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COLLEGE OF AGRICULTURE AND NATURAL RESOURCES

FACULTY OF RENEWABLE NATURAL RESOURCES

DEPARTMENT OF AGROFORESTRY

COMPATIBILITY OF *JATROPHