04
T11	0.43	1.33	1.28	0.56	0.02	0.04
AVERAGE	0.32	0.95	1.15	0.57	0.05	0.11
LSD (P<0.05)	0.32					

*LSD is for respective monthly average growth rates of all the treatments

T0 = Control (no fertilizer),
T1 = 250 Kg / ha of NPK,
T2 = 300 Kg / ha of NPK,
T3 = 2000 Kg / ha of Jatropha cake,
T4 = 3000 Kg / ha of Jatropha cake
T5 = 4000 Kg / ha of Jatropha cake
T6 = 1000 Kg / ha of Jatropha cake + 125 Kg / ha of NPK
T7 = 1500 Kg /ha of Jatropha cake + 125 Kg / ha of NPK
T8 = 2000 Kg / ha of Jatropha cake + 125 Kg / ha of NPK
T9 = 1000 Kg / ha of Jatropha cake + 150 Kg / ha of NPK
T10 = 1500 Kg /ha of Jatropha cake + 150 Kg / ha of NPK
T11 = 2000 Kg / ha of Jatropha cake + 150 Kg / ha of NPK

4.1.3 Stem Diameter

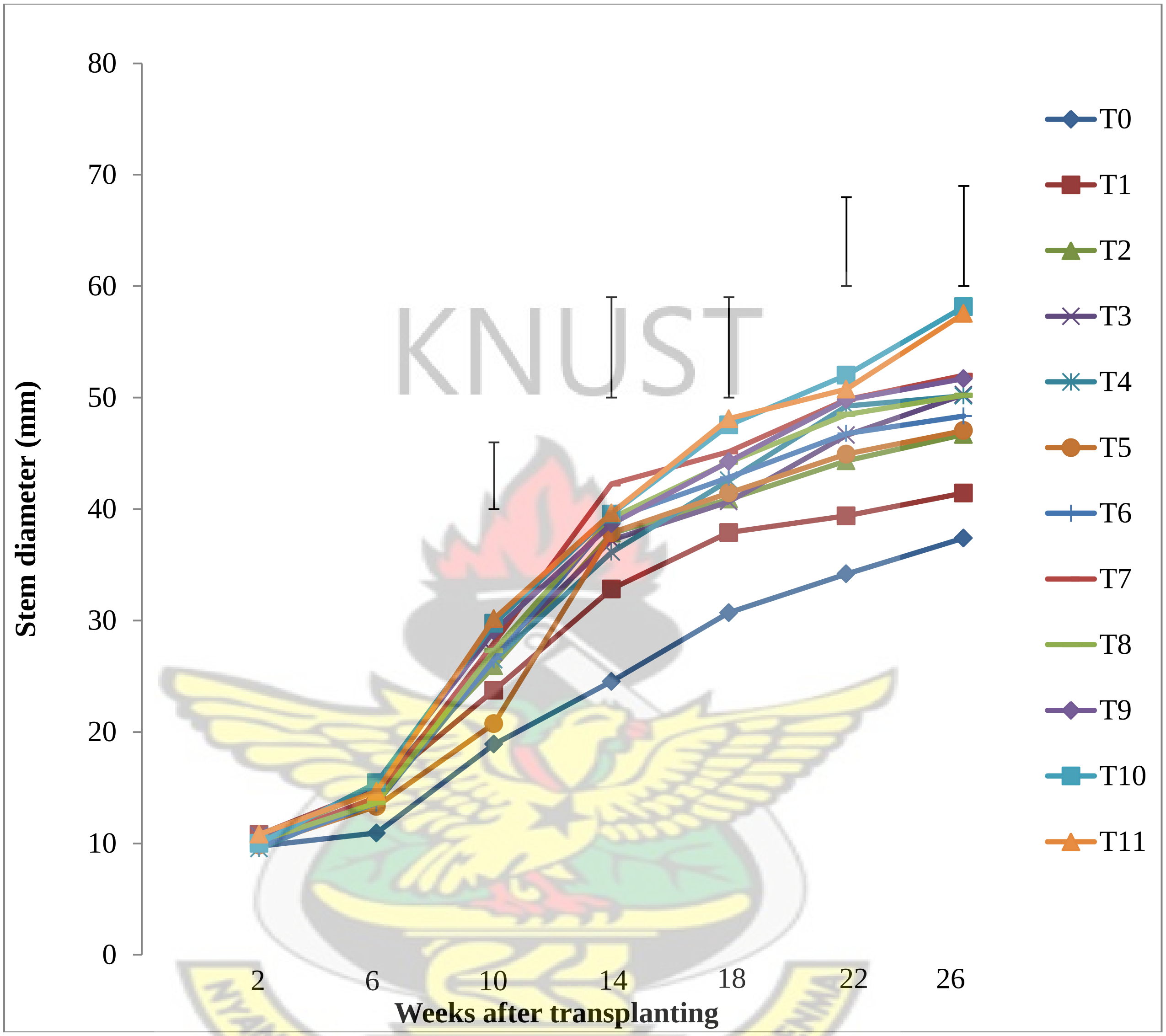

Fig.4.3 Mean stem diameter (mm) of *Jatropha curcas* plants grown under different levels and combinations of NPK and jatropha cake for 26 weeks after transplanting (Bars represent LSD's at 5% significance level)

T0 = Control (no fertilizer),	T6 = 1000 Kg / ha of Jatropha cake + 125 Kg / ha of NPK
T1 = 250 Kg / ha of NPK,	T7 = 1500 Kg /ha of Jatropha cake + 125 Kg / ha of NPK
T2 = 300 Kg / ha of NPK,	T8 = 2000 Kg / ha of Jatropha cake + 125 Kg / ha of NPK
T3 = 2000 Kg / ha of Jatropha cake,	T9 = 1000 Kg / ha of Jatropha cake + 150 Kg / ha of NPK
T4 = 3000 Kg / ha of Jatropha cake	T10 = 1500 Kg /ha of Jatropha cake + 150 Kg / ha of NPK
T5 = 4000 Kg / ha of Jatropha cake	T11 = 2000 Kg / ha of Jatropha cake + 150 Kg / ha of NPK

Stem diameter increased gradually throughout the experiment. There were no significant differences (P> 0.05) between treatments up to six weeks after transplanting. At week 10, all fertilized treatments except 250 Kg/ha of NPK only (T1) and the highest level of Jatropha cake only T5(4000 Kg/ha) had significantly higher stem diameters (P< 0.05) than the control (T0). Also all treatment combinations of Jatropha cake and NPK except that of 1000 Kg/ha of Jatropha cake + 125 Kg/ha of NPK (T6) had significantly higher (P< 0.05) stem diameters than plants treated with 4000 Kg/ha of Jatropha cake only (T5). All fertilized treatments except 250 Kg/ha of NPK were significantly higher (P < 0.05) than the control (T0) at week 14.

Stem diameter then followed a similar trend to that at week 14 until week 26. At the final week (week 26) plants receiving 1500 Kg/ha of Jatropha cake + 150 Kg/ha of NPK (T10) recorded the highest stem diameter of 57.6mm while the control (T0) recorded the lowest stem diameter of 37.4mm. Plants receiving 1500 Kg/ha of Jatropha cake + 150 Kg/ha of NPK and 2000 Kg/ha of Jatropha cake + 150 Kg/ha of NPK (T10, T11) had significantly higher (P < 0.05) stem diameters than treatments that received NPK only (T1 and T2). The highest rate of increase in stem diameter ranging between 0.28mm and 0.55mm was observed between week 6 and week 10 as shown in table 4.2.

Table 4.2 Rate of increase in stem diameter (mm/day) of *Jatropha curcas* plants grown under different levels and combinations of Jatropha cake and NPK 26 weeks after transplanting

Treatments	Wk2 – Wk6	Wk6 - Wk10	Wk10 – Wk14	Wk14 - Wk18	Wk18 – Wk22	Wk22 – Wk26
T0	0.04	0.28	0.20	0.22	0.12	0.12
T1	0.15	0.31	0.32	0.18	0.05	0.07
T2	0.15	0.40	0.43	0.11	0.12	0.08
T3	0.15	0.44	0.36	0.12	0.21	0.13
T4	0.16	0.45	0.34	0.23	0.24	0.03
T5	0.12	0.27	0.61	0.13	0.12	0.08
T6	0.14	0.46	0.45	0.13	0.14	0.06
T7	0.14	0.49	0.51	0.10	0.17	0.08
T8	0.12	0.49	0.42	0.18	0.15	0.06
T9	0.19	0.49	0.34	0.20	0.20	0.07
T10	0.19	0.51	0.35	0.29	0.16	0.22
T11	0.14	0.55	0.34	0.30	0.09	0.24
AVERAGE	**0.14**	**0.43**	**0.39**	**0.18**	**0.15**	**0.10**
LSD(P<0.05)	0.13					

* LSD is for respective monthly average growth rates of all the treatments

T0 = Control (no fertilizer), T6 = 1000 Kg / ha of Jatropha cake + 125 Kg / ha of NPK

T1 = 250 Kg / ha of NPK, T7 = 1500 Kg /ha of Jatropha cake + 125 Kg / ha of NPK

T2 = 300 Kg / ha of NPK, T8 = 2000 Kg / ha of Jatropha cake + 125 Kg / ha of NPK

T3 = 2000 Kg / ha of Jatropha cake, T9 = 1000 Kg / ha of Jatropha cake + 150 Kg / ha of NPK

T4 = 3000 Kg / ha of Jatropha cake T10 = 1500 Kg /ha of Jatropha cake + 150 Kg / ha of NPK

T5 = 4000 Kg / ha of Jatropha cake T11 = 2000 Kg / ha of Jatropha cake + 150 Kg / ha of NPK

Reproductive Growth

4.1.4 Flowering

Table 4.3 Mean number of days to first and 50% flowering of *Jatropha curcas* plants grown under different levels and combinations of Jatropha cake and NPK.

Treatments	No. of days to 1st flowering	No of days to 50% flowering
T0 = Control (no fertilizer)	152	180
T1 = 250 Kg / ha of NPK	124	142
T2 = 300 Kg / ha of NPK	114	142
T3 = 2000 Kg / ha of Jatropha Cake	110	13
T4 = 3000 Kg / ha of Jatropha cake	105	142
T5 = 4000 Kg / ha of Jatropha cake	110	138
T6 = 1000 Kg / ha of Jatropha cake + 125 Kg / ha of NPK	110	138
T7 = 1500 Kg / ha of Jatropha cake + 125 Kg / ha of NPK	110	133
T8 = 2000 Kg / ha of Jatropha cake + 125 Kg / ha of NPK	105	133
T9 = 1000 Kg / ha of Jatropha cake + 150 Kg / ha of NPK	110	133
T10 = 1500 Kg /ha of Jatropha cake + 150 Kg / ha of NPK	105	133
T11 = 2000 Kg / ha of Jatropha cake + 150 Kg / ha) of NPK	105	133
LSD (P<0.05)	**14**	**14**

All treatments flowered between 105 and 152 days after transplanting. Fertilized treatments developed flowers significantly earlier (P<0.05) than the control (T0). There was late flower development in treatments that received 250Kg/ha of NPK (T1) than all the other fertilized treatments. Again all fertilized treatments reached 50% flowering significantly earlier (P<0.05) than control plants (T0) which took 180 days to reach 50% flowering. There were no significant (P>0.05) differences between fertilized treatments with respect to number of days to 50% flowering. All treatments reached 50% flowering between 133 and 180 days.

4.1.5. Seed Yield

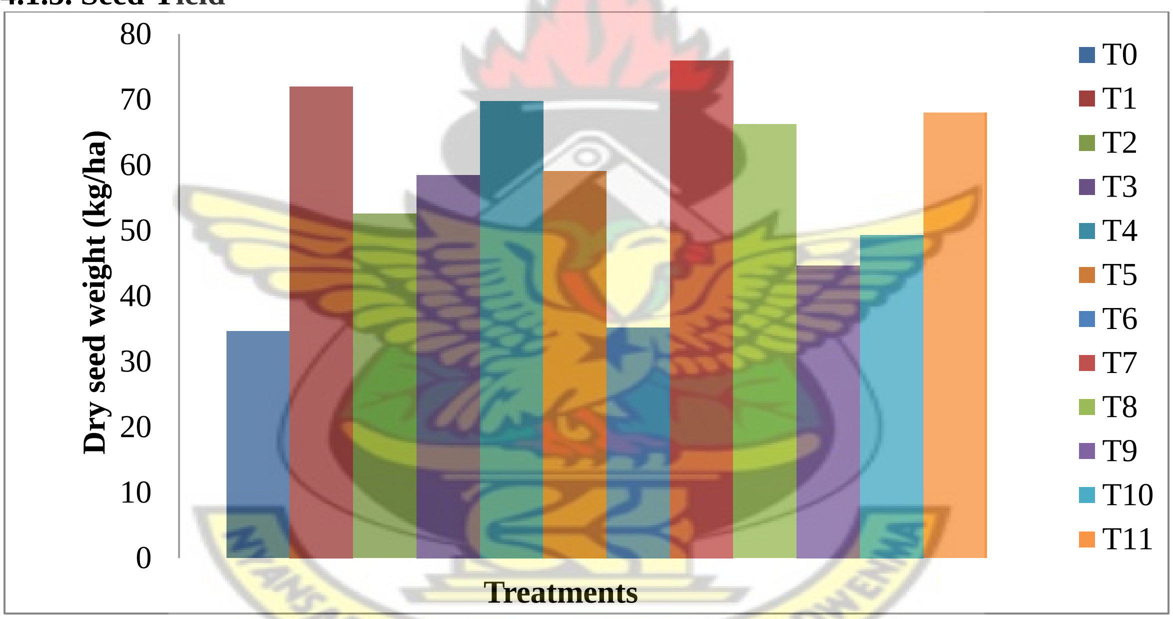

Fig.4.4 Seed dry weight (kg/ha) of *Jatropha curcas* plants grown under different levels and combinations of NPK and jatropha cake, 32 weeks after transplanting

T0 = Control (no fertilizer),	T6 = 1000 Kg / ha of Jatropha cake + 125 Kg / ha of NPK
T1 = 250 Kg / ha of NPK,	T7 = 1500 Kg /ha of Jatropha cake + 125 Kg / ha of NPK
T2 = 300 Kg / ha of NPK,	T8 = 2000 Kg / ha of Jatropha cake + 125 Kg / ha of NPK
T3 = 2000 Kg / ha of Jatropha cake,	T9 = 1000 Kg / ha of Jatropha cake + 150 Kg / ha of NPK
T4 = 3000 Kg / ha of Jatropha cake	T10 = 1500 Kg /ha of Jatropha cake + 150 Kg / ha of NPK
T5 = 4000 Kg / ha of Jatropha cake	T11 = 2000 Kg / ha of Jatropha cake + 150 Kg / ha of NPK

There was about 90% to 130% increment in seed dry weights of some treatments over the controls. Surprisingly, statistical analysis showed no significant differences ($P<0.05$) between the seed dry weights of all treatments. It ranged between 34.6Kg/ha for the control (T0) and 75.9 Kg/ha for treatments that received 1500 Kg/ha of Jatropha cake + 125 Kg/ha of NPK (T7).

4.1.6 Yield Components

No significant differences existed between treatments in all yield components (seed weight, husk weight and fruit weight) that were measured (Table 4.4).

Table 4.4 Yield and yield components of *Jatropha curcas* plants grown under different levels and combinations of Jatropha cake and NPK 15:15:15 30 weeks after transplanting

Treatments	Seed weight Kg/ha	Husk weight Kg/ha	Fruit weight Kg/ha	Percentage seed weight (%)
T0 = control (no fertilizer)	34.6	18.2	52.8	66
T1 = 250 Kg / ha of NPK	72.0	36.1	108.1	67
T2 = 300 Kg / ha of NPK	52.6	27.7	80.3	66
T3 = 2000 Kg / ha of Jatropha cake	58.5	31.2	89.7	65
T4 = 3000 Kg / ha of Jatropha cake	69.8	25.7	95.5	73
T5 = 4000 Kg / ha of Jatropha cake	59.1	26.6	85.7	69
T6 = 1000 Kg/ha of Jatropha cake + 125 Kg / ha of NPK	35.2	20.8	56.0	63
T7 = 150 Kg/ha of Jatropha cake + 125 Kg/ha of NPK	75.9	42.2	118.1	64
T8 = 2000 Kg / ha of Jatropha cake + 125 Kg / ha of NPK	66.2	43.3	109.5	60
T9 = 1000 Kg/ha of Jatropha cake + 150 Kg/ha of NPK	44.7	27.2	71.9	62
T10 = 1500 Kg/ha of Jatropha cake + 150 Kg/ha of NPK	49.3	32.8	82.1	60
T11 = 2000 Kg/ha of Jatropha cake + 150 Kg/ha of NPK	68.0	41.7	109.7	62

4.2 Minor Season

Vegetative Growth

4.2.1 Number of New Branches

New branches refer to the branches that sprouted from the buds of the first season's branches that had already shed all their leaves.

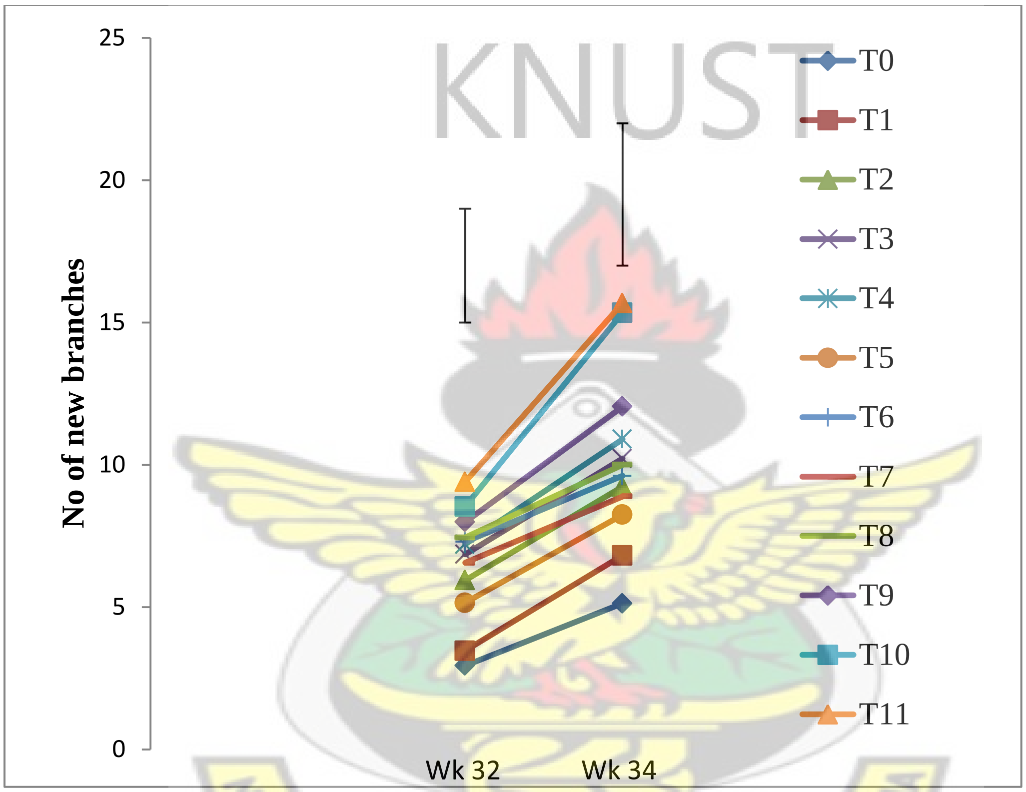

Fig.4.5 Average number of branches per plant of *Jatropha curcas* plants grown under different levels and combinations of NPK and jatropha cake, in the minor season between (32 and 34 weeks after transplanting)
***Bars represent LSD's at 5% significant level**

T0 = Control (no fertilizer),
T1 = 250 Kg / ha of NPK,
T2 = 300 Kg / ha of NPK,
T3 = 2000 Kg / ha of Jatropha cake,
T4 = 3000 Kg / ha of Jatropha cake
T5 = 4000 Kg / ha of Jatropha cake
T6 = 1000 Kg / ha of Jatropha cake + 125 Kg / ha of NPK
T7 = 1500 Kg /ha of Jatropha cake + 125 Kg / ha of NPK
T8 = 2000 Kg / ha of Jatropha cake + 125 Kg / ha of NPK
T9 = 1000 Kg / ha of Jatropha cake + 150 Kg / ha of NPK
T10 = 1500 Kg /ha of Jatropha cake + 150 Kg / ha of NPK
T11 = 2000 Kg / ha of Jatropha cake + 150 Kg / ha of NPK

At week 32, plants that received combined treatments except 1500 Kg/ha of Jatropha cake + 150 Kg/ha of NPK (T7) had significantly higher (P<0.05) number of new branches than the control (T0). No significant differences (P>0.05) existed between plants that received NPK only and the controls. With the exception of plants that received 3000 Kg/ha of jatropha cake only, no significant differences existed between plants that received treatments of jatropha cake only and the controls. Also, all combinations consisting of the different levels of Jatropha cake and 150 Kg/ha NPK (T9, T10, T11) produced significantly higher (P<0.05) number of new branches than treatments that received 250 Kg/ha of NPK only and the controls at both weeks 32 and 34.

At week 34, combinations consisting of 1500 Kg/ha of Jatropha cake + 150 Kg/ha of NPK (T10) and 2000 Kg/ha of Jatropha cake + 150 Kg/ha of NPK (T11) produced significantly higher (P<0.05) number of new branches than all the other treatments except plants that received 1000 Kg/ha of Jatropha cake + 150 Kg/ha of NPK (T9). Plants that received lower and moderate levels of jatropha cake (T3 and T4) also produced significantly higher number of branches than the controls. No significant differences (P>0.05) existed between plants that received the other fertilized treatments and the controls. Plants that received treatment combinations of 2000Kg/ha of Jatropha cake + 150Kg/ha NPK (T11) recorded the highest number of new branches (16) while the control had the least number of new branches (5).

4.2.2 Stem Height

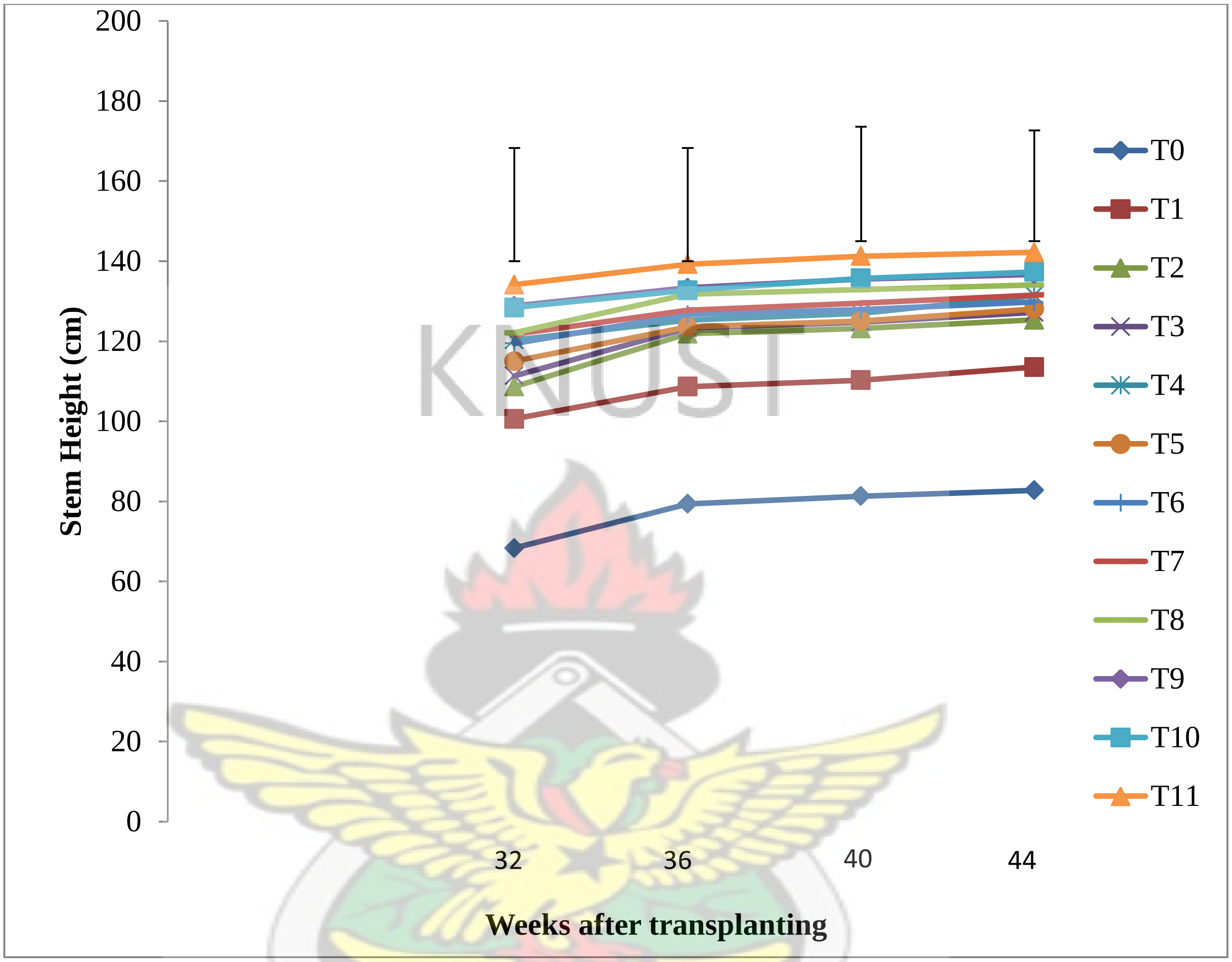

Fig.4.6 Mean stem height (cm) of *Jatropha curcas* plants grown under different levels and combinations of NPK and jatropha cake, between in the minor season (between 32 and 44 weeks after transplanting) *Bars represent LSD's at 5% significance level

T0 = Control (no fertilizer),	T6 = 1000 Kg / ha of Jatropha cake + 125 Kg / ha of NPK
T1 = 250 Kg / ha of NPK,	T7 = 1500 Kg /ha of Jatropha cake + 125 Kg / ha of NPK
T2 = 300 Kg / ha of NPK,	T8 = 2000 Kg / ha of Jatropha cake + 125 Kg / ha of NPK
T3 = 2000 Kg / ha of Jatropha cake,	T9 = 1000 Kg / ha of Jatropha cake + 150 Kg / ha of NPK
T4 = 3000 Kg / ha of Jatropha cake	T10 = 1500 Kg /ha of Jatropha cake + 150 Kg / ha of NPK
T5 = 4000 Kg / ha of Jatropha cake	T11 = 2000 Kg / ha of Jatropha cake + 150 Kg / ha of NPK

At week 32, stem heights of all fertilized treatments (except the treatment that received 250 Kg/ha of NPK only (T1) were significantly higher (P<0.05) than that of the control (T0). Also stem height in the treatment combination of 2000 Kg/ha of Jatropha cake + 150 Kg/ha of NPK (T11) was significantly higher (P<0.05) than treatments that received T1 (250 Kg/ha of NPK only).

A similar trend to the observation at week 32 continued until week 44. Treatment combinations of 2000Kg/ha of Jatropha cake + 150Kg Kg/ha of NPK (T11) recorded the highest stem height of 142.2cm at the end of the experiment while the control (T0) recorded the least height of 82.8cm. This represents a 72% increase in stem height of plants that received T11 (2000Kg/ha of Jatropha cake +150Kg Kg/ha of NPK) over the control. From Fig.4.2.1, it is clear that, higher stem heights were observed in plants that received combined treatments of jatropha cake and NPK (T6, T7, T8, T9, T10, T11) than those that received the other fertilized treatments though not significant. It is also evident that the plant height increased as jatropha cake in the combined treatments also increased, which is from T9 to T10 and finally T11.

The rate of increase in stem heights in all treatments was not significantly different (P>0.05) from each other between week 32 and 40 (Table 4.5). However, the rate of increase of stem heights of plants that received 3000 Kg/ha of jatropha cake (T4) was significantly higher (P<0.05) than all other plants except those that received 4000 Kg/ha of jatropha cake (T5) at week 44.

Table 4.5 Rate of increase in stem height (cm/day) of *Jatropha curcas* plants grown under different levels and combinations of Jatropha cake and NPK in the minor season (between 32 and 44 weeks after transplanting)

Treatments	Wk 32 – Wk 36	Wk 36 – Wk 40	Wk 40 – Wk 44
T0	0.39	0.07	0.05
T1	0.29	0.06	0.06
T2	0.43	0.04	0.08
T3	0.43	0.06	0.08
T4	0.18	0.06	0.16
T5	0.30	0.05	0.11
T6	0.26	0.04	0.07
T7	0.22	0.06	0.07
T8	0.34	0.04	0.05
T9	0.18	0.08	0.05
T10	0.18	0.10	0.06
T11	0.18	0.07	0.05
LSD ($P<0.05$)			**0.06**

*LSD is for Week40 to Week 44 only.

T0 = Control (no fertilizer),
T1 = 250 Kg / ha of NPK,
T2 = 300 Kg / ha of NPK,
T3 = 2000 Kg / ha of Jatropha cake,
T4 = 3000 Kg / ha of Jatropha cake
T5 = 4000 Kg / ha of Jatropha cake
T6 = 1000 Kg / ha of Jatropha cake + 125 Kg / ha of NPK
T7 = 1500 Kg /ha of Jatropha cake + 125 Kg / ha of NPK
T8 = 2000 Kg / ha of Jatropha cake + 125 Kg / ha of NPK
T9 = 1000 Kg / ha of Jatropha cake + 150 Kg / ha of NPK
T10 = 1500 Kg /ha of Jatropha cake + 150 Kg / ha of NPK
T11 = 2000 Kg / ha of Jatropha cake + 150 Kg / ha of NPK

4.2.3 Stem Diameter

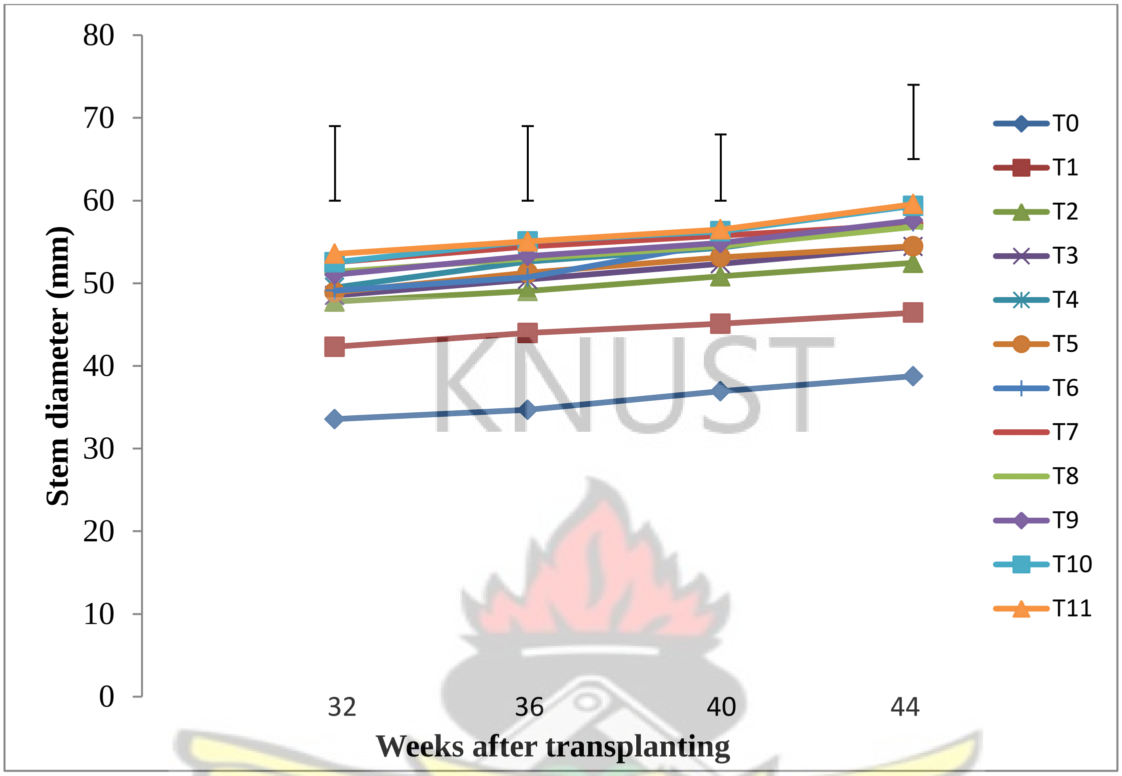

Fig.4.7 Mean stem diameter (mm) of *Jatropha curcas* plants grown under different levels and combinations of NPK and jatropha cake, in the minor season (between 32 and 44 weeks after transplanting) *Bars represent LSD's at 5% significant level

T0 = Control (no fertilizer),	T6 = 1000 Kg / ha of Jatropha cake + 125 Kg / ha of NPK
T1 = 250 Kg / ha of NPK,	T7 = 1500 Kg /ha of Jatropha cake + 125 Kg / ha of NPK
T2 = 300 Kg / ha of NPK,	T8 = 2000 Kg / ha of Jatropha cake + 125 Kg / ha of NPK
T3 = 2000 Kg / ha of Jatropha cake,	T9 = 1000 Kg / ha of Jatropha cake + 150 Kg / ha of NPK
T4 = 3000 Kg / ha of Jatropha cake	T10 = 1500 Kg /ha of Jatropha cake + 150 Kg / ha of NPK
T5 = 4000 Kg / ha of Jatropha cake	T11 = 2000 Kg / ha of Jatropha cake + 150 Kg / ha of NPK

At week 32, stem diameter of all fertilized treatments except treatment T1 (250 Kg/ha of NPK only), were significantly higher ($P<0.05$) than that of controls (T0). Also treatment combinations that received 1500 Kg/ha of Jatropha cake + 150 Kg/ha of NPK (T10) and 2000 Kg/ha of Jatropha cake + 150 Kg/ha of NPK (T11) had significantly ($P<0.05$) larger stem diameters than treatments that received 250 Kg/ha of NPK only. A similar trend was observed at week 36. At week 40 however, all treatment combinations (T6, T7, T8, T9, T10, T11) were significantly higher ($P<0.05$) than treatments that received 250 Kg/ha of NPK only and controls. A similar trend was observed at week 44. With the exception of treatments that received 250 Kg/ha of NPK, no significant differences existed between all the fertilized treatments. Plants that received treatment combinations of 1500 Kg/ha of Jatropha cake + 150 Kg/ha of NPK (T10) and 2000 Kg/ha of Jatropha cake + 150 Kg/ha of NPK (T11) recorded the largest diameter of 59mm while the control (T0) had the smallest diameter of 39mm (Fig 4.7).

Table 4.6 Rate of increase in stem diameter (mm/day) of *Jatropha curcas* plants grown under different levels and combinations of jatropha cake and NPK in the minor season (between 32 and 44 weeks after transplanting)

Treatments	Wk 32 – Wk 36	Wk 36 – Wk 40	Wk 40 – Wk 44
T0	0.08	0.08	0.06
T1	0.05	0.04	0.05
T2	0.06	0.06	0.06
T3	0.05	0.07	0.08
T4	0.08	0.06	0.12
T5	0.06	0.07	0.05
T6	0.12	0.10	0.09
T7	0.05	0.05	0.05
T8	0.07	0.05	0.08
T9	0.10	0.06	0.10
T10	0.11	0.04	0.11
T11	0.08	0.05	0.11

T0 = Control (no fertilizer), T6 = 1000 Kg / ha of Jatropha cake + 125 Kg / ha of NPK

T1 = 250 Kg / ha of NPK, T7 = 1500 Kg /ha of Jatropha cake + 125 Kg / ha of NPK

T2 = 300 Kg / ha of NPK, T8 = 2000 Kg / ha of Jatropha cake + 125 Kg / ha of NPK

T3 = 2000 Kg / ha of Jatropha cake, T9 = 1000 Kg / ha of Jatropha cake + 150 Kg / ha of NPK

T4 = 3000 Kg / ha of Jatropha cake T10 = 1500 Kg /ha of Jatropha cake + 150 Kg / ha of NPK

T5 = 4000 Kg / ha of Jatropha cake T11 = 2000 Kg / ha of Jatropha cake + 150 Kg / ha of NPK

Reproductive Growth

4.2.4 Flowering and Fruiting

Table 4.7 Number of days to flowering, 50% flowering, fruiting and 50% fruiting of *Jatropha curcas* plants grown under different levels and combinations of jatropha cake and NPK.

Treatments	No of days to flowering	No of days to 50% flowering	No of days to fruiting	No of days to 50% fruiting
T0 = control (no fertilizer)	207	223	228	236
T1 = 250 Kg / ha of NPK	205	216	222	228
T2 = 300 Kg / ha of NPK	205	214	222	228
T3 = 2000 Kg / ha of Jatropha Cake	200	211	215	218
T4 = 3000 Kg / ha of Jatropha cake	200	203	210	215
T5 = 4000 Kg / ha of Jatropha cake	204	209	217	226
T6 = 1000 Kg / ha of Jatropha cake + 125 Kg / ha of NPK	200	205	211	215
T7 = 1500 Kg/ha of Jatropha cake + 125 Kg / ha of NPK	203	209	213	221
T8 = 2000 Kg / ha of Jatropha cake + 125 Kg / ha of NPK	202	206	213	225
T9 = 1000 Kg / ha of Jatropha cake + 150 Kg / ha of NPK	200	203	210	220
T10 = 1500 Kg/ha of Jatropha cake + 150 Kg / ha of NPK	202	205	213	219
T11 = 2000 Kg / ha of Jatropha cake + 150 Kg / ha of NPK	200	202	210	218
LSD ($P<0.05$)	**7**	**11**	**8**	**9**

Flowering began in the minor season between 200 and 207 days after transplanting. There were no significant differences (P>0.05) between all the treatments. However significant differences (P<0.05) were observed between treatments with respect to the number of days to 50% flowering. All fertilized treatments except treatments that received NPK only (T1 and T2) reached 50% flowering significantly earlier (P<0.05) than the control (T0). Also all combinations consisting of the different levels of Jatropha cake and 150 Kg/ha of NPK (T9, T10, T11), the highest rate of Jatropha cake (T4) and combinations of 1000 Kg/ha of Jatropha cake + 125 Kg/ha of NPK (T6) reached 50% flowering significantly earlier (P<0.05) than the lower rate of NPK only (T1). It took between 202 and 223 days after transplanting for all the treatments to reach 50% flowering in the minor season.

Fruiting started in all treatments between 210 and 228 days after transplanting. All fertilized treatments except the treatment that received NPK only started fruiting significantly earlier (P<0.05) than the control (T0). All treatment combinations (T6, T7, T8, T9, T10, T11) and treatments that received Jatropha cake only at 3000 Kg/ha (T4) fruited significantly earlier (P<0.05) than the treatment that received NPK only.

Similar to the time of first fruit appearance, all fertilized treatments except plants receiving NPK only reached 50% fruiting significantly earlier (P<0.05) than the controls (T0). Treatment combinations of 1500 Kg/ha of Jatropha cake + 150 Kg/ha of NPK (T10), 2000 Kg/ha of Jatropha cake + 150 Kg/ha of NPK (T11), 1000 Kg/ha of Jatropha cake + 125 Kg/ha of NPK (T6) and treatments that received jatropha cake only at 2000 Kg/ha (T3) and 3000 Kg/ha (T4) reached 50% fruiting significantly earlier (P<0.05) than treatment that received NPK only. No significant differences (P>0.05) existed among the other fertilized treatments.

4.2.5 Seed Yield

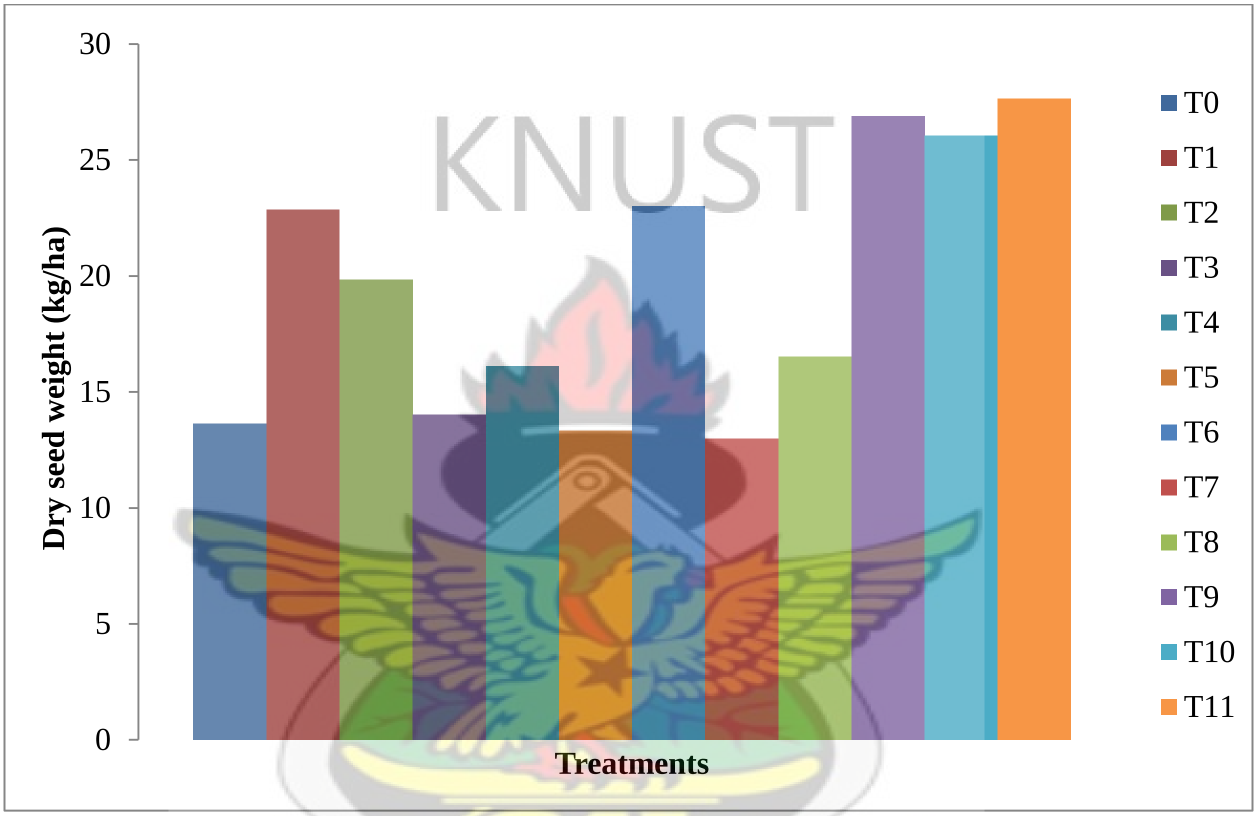

Fig.4.8 Seed dry weight (kg/ha) of *Jatropha curcas plants* grown under different levels and combinations of NPK and jatropha cake 48 weeks after transplanting (Minor season harvest).

T0 = Control (no fertilizer),	T6 = 1000 Kg / ha of Jatropha cake + 125 Kg / ha of NPK
T1 = 250 Kg / ha of NPK,	T7 = 1500 Kg /ha of Jatropha cake + 125 Kg / ha of NPK
T2 = 300 Kg / ha of NPK,	T8 = 2000 Kg / ha of Jatropha cake + 125 Kg / ha of NPK
T3 = 2000 Kg / ha of Jatropha cake,	T9 = 1000 Kg / ha of Jatropha cake + 150 Kg / ha of NPK
T4 = 3000 Kg / ha of Jatropha cake	T10 = 1500 Kg /ha of Jatropha cake + 150 Kg / ha of NPK
T5 = 4000 Kg / ha of Jatropha cake	T11 = 2000 Kg / ha of Jatropha cake + 150 Kg / ha of NPK

The fruits reached maturity sixteen (16) weeks after the major season's harvest. Yields were generally lower than the major season's harvest. Similar to yields of the major season, no significant differences (P>0.05) existed between the various treatments. Seed dry weight for all the treatments ranged between 13.6kg/ha for the control (T0) and 27.6kg/ha for treatments that received 2000 Kg/ha / ha of Jatropha cake + 150 Kg/ha of NPK (T11).

4.2.6 Yield Components

No significant differences (P>0.05) existed between treatments for all the components (seed husk and fruit weights) that were measured (Table 4.8).

Table 4.8 Yield and yield components of *Jatropha curcas* plants grown under different levels and combinations of Jatropha cake and NPK 15:15:15 in the minor season (between 32 and 48 weeks after transplanting)

Treatments	Seed weight Kg/ha	Husk weight Kg/ha	Fruit weight Kg/ha	Percentage seed weight (%)
T0 = control (no fertilizer)	13.6	5.4	19.0	71
T1 = 250 Kg / ha of NPK	22.9	15.1	38.0	60
T2 = 300 Kg / ha of NPK	19.8	11.5	31.3	63
T3 = 2000 Kg / ha of Jatropha cake	14.0	5.8	19.8	71
T4 = 3000 Kg / ha of Jatropha cake	14.0	8.2	22.2	63
T5 = 4000 Kg / ha of Jatropha cake	13.3	5.0	18.3	73
T6 = 1000 Kg/ha of Jatropha cake + 125 Kg/ha of NPK	23.0	13.3	36.3	63
T7 = 1500 Kg/ha of Jatropha cake + 125 Kg/ha of NPK	13.0	7.2	20.2	64
T8 = 2000 Kg/ha of Jatropha cake + 125 Kg/ha of NPK	16.5	9.3	25.8	64
T9 = 1000 Kg/ha of Jatropha cake + 150 Kg/ha of NPK	26.9	15.2	42.1	64
T10 = 1500 Kg/ha of Jatropha cake + 150 Kg/ha of NPK	26.1	15.1	41.2	63
T11 = 2000 Kg/ha of Jatropha cake + 150 Kg/ha of NPK	27.7	8.3	36.0	76

4.2.7 Total Seed yields (Major Season + Minor Season)

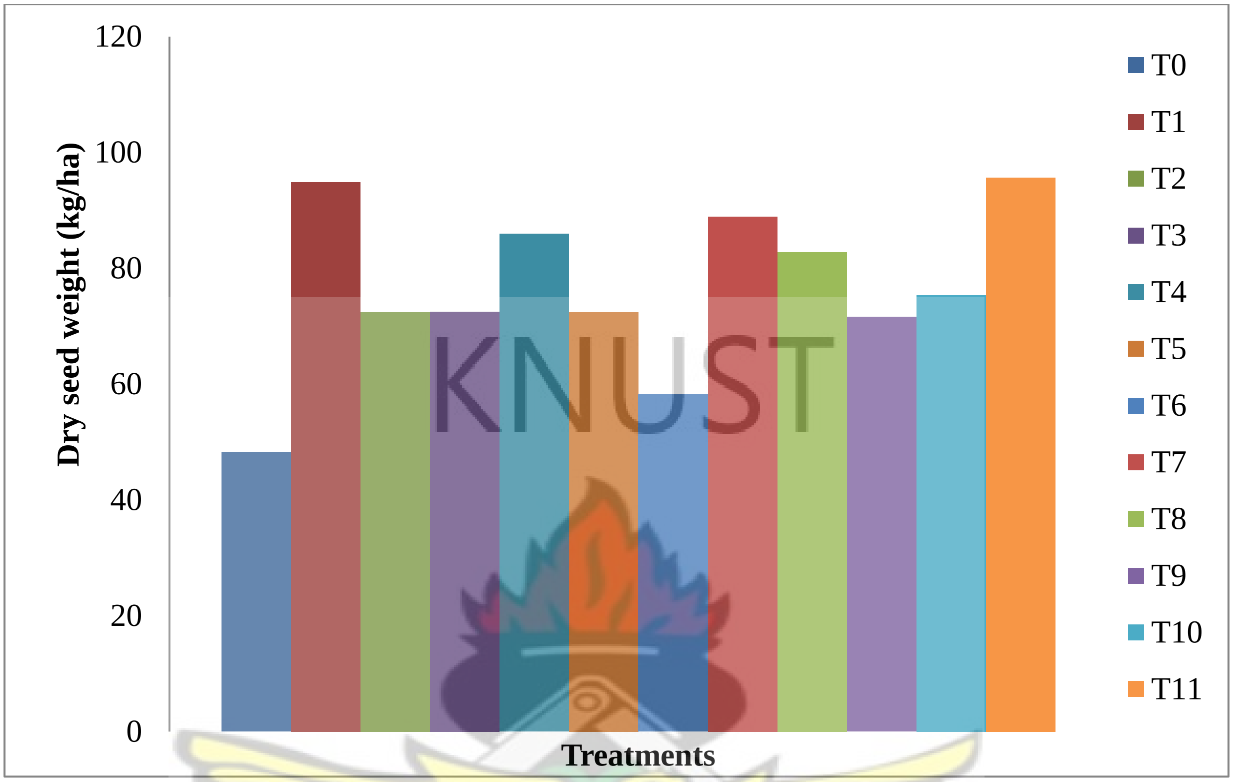

Fig.4.9 Total seed dry weight (kg/ha) of *Jatropha curcas* plants grown under different levels and combinations of NPK and jatropha cake 48 weeks after transplanting (Major season + Minor season).

T0 = Control (no fertilizer),
T1 = 250 Kg / ha of NPK,
T2 = 300 Kg / ha of NPK,
T3 = 2000 Kg / ha of Jatropha cake,
T4 = 3000 Kg / ha of Jatropha cake
T5 = 4000 Kg / ha of Jatropha cake
T6 = 1000 Kg / ha of Jatropha cake + 125 Kg / ha of NPK
T7 = 1500 Kg /ha of Jatropha cake + 125 Kg / ha of NPK
T8 = 2000 Kg / ha of Jatropha cake + 125 Kg / ha of NPK
T9 = 1000 Kg / ha of Jatropha cake + 150 Kg / ha of NPK
T10 = 1500 Kg /ha of Jatropha cake + 150 Kg / ha of NPK
T11 = 2000 Kg / ha of Jatropha cake + 150 Kg / ha of NPK

No significant differences (P>0.05) existed among all the treatments for total seed yield for both the major and the minor season's harvest. Seed weights were generally low ranging between 46.3 kg/ha for the control (T0) and 95.6kg/ha for treatments that received 2000 Kg/ha of Jatropha cake + 150 Kg/ha of NPK (T11).

4.2.8 Yield Components (Major season + Minor season)

Table 4.9a Yield and yield components of *Jatropha curcas* plants grown under different levels and combinations of Jatropha cake and NPK 48 weeks after transplanting

Treatments	Seed weight Kg/ha	Husk weight Kg/ha	Fruit weight Kg/ha	Percentage seed weight (%)
T0 = control (no fertilizer)	48.3	23.6	71.9	67
T1 = 250 Kg / ha of NPK	94.9	51.2	146.1	65
T2 = 300 Kg / ha of NPK	72.4	39.1	111.5	65
T3 = 2000 Kg / ha of Jatropha cake	72.5	38.9	111.4	65
T4 = 3000 Kg / ha of Jatropha cake	85.9	33.9	119.8	72
T5 = 4000 Kg / ha of Jatropha cake	72.5	39.0	111.5	65
T6 = 1000 Kg/ha of Jatropha cake + 125 Kg/ha of NPK	58.2	34.1	92.3	63
T7 = 1500 Kg/ha of Jatropha cake + 125 Kg/ha of NPK	88.9	49.5	138.4	64
T8 = 2000 Kg/ha of Jatropha cake + 125 Kg/ha of NPK	82.8	44.3	127.1	65
T9 = 1000 Kg/ha of Jatropha cake + 150 Kg/ha of NPK	71.6	44.2	115.8	62
T10 = 1500 Kg/ha of Jatropha cake + 150 Kg/ha of NPK	75.4	45.3	120.7	62
T11 = 2000 Kg/ha of Jatropha cake + 150 Kg/ha of NPK	95.6	55.5	151.1	63

Table 4.9b Weight per seed of *Jatropha curcas* grown under different levels and combinations of Jatropha cake and NPK 15:15:15 in the major and minor rainfall seasons

	Weight per seed (g)		
Treatments	**Major season**	**Minor Season**	**Average of Major and minor**
T0 = control (no fertilizer)	0.62	0.66	0.65
T1 = 250 Kg/ha of NPK	0.63	0.55	0.59
T2 = 300 Kg/ha of NPK	0.70	0.55	0.63
T3 = 2000 Kg / ha of Jatropha Cake	0.62	0.55	0.58
T4 = 3000 Kg / ha of Jatropha cake	0.55	0.58	0.56
T5 = 4000 Kg / ha of Jatropha cake	0.58	0.59	0.59
T6 = 1000 Kg / ha of Jatropha cake + 125 Kg / ha of NPK	0.69	0.55	0.60
T7 = 1500 Kg/ha of Jatropha cake + 125 Kg / ha of NPK	0.66	0.60	0.63
T8 = 2000 Kg / ha of Jatropha cake + 125 Kg / ha of NPK	0.64	0.66	0.65
T9 = 1000 Kg / ha of Jatropha cake + 150 Kg / ha of NPK	0.63	0.56	0.59
T10 = 1500 Kg / ha of Jatropha cake + 150 Kg / ha of NPK	0.64	0.58	0.61
T11 = 2000 Kg / ha of Jatropha cake + 150 Kg / ha of NPK	0.60	0.62	0.61

4.3 Study II (Influence of different levels of jatropha cake and inorganic fertilizer on the chemical and physical properties of soil two years after establishment of *Jatropha curcas*)

Table 4.10 Effect of treatment on soil chemical properties

Treatments	**Soil Properties**				
	PH	**N (%)**	**P (ppm)**	**K (Cmol/Kg)**	**OM (%)**
Initial soil characteristics	4.92±0.12	0.11±0.01	11.29±1.60	0.41±0.05	4.17±0.21
After 2 years					
T0 (Control)	5.62±0.41	0.13±0.01	14.99±2.05	0.45±0.08	4.62±0.19
T1T2 (NPK only)	5.49±0.04	0.09±0.06	16.21±2.13	0.56±0.09	3.8±0.09
T3-T5 (Jatropha cake only)	5.45±0.12	0.12±0.06	14.66±2.06	0.53±0.10	4.18±0.18
T6-T11 (Jatropha cake and NPK)	5.48±0.03	0.13±0.02	16.84±2.14	0.55±0.06	3.91±0.25
LSD (0.05)	0.33				

*N-Nitrogen, P- Phosphorus, K- Potassium, OM- Organic matter

There were no significant differences ($P<0.05$) between treatments for soil characteristics after two years. When compared to the initial soil properties however, all the treatments had significantly higher ($P<0.05$) pH values than the initial pH of 4.92 (Table 4.10). No significant differences ($P<0.05$) existed between the nitrogen, phosphorus, potassium and organic matter content of all the treatments and the initial soil concentrations.

Table 4.11 Effect of treatment on Soil physical properties

Treatments	Moisture content (%)	Bulk density (g/cm^3)
T0 (Control)	9.1±0.3	1.30±0.11
T1T2 (NPK only)	8.8±1.6	1.42±0.06
T3-T5 (Jatropha cake only)	9.8±0.4	1.36±0.08
T6-T11 (Jatropha cake and NPK)	8.5±0.8	1.45±0.05

There were no significant differences ($P<0.05$) between any of the treatments in the physical characteristics of the soil after two years.

CHAPTER FIVE

5.0 DISCUSSION

5.1 *Study I*: Influence of different levels and combinations of jatropha cake and NPK on the growth and yield of *Jatropha curcas*

5.1.1 Major Season

Vegetative Growth

Results from the study showed that vegetative growth of *Jatropha curcas* plants (number of leaves, stem heights and stem diameters) responded positively to both organic (Jatropha cake) and inorganic (NPK) fertilizers and their combinations. Lower levels of NPK did not influence vegetative growth (Figs. 4.1, 4.2 and 4.3).

All the plants recorded similar number of leaves, stem heights and diameters two weeks after transplanting probably because of root establishment and adaptation of the young seedlings to the shock of transplanting. This may have affected their uptake of nutrients and therefore their responses to the different treatments had not been established. At week four, seedling roots had been established and plants could access nutrients from the soil. Leaf number therefore increased rapidly in some fertilized treatments over the controls. The responses were higher in plants receiving NPK only and those receiving a combination of NPK and jatropha cake but plants receiving jatropha cake only had similar number of leaves as the controls. Inorganic fertilizer, NPK had readily available nitrogen in soluble forms that could be used by the plants whereas the process of decomposition and mineralization of the jatropha cake only were probably not rapid enough for plants receiving these treatments to readily obtain the required nutrients. According to Koenig and Cochran (1994), the extent to which plant residues influence soil fertility is partly determined by their biochemical properties, decomposition and concurrent timing of nutrient release and crop demand. Gunapala *et al.* (1998) added that the rate of decomposition of organic material may be used as a measure of biological activity in the soil and of the potential for the soil to provide adequate inorganic N to a crop. This assertion is also confirmed by Clarholm (1984) who stated that availability of nutrients from soil organic matter to plants relies on the mineralization of nutrients from their immobilized forms. Plants that received jatropha cake only still had similar number of leaves as controls at week six suggesting that mineralization of nitrogen may not have been adequate to influence soil nitrogen and nitrogen uptake by plants.

The nitrogen supplied by lower levels of NPK (T1 = 250 Kg/ha) may not have increased the N level in the soil significantly over the controls accounting for the similarity in performance of controls and those receiving lower levels of NPK (T1=250Kg/ha). According to Loomis and Connor (1992), crop plants use typically less than half of the fertilizer applied to the soils around them. The remaining minerals may leach into surface waters, ground water, become attached to soil particles or contribute to air pollution (Taiz and Zeiger, 2010).

While leaf numbers responded positively to higher levels of NPK as well as combinations of NPK and jatropha cake compared to controls, there was no such response of stem height and diameter of plants to any of the treatments. It can therefore be inferred from this finding that, the young *Jatropha curcas* plants at the early stages of growth used readily available nitrogen to produce more leaves rather than increase in height and thickness of the stems. With more leaves, higher rates of photosynthesis will be expected with subsequent healthy growth of other parts of the plant. Yong *et al*. (2010) reported of higher rates of photosynthesis in leaves of *Jatropha curcas* plants if nitrogen is not limiting.

A similar result with regards to plant canopy development was also established by Behera *et al*. (2010) who found that jatropha plants that received NPK fertilizer significantly developed larger canopies than controls (no fertilization). The findings of this current study show that, the availability of nitrogen at the first six weeks of growth of jatropha plants may influence rapid leaf development rather than stem height and stem diameter.

All the plants experienced a fast increase in stem heights and diameters from six weeks after transplanting (Table.1). At this time, mineralization of nitrogen had presumably begun in treatments that received lower and moderate levels of jatropha cake only, making N available to plants. This period was characterized by larger and taller stems of plants that received these treatments compared to controls. Nitrogen mineralization in soil is significantly enhanced by the activities of bacterial-feeding nematodes (Anderson *et al.*, 1979, 1983; Ferris *et al.*, 1998; Ingham *et al.*, 1985). The presence of organic nitrogen in the cake may have attracted more nematodes to the sites that received the cake. The Sustainable Agriculture Farming System in Davis, CA observed a significant higher microbial biomass and activity in an organic farming system than conventional systems after four years (Scow *et al.*, 1994; Temple *et al.*, 1994a, b). Ferris *et al.* (1996) also made a similar observation in the abundance of nematodes involved in decomposition in an organic system than that in a conventional system. In a study to determine the influence of organic *Crotalaria juncea*

(Sunn hemp) hay and ammonium nitrate fertilizers on soil nematode communities, Wang *et al.* (2006) reported that sunn hemp fertilizer resulted in a stimulation of nematodes involved in nutrient cycling, while ammonium nitrate supported a soil ecosystem more conducive to plant parasitic nematodes.

In the current study plants that received the highest level of jatropha cake (T5 = 4000 Kg/ha) had similar heights and diameters as that of controls at ten weeks after transplanting. It is reasonable to suppose that immobilization might have still been occurring in this treatment. After this period (week 14), these plants had significantly higher stem heights and diameter than the controls supporting higher mineralization rates and availability of N for growth. These plants also had similar stem heights and diameters as the other fertilized treatments except those from the lower levels of NPK (T1 = 300 Kg/ha). The improved performance of plants receiving jatropha cake treatments was probably due to continuous supply of nitrogen from increased activity of soil microbes resulting in increased mineralization while for the combined treatments, it could be attributed to the availability of inorganic nitrogen for early development of leaves, improved soil structure resulting from microbial activity on the organic matter and later availability of nitrogen after mineralization of the organic matter. Better growth of plants as a result of the combination of organic and inorganic sources of nutrients has been reported by Dhoble, (1998) and Surgave *et al*., (1998).

For plants that received higher rates of NPK only, their increased stem height and diameters observed at this stage compared to controls was probably due to increased photosynthesis induced by their higher leaf numbers at the initial stages of growth.

Reproductive Growth

Early flowering occurred in fertilized treatments. However, fertilization did not influence seed yields. Fertilized plants flowered between 33 and 44 days earlier than controls (Table 4.3). This may have resulted from the better vegetative growth of the fertilized treatments. Perhaps, the healthy, larger stems of the plants that received fertilization supported the fast growth of branches with subsequent early flower production. This result supports the assertion of Openshaw (2000) that, flower and seed production of *Jatropha curcas* plants respond to rainfall and nutrients.

Although, plants that received lower levels of NPK did not produce larger and taller stems, flower production in such plants was similar to those that received higher levels of fertilization (Table 4.3). Perhaps, plants receiving lower levels of NPK had levels of nitrogen adequate to induce flowers but not stem growth. It is reasonable to infer that, the nitrogen for early flower development in the plants that received lower levels of NPK in the current study was supplied by the leaves because they had similar number of leaves as the other fertilized treatments during the early stages of their growth. Although, translocation and cycling of nitrogen may be very different for different species and different life forms (Dickson, 1989), similar results to the current study were reported by Dalling *et al.* (1976) who reported that grain filling period is commonly associated with low level of nitrogen in the soils where they are grown. William (1955) explained that, under such conditions, the nitrogen needed by the developing grains is mostly supplied by mobilization of protein from vegetative organs. In a similar study to that of Dalling *et al.* (1976), Dickson (1989) found that the leaves contributed the largest quantity of the nitrogen supplied for grain development.

Most fertilized treatments reached 50% flowering within 133 to 138 days (four and half months) whilst the controls reached 50% flowering at 180 days. This agrees with Heller (1996) that the plant can flower within five months under good conditions.

Yield and Yield Components

Better vegetative growth as well as early flowering in plants that received fertilization did not translate into higher seed yields. Although such plants had the capacity for higher photosynthetic rates, seed weights in these plants were similar to that of controls. This could be due to low rainfall during the fruiting period (November 2010 to January 2011) (Appendix 1). Although these plants had better vegetative growth as well as early flowering, it is reasonable to suppose that, moisture stress during the pod filling period might have inhibited fruit production as a result of reduced photosynthesis and translocation of assimilates. Drought-related reduction of plant growth and yield is largely owed to stomata closure in response to low soil water content, which decreases the intake of carbon dioxide and as a result, decreases photosynthesis (Pompelli *et al.* 2010). The moisture stress may also have caused some plants to develop premature fruits which resulted in smaller or no seeds in their pods.

Weight per seed of all the plants was similar indicating that equal amounts of dry matter were partitioned into the fruits of all the plants irrespective of the differences in amounts stored in their vegetative parts. This means weight per seed of the plant might be more of a genetic rather than environmental factor. Husk dry weights were also similar.

5.1.2 Minor Season

Vegetative Growth

Vegetative growth in the minor season followed a similar trend to that of the major season. However, rate of stem height and diameter increases of plants were generally low. Seed yields were also relatively lower than those of the major season. At the onset of the minor season, sprouting of new branches occurred in all treatments after the plants had shed all their leaves at the end of the major season (Tables 4.5 and 4.6).

At week thirty two (32) plants that received either NPK or jatropha cake only (except T5, 4000 Kg/ha jatropha cake only) had similar number of branches as controls (Fig.4.5). Nitrogen may have been limiting in the soils supplied with NPK thirty weeks after application. For the jatropha cake treatments, the low rainfall might have affected microbial activity which resulted in a slow decomposition process and low availability of nitrogen.

Plants that received combined treatments (except T8, 2000 Kg/ha of jatropha cake + 125 Kg/ha of NPK) developed more branches than controls. A similar observation was made at week thirty four. Combinations of higher levels of jatropha cake and NPK (T10 = 1500 Kg/ha + 150 Kg/ha of NPK and T11 = 2000 Kg/ha + 150 Kg/ha of NPK) had more branches than all other plants except those that received T9 (1000 Kg/ha of jatropha cake + 150 Kg/ha of NPK). It can be inferred from this result that, a higher supply of combined organic and inorganic nutrition to *Jatropha curcas* can induce the development of more branches after the period of leaf shedding. The higher response of the plants to the combined treatments agrees with that of Krishna *et al.* (2008) which indicated a higher number of lateral branches in unpruned jatropha plants treated with a combination of 46:50:25 kg/ha NPK and 5 kg of farm yard manure than others that received either NPK or farm yard manure only and the controls.

Plants that received NPK only still produced similar number of branches as controls. However, plants that received 2000 Kg/ha (T3) and 3000 Kg/ha of jatropha cake only had more branches compared to controls. These plants probably continued to benefit from nitrogen through mineralization by soil microbes. Higher microbial activity on organic matter accelerates the decay process resulting in a larger net release of humus and nutrients at the end of the process, a condition called the "Priming Effect" (Brady and Weil, 2008). In a study to investigate the performance of *Jatropha curcas* under different agro-practices, Behara *et al*. (2010) reported higher number of lateral branches in plants that received jatropha cake only compared to control plants after one year of establishment. In contrast to the result of this work however, inorganic fertilizer (NPK) in his study also produced higher number of branches than control plants.

Despite the development of new branches after the plants had shed their leaves, stem height and diameter increases were really low as compared to that of the major season. Low rainfall and pest infestation might have accounted for the poor growth. According to Openshaw (2000), growth of *Jatropha curcas* plants is dependent on soil fertility and rainfall, especially the latter. Provided the nutrient level is sufficient, plant growth is a function of water availability, especially in the tropics. Several workers have reported the detrimental effects of moisture stress on soil microbial activity and plant growth (Jenny, 1980; Post *et al.*, 1985 and Gunapala *et al.* (1998). Although it has been reported that jatropha is drought resistant and can tolerate low moisture regimes (Heller, 1996; Katwal and Soni, 2003 and Gadekar, 2006), this does not undermine the fact that, healthy growth and better yields of plants are enhanced by adequate moisture and nutrition (Taiz and Zeiger, 2010). During period of drought, plants suffer from water deficits that lead to inhibition of shoot growth, leaf expansion and photosynthesis (Taiz and Zeiger, 2010). Drought-related reduction of plant growth and yield is largely owed to stomata closure in response to low soil water content, which decreases the intake of carbon dioxide and as a result, decreases photosynthesis (Pompelli *et al.*, 2010). The result of this current study is consistent with that of Maes *et al.* (2009) who in studying the effects of drought on plants growth reported that, drought significantly reduced relative growth rates of the *Jatropha curcas* species.

During the minor season, plants were infested by the Shield backed scutellera bug which might have contributed to the generally low increments in stem heights and diameters of the plants. According to Brittaine and Lutaladio (2010), Scutellera bug (*Scutellera nobilis*) is a popular pest of jatropha which causes flower fall, fruit abortion and seed malformation. Shanker and Dhyani (2006) reported Scutellera bug (*Scutellera nobilis*) and the inflorescence capsule-borer *Pempelia morosalis* as the two major pests of *Jatropha curcas* plants. The nymphs and adults suck the cell sap from leaves, tender parts of the plant, flowers and capsules (Shanker and Dhyani, 2006).

In this study, the bugs were common on the developing fruits and leaves causing fruit abortion and brownish patches on the lamina of the leaves respectively. This may have reduced the photosynthetic capacity of the affected leaves leading to reduction in the growth of the plants. Although the pests were controlled with cymethoate, their effect was severe and lasting because they resurfaced within a few weeks after application. In a bionomic study of *Scutellera perplexa*, a major jatropha pest from the same family (Scutellaridae) as *scutellera nobilis*, Parveen *et al.* (2010) made a similar observation in India and reported that, the scutellera bug remained active throughout the year and severe damage to foliage and developing fruits was observed between July and March.

Although, stem growth was generally low, plants that received the fertilized treatments (except those that received low levels of NPK at 250 Kg/ha (T1) performed better than controls (Figs. 4.6 and 4.7). It was however evident that, the better performance of fertilized treatments was a function of their growth during the major season as their rates of growth were similar to that of controls from week 32 to week 40. Between weeks 40 and 44, the rate of increase in stem height of plants that received 3000 Kg/ha of jatropha cake only (T4) was higher than all other treatments except those that received the 4000 Kg/ha of jatropha cake only (T5). This could be due to late release of nitrogen which might have been bound to the soil due to the high organic matter in the jatropha cake. Effect of high organic matter in binding soil nutrients is explained by Brady and Weil (2008).

At the end of the experiment, all fertilized plants except T1 (those that received 250 Kg/ha of NPK) had higher and thicker stems than control plants. Krishna *et al.* (2008) and Chaturvedi *et al.* (2009) have reported similar responses of stem heights and diameters of the plant to organic and inorganic nutrition. Patolia *et al*. (2007) reported of a 22% annual increment in height of plants treated with combinations of 2.25 tonnes of farm yard manure and jatropha cake plus 60 kg/ha nitrogen (urea) over plants that did not receive any fertilizer. Behera *et al*. (2010) also reported similarly. His value of 121.46cm for stem heights after one year of establishment was similar to values recorded in this study for plants that received jatropha cake only. Behera *et al*. (2010) again reported larger stems of jatropha plants that received jatropha cake only over controls.

In contrast to the results of the current study where NPK at lower levels supplying 11.25g of nitrogen per plant produced plants of similar stem heights and diameters as controls, Behera et al. (2010) recorded increased stem height and diameter in plants that received all levels of nitrogen (5g and 10g through urea) per plant than the controls. Again in their experiment, plants that received jatropha cake only had increased stem heights and diameters than those that received NPK only whereas the results of this current study indicated similar heights and stem diameters of plants that received these two treatments. The differences between their work and the current study may have resulted from, differences in the type of fertilizers applied, differences in soil characteristics, spacing (2m x 2m was used by Behera *et al*., 2010) and lack of irrigation in the current study against 15 days interval irrigation of the study by Behera *et al*. 2010.

Reproductive Growth

The reproductive phase of the plants responded well to jatropha cake only and their combinations with NPK. Plants that received these treatments reached 50% flowering 12 to 21 days earlier than controls (Table 4.7). Probably there was a continuous supply of nitrogen through the decomposition process and eventual mineralization. Deewan (1982) reported that the application of a mixture consisting of 20 kg of well rotten cow dung, 200g Jatropha cake and 100g bone meal applied after pruning of plants resulted in improved growth and flowering of roses in India. In the current study however, plants that received inorganic fertilizer (NPK) and control plants produced flowers at the same time. The amount of nitrogen present in the control plots might have been enough to induce flowering at the same time as those plots treated with NPK only. This is in contrast to Yong *et al.* (2010) who recorded 50% to 100% flowering for jatropha plants that received different levels of inorganic fertilizer (osmocote) while the controls did not flower throughout the study period. Early flowering in plants that received jatropha cake only and their combinations with NPK expectedly influenced them to reach 50% fruiting 10 to 18 days earlier than controls.

Yield and Yield Components

The minor season recorded relatively lower yield compared to the major season (Fig 4.8). Low rainfall and pest infestation probably accounted for this. According to Boyer (1982), soil moisture deficit is the most limiting environmental factor for plant growth and yield in most parts of the world. The detrimental effect of low moisture and the activity of scutellera bug on the plants at the vegetative growth stage caused reduced yields in the minor season. This finding makes the assertion that *Jatropha curcas* can grow in marginal soils questionable. Low yields have often been reported from such marginal soils (Ye *et al.*, 2009). In addition to lower nutrient levels, drought stress in marginal soils may account for low yield (Fujimaki and Kikuchi, 2010).The reproductive phase also suffered fruit abortion through the activities of the scutellera bug which contributed to the lower yields. Lower yields as a result of low moisture and pest infestation on *Jatropha curcas* plants have been reported by several workers (Maes *et al.*, 2009 and Sharma and Srivastava, 2010).

As found in the major season, plants that received the fertilized treatments except the lower level of NPK (T1=250 Kg/ha) showed superior vegetative growth over controls but this did not translate into superior seed yield. The effect of moisture stress and pest infestation might have suppressed fruit development in the plants. All treatments yielded similar husk weights. Weight per seed of the plants was also similar between treatments at both seasons. It can therefore be inferred that the lower yields recorded for the minor season resulted from lower number of fruits produced per plant. This means low rainfall and pest infestation caused a reduction in the number of matured fruits per plant rather than seed weight or size.

5.1.3 Total Yields of Major and Minor Season

All treatments yielded similar seed weights, husk weights and weight per seed at the end of the experiment. The similarity in seed weights of fertilized treatments and controls is in contrast to work reported by Ghosh *et al.* (2007) and Patolia *et al.* (2007). Patolia *et al.* (2007) recorded significantly higher yields in jatropha plants that received N and P (through urea, single super phosphate, farm yard manure and jatropha cake) over the controls. Relatively lower yields were reported in the first year compared to the yields of the present study. However, a relatively higher yield of 300% to 500% over the maximum yields of this study was recorded for fertilized treatments in the second year. The differences in yield recorded by Patolia *et al.* 2007 compared to the current study may be attributed to soil moisture deficit and activities of the scutellera bug.

The general yields of the current study ranging between 48 Kg/ha (0.048 tonnes/ha) to 96 Kg/ha (0.096 tonnes/ha) are low compared to several reports. For instance, Heller (1996) reported yields between 0.1 and 8.0 tonnes /ha for different countries and ecological zones. Openshaw (2000) also reported seed yields ranging between 0.4 to 12 tonnes /ha. In a semi arid environment in India, Wani *et al.* (2008) projected a potential yield of 1.0 tonne/ha.

It is however difficult to establish the balance between these reported yields and that of the present study because they usually have little or no information on site characteristics (rainfall, soil type and soil fertility), plant age, genetics and management (propagation method, spacing, pruning, fertilization, irrigation, etc.). According to Jongschaap *et al.* (2007), earlier reported yields used data which were highly variable, and claims of high yields were probably due to extrapolation of values taken from single, high-yielding elderly trees. Also, these popularly reported yields do not show if the seed weights were fresh weights, air dried weights or oven dried weights. For instance, a jatropha project in Mali reported yields of 0.8 to 1.0Kg of seed per metre of live fence (Henning, 1996) which is equivalent to 2.5 and 3.5 tonnes/ha/year based on the assumption that the yields are of air dry tones/ha with an average nut moisture of about 10 % (Openshaw, 2000). Age of plants of the current study could be a factor of its low yields compared to yields of other reports. This agrees with the assertion that, *Jatropha curcas* reach economic maturity after 3 to 5 years of establishment. Evidences of low yields within the first year of establishment of *Jatropha curcas* have been variously reported (Matsuno *et al.*, 1985; Heller, 1996 and Patolia *et al.*, 2007).

5.2 *Study II*: Influence of different levels of Jatropha Cake and inorganic fertilizer on the Chemical and Physical composition of soil two years after establishment of *Jatropha curcas*

5.2.1 Effect of treatment on Soil Chemical properties

Percentage nitrogen in the soils of all the treatments did not differ after two years. It is evident that *Jatropha curcas* had nitrogen productivity as higher growth in stem height and diameter (Figs.4.6 and 4.7) were observed in plants that received fertilization. This might have accounted for the similar nitrogen contents in the soils of all the treatments. Plant species with high nitrogen productivity are able to respond rapidly to increased nutrient availability: they have a relatively large photosynthetic apparatus and so can rapidly convert an increased nitrogen uptake into an increased biomass production (Berendse and Aerts, 1987). Perhaps most of the nitrogen in the jatropha cake and NPK were used for higher woody biomass production by plants that received them, hence returning little amount of nitrogen comparable to the controls to their soils through litter fall.

The amount of nutrients that are recycled and remain in the mineral soil pool depends on factors such as quantity and rate of decomposition of litter, nutrient release from dying roots, nutrient losses by leaching, surface runoff and uptake by plants (Campbell *et al*., 1967, Berendse, 1987 and Ingestad, 1981). Being litter from the same species and variety of plant, similar substrate qualities were expected for all treatments and subsequently similar decomposition rates occurred. Nutrient losses through leaching and surface runoffs were similar for all treatments since there were no differences in the moisture contents and bulk densities in the soils of all the treatments (Table 2). Nutrient loss by leaching and runoff depends on soil properties such as water holding capacity, bulk density and organic matter content of the soil (Ingestad, 1981).

The results also indicate that no significant differences (P>0.05) existed between the initial and final chemical properties of the soil with or without fertilization except pH. It can therefore be inferred that *Jatropha curcas* can maintain soil fertility with or without fertilization in the first two years of their establishment. This might be due to an efficient nutrient cycling of jatropha. The litter might be of high quality with a low C: N ratio. In general, nitrogen may be easily mineralized when the C:N ratio is < 20:1 (Ferris and Matute, 2003). Abugre *et al*. (2011) reported a C:N ratio ranging between 17:1 and 9:1 of jatropha litter from 30 to 120 days after leaf fall in a closed canopy system. This low C:N ratio indicates that jatropha litter is a high quality substrate and hence there was faster rate of decomposition and mineralization making nutrients in the litter available for plants use in the current study. It is evident that, jatropha plants produce high quality litter that can sustain both plant growth and physicochemical properties of soil for two years.

A similar observation to that of the current study was reported by Ogunwole *et al*. (2008). In assessing the contribution of *Jatropha curcas* to soil quality improvement, Ogunwole *et al*. (2008) reported maintenance of organic carbon and nitrogen content of entisols on which *Jatropha curcas* was grown with and without fertilization for one year. Increased carbon content was however recorded in wastelands grown with jatropha in India by Garg *et al*. (2011). Other works by Rao and Korwar (2003), Chaudhary (2007) and Ayele (2011) indicated significant increases in nitrogen, carbon and phosphorus contents of soils planted with *Jatropha curcas*. The results of the current study and that of Rao and Korwar (2003), Chaudhary (2007) and Ayele (2011) confirm the assertion by Achten (2008) and Kumar and Shamar (2008) that *Jatropha curcas* can maintain or improve soil fertility as well as reclaim marginal lands.

Soils of all treatments had similar acidity levels or pH values after two years (Table 4.10). This can be attributed to the similar levels of potassium returned to the soils. Potassium forms part of the ion complex that maintains or reduces the acidity of soils (Brady and Weil, 2008). The results however indicate that, acidity of the soil of all treatments was reduced after the two years (Table 4.10). Reports have shown that, the application of fertilizer can maintain, increase or decrease soil pH and microbial activity depending on factors such as type of fertilizer, the time scale, the fertilizer rate and the productivity of the forest involved (Will *et al*., 1984; Titus and Malcolm, 1987; Prescott *et al*., 1992 and Thirukkumaran and Parkinson, 2000). The reduction in the acidity of the soils of the current study however cannot be attributed to fertilizer effects since no differences existed between the various fertilized treatments and the controls. It could be due to the nutrient composition of the jatropha litter and low rainfall recorded for the two years. *Jatropha curcas* litter might have higher concentrations of non-acid cations; Ca^{2+}, Mg^{2+}, Na^{+} and K^{+}. In a spacing trial in India, Chaudhary *et al*. (2007) recorded percentages of 2% Mg and 2-4 % Ca in leaves of jatropha which were higher than nitrogen percentages. According to Brady and Weil (2008), higher concentrations of Ca^{2+}, Mg^{2+}, Na^{+} and K^{+} in soils where leaching is less reduces the acidity of soils whose pH is less than 7. Some of these cations are released by decomposition of organic residues such as plant litter and animal manure (Ano and Ubochi, 2007 and Brady and Weil, 2008). Ayele (2011) reported of significant levels of Ca and Na in soils under stands of jatropha than soils away from the stands. He proposed that, the *Jatropha curcas* plants could improve the availability of these base cations. The result of this study is in contrast to Ayele (2011) who reported no significant differences in the pH of basic soils (pH of 8.9) under jatropha stands and those away from the stands. As already indicated by Brady and Weil (2008), the base cations Ca^{2+}, Mg^{2+}, Na^{+} and K^{+} reduce acidity of soils whose pH is only less than 7, hence the contrast between the study by Ayele (2011) and the current study (initial soil pH < 7).

5.2.2 Effect of treatment on Soil physical properties

The similarity in the amount of organic matter in the soils of all the treatments accounted for their similar moisture contents and bulk densities. Soil organic matter may have affected soil aggregate stabilities and water holding capacities to similar extents because it came from the same litter and was affected by similar environmental conditions. Factors such as the old and new land use types, the soil type, management and climate cause changes in soil organic matter and these changes typically result in differing rates of soil erosion, aggregate formation, biological activity, and drainage (Lantz *et al*., 2001 and Lettens *et al*., 2004).

Several studies have shown that organic residues act as binding agents that contribute to soil water and aggregate stabilities (Edwards and Bremner, 1967; Hamblin, 1977; Turchenek and Oades, 1978 and Tisdall and Oades, 1980). The organic residue (litter) may have attracted microbial masses which contributed to the macro aggregate stabilities of the soils. According to Haynes and Beare (1997), deposition of organic material from tree canopies result to a large active microbial biomass beneath the canopy, which in turn exudes microbial products that act as binding and gluing agents, thus improving aggregation. Work by Sreedevi *et al.*, (2009) which indicated that bacterial populations within the rhizosphere of jatropha plants doubled after a year confirms this assertion.

CHAPTER SIX

6.0 CONCLUSION AND RECOMMENDATION

6.1 Conclusion

The study has demonstrated that *Jatropha curcas* contrary to the belief that it does well on marginal lands requires a good supply of nutrients for good growth and production. Nutrients can be supplied from both organic and inorganic sources. There was an early response of the crop to inorganic sources and their combinations with organic sources characterized by early development of leaves after transplanting. Jatropha cake also had the potential to supply needed plant nutrients required for efficient performance of the plant. However, owing to the process of decomposition, the cake was able to make significant amount of nutrients available to plants after six weeks of application. It was however evident that, application of the cake in large quantities (4000 Kg/ha) resulted in delayed nutrient release to the plants due to nutrient immobilization by bacteria. Combinations of both organic and inorganic fertilizers appear to be more efficient in promoting growth and yield of *Jatropha curcas* since it ensured increased vegetative growth (early sprouting of leaves, increased stem height and diameter).

Availability of nutrients for growth induced earlier flowering in *Jatropha curcas* compared to non-fertilized plants. Higher vegetative growth and earlier flowering of fertilized plants however did not translate to seed yields. Soil moisture appears to have a major influence on the plant's growth and yield. The major (wet) season was characterized by rapid growth and high seed yield while growth rate and seed yields were low in the minor (dry) season. Despite increased vegetative growth and early flowering in the major season, seed yields of fertilized treatments did not differ from non-fertilized ones due to moisture stress and pest infestations. This provides the knowledge that adequate supply of nutrients cannot bring about increased seed yields if other unsuitable conditions such as inadequate rainfall and pest infestations exist. Weight per seed of *Jatropha curcas* was not influenced by fertilization. Similarly, the percentage of total fruit weight attributed to seed was not influenced by fertilizer application. An average of 67.5% of the fruit's dry matter was partitioned into seed with or without fertilizer application.

Although moisture stress especially in the minor season largely affected the growth of all plants in general, the development of new branches in this season was influenced by the fertilizer application. Development of branches was more rapid in plants that received a combination of organic and inorganic fertilizers. Lower levels of inorganic fertilizer application could not induce rapid development of branches. Differences in vegetative growth (stem height and diameter) of plants in this season were a consequence of their increased growth during the major season. Although similar rates of growth occurred for all treatments during the minor season, higher levels of jatropha cake (4000 Kg/ha) resulted in a late surge in vegetative growth in plants as a result of late release of nutrients from decomposition of the cake. Also, the superiority of the jatropha cake only and the combined treatments did not translate into seed yields of plants probably due to moisture stress and pest infestation. As found in the major season, similar quantities of dry matter were partitioned into the seeds of plants of all treatments.

The study has also shown that even without fertilization, *Jatropha curcas* can maintain soil chemical properties after two years of establishment. The plant litter returned to the soil may contribute to and improve nutrient levels in the soil. Also soil physical properties were not influenced by fertilization. Again, reduced acidity was associated with soils grown with the plant for two years irrespective of treatment imposed.

The results of this work will be helpful to various jatropha stakeholders in many ways. For instance, the improved vegetative growth of the plants supplied with fertilizer may be an indication of increased seed yields if other conditions such as adequate soil moisture exist. Where available, jatropha farmers can use jatropha cake to boost seed yields when moisture is adequate. Higher seed yields will contribute significantly to the country's biodiesel needs. The use of the jatropha cake may not just be a cheap source of fertilizer for farmers but a way of controlling the waste that might result after extraction of oil from the seed of jatropha plant. Furthermore, this report will potentially allay the fears of a destructive effect of jatropha on soils grown to the crop.

6.2 Recommendations

- A combination of jatropha cake and NPK can improve the growth and yield of *Jatropha curcas* and can be recommended to farmers to boost production of their crops.

- It is not advisable to apply quantities up to 4000 Kg/ha of jatropha cake to plants because it leads to late release of nutrients which subsequently results in a slow growth at early stages of plants.

- The litter of the jatropha plant can be used as mulch to reduce soil acidity and to improve the fertility of the soil.

- The plant's ability to maintain soil chemical properties after two years provides some indication of its potential to be intercropped with other agricultural crops.

- The effects of moisture stress and pest attack on the plant should be thoroughly investigated so that appropriate interventions could be proposed to ensure significant seed yields especially at the first year of production.

- About 27% to 38% of the fruit weight was husk which gives an appreciable amount of waste after the removal of the seed. Since the husk is directly combustible, it can be used as household fuel and to light charcoal fires in the rural areas of the country.

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APPENDICES

Appendix 1. Rainfall Data of the Agricultural Research Station of the Faculty of Agriculture and Natural Resources-KNUST, at Awomaso

Year / Month	2010		2011		2012	
	TR(mm)	NRD	TR (mm)	NRD	TR (mm)	NRD
January	-	-	42.4	4	12	1
February	77.4	6	125.7	7	30.85	5
March	69.3	8	192.5	12	111.3	6
April	120.7	11	81.5	7	185	7
May	78.6	9	59.7	10	186.2	14
June	208.4	11	331.5	14	254.2	10
July	111.4	10	152.5	13	58	5
August	135.6	14	44.2	9	3.1	2
September	145.0	13	340.1	14	91.4	11
October	248.8	18	298.9	15	203.3	18
November	92.1	9	32	2	40	6
December	34.9	6	-	-	52	3

(Source: CSIR-FORIG)

TR : Total Rainfall

NRD: Number of Rainy Days

Appendix 2. Plant Analysis Sheet showing pH and contents of Organic matter, Nitrogen, Phosphorus and Potassium of Jatropha cake

KWAME NKRUMAH UNIVERSITY OF SCIENCE AND TECHNOLOGY
FACULTY OF RENEWABLE NATURAL RESOURCES
AGROFORESTRY SOIL LABORATORY

PLANT ANALYSIS SHEET **DATE: 04/10/10**

SAMPLE	pH	ORGANIC MATTER (%)	NITROGEN (%)	PHOSPHOROUS (%)	POTASSIUM (%)
A	6.21	90.4	4.13	0.69	9.50
B	6.18	90.8	4.06	0.55	13.0
C	6.20	91.5	3.92	0.60	9.4
AVERAGE	**6.20**	**90.9**	**4.04**	**0.61**	**10.6**

Analyzed by: Mrs. Selina Bondzie,
Mrs.Gloria Owusu-Ansah

Appendix 3. Analysis of variance at 5% significant level for number of leaves of *Jatropha curcas* plants grown under different levels and combinations of NPK 15: 15:15 and Jatropha cake at week 6

Source	DF	Anova SS	Mean Square	F Value	Pr > F	F critical
Blocks	2	418.2	209.1	4.71	0.02	2.07
Treatments	11	1090.3	99.1	2.23	0.04	2.07
Error	22	976.5	44.4			
Corrected Total	35	2485.0				

Appendix 4. Analysis of variance at 5% significant level for Stem heights **of *Jatropha curcas* plants grown under different levels and combinations of NPK 15: 15:15 and jatropha cake at week 26 (End of Major Season)**

Source	DF	Anova SS	Mean Square	F Value	Pr > F	F critical
Blocks	2	2812.5	1406.3	6.01	0.0083	2.07
Treatments	11	8888.2	808.0	3.45	0.0064	2.07
Error	22	5147.0	234.0			
Corrected Total	35	16847.8				

Appendix 5. Analysis of variance at 5% significant level for Stem diameter **of *Jatropha curcas* plants grown under different levels and combinations of NPK 15: 15:15 and jatropha cake at week 26 (End of Major Season)**

Source	DF	Anova SS	Mean Square	F Value	Pr > F	F critical
Block	2	157.9	78.9	3.06	0.1	2.07
Treatments	11	1134.6	103.1	3.99	0.01	2.07
Error	22	568.3	25.8			
Corrected Total	35	1860.9				

Appendix 6. Analysis of variance at 5% significant level for number of days time to flowering of *Jatropha curcas* plants grown under different levels and combinations of NPK 15: 15:15 and jatropha cake

Source	DF	Anova SS	Mean Square	F Value	Pr > F	F critical
Block	2	392.0	196.0	3.00	0.0705	2.07
Treatments	11	5765.7	524.2	8.02	0.0001	2.07
Error	22	1437.3	65.3			
Corrected Total	35	7595.0				

Appendix 7. Analysis of variance at 5% significant level for number of days to 50 % flowering of *Jatropha curcas* plants grown under different levels and combinations of NPK 15: 15:15 and jatropha cake

Source	DF	Anova SS	Mean Square	F Value	Pr > F	F critical
Block	2	443.7	221.9	3.15	0.0626	2.07
Treatments	11	5547.9	504.4	7.16	0.0001	2.07
Error	22	1548.9	70.4			
Corrected Total	35	7540.6				

Appendix 8. Analysis of variance at 5% significant level for seed weights of *Jatropha curcas* plants grown under different levels and combinations of NPK 15: 15:15 and jatropha cake (End of Major Season)

Source	DF	Anova SS	Mean Square	F Value	Pr > F	F critical
Blocks	2	6277.4	3138.7	3.14	0.06	2.07
Treatments	11	6499.4	590.9	0.59	0.81	2.07
Error	22	21960.3	998.2			
Corrected Total	35	34737.0				

Appendix 9. Analysis of variance at 5% significant level for number of new branches of *Jatropha curcas* plants grown under different levels and combinations of NPK 15: 15:15 and jatropha cake at week 34 (Minor Season)

Source	DF	Anova SS	Mean Square	F Value	Pr > F	F critical
Blocks	2	93.7	46.9	6.20	0.0073	2.07
Treatments	11	310.3	28.2	3.73	0.0041	2.07
Error	22	166.3	7.6			
Corrected Total	35	570.3				

Appendix 10. Analysis of variance at 5% significant level for Stem heights of *Jatropha curcas* plants grown under different levels and combinations of NPK 15: 15:15 and jatropha cake at week 44 (End of Minor Season)

Source	DF	Anova SS	Mean Square	F Value	Pr > F	F critical
Blocks	2	2668.0	1334.0	4.98	0.016	2.07
Treatments	11	8028.2	729.8	2.72	0.022	2.07
Error	22	5892.7	267.8			
Corrected Total	35	16588.9				

Appendix 11. Analysis of variance at 5% significant level for Stem diameter of *Jatropha curcas* plants grown under different levels and combinations of NPK 15: 15:15 and jatropha cake at week 44 (End of Minor Season)

Source	DF	Anova SS	Mean Square	F Value	Pr > F	F critical
Blocks	2	782.9	391.4	14.08	0.0001	2.07
Treatments	11	1171.0	106.5	3.83	0.0036	2.07
Error	22	611.8	27.8			
Corrected Total	35	2565.6				

Appendix 12. Analysis of variance at 5% significant level for seed weights of *Jatropha curcas* plants grown under different levels and combinations of NPK 15: 15:15 and jatropha cake (End of Minor Season)

Source	DF	Anova SS	Mean Square	F Value	Pr > F	F critical
Block	2	227.2	113.6	1.25	0.307	2.07
Treatments	11	1057.4	96.1	1.05	0.438	2.07
Error	22	2007.4	91.2			
Corrected Total	35	3292.0				

Appendix 13. Analysis of variance at 5% significant level for seed weights of *Jatropha curcas* plants grown under different levels and combinations of NPK 15: 15:15 and jatropha cake after one year (Major season + Minor season)

Source	DF	Anova SS	Mean Square	F Value	Pr > F	F critical
Blocks	2	8396.7	4198.3	3.53	0.05	2.07
Treatments	11	6579.7	598.1	0.50	0.88	2.07
Error	22	26166.8	1189.4			
Corrected Total	35	41143.3				

Appendix 14. Analysis of variance at 5% significant level for Nitrogen content of soil after two years of establishment of *Jatropha curcas* plants grown under different levels and combinations of NPK 15: 15:15 and jatropha cake

Source	DF	Anova SS	Mean Square	F Value	Pr > F	Fcritical
Block	2	0.00577	0.00289	2.60	0.135	2.3
Treatments	4	0.00247	0.00062	0.55	0.702	2.3
Error	8	0.00889	0.00111			
Corrected Total	14	0.01713				

Appendix 15. Analysis of variance at 5% significant level for pH of soil after two years of establishment of *Jatropha curcas* plants grown under different levels and combinations of NPK 15: 15:15 and jatropha cake

Source	DF	Anova SS	Mean Square	F Value	Pr > F	F critical
Blocks	2	0.147	0.074	2.34	0.1581	2.3
Treatments	4	0.889	0.222	7.08	0.0097	2.3
Error	8	0.251	0.031			
Corrected Total	14	1.288				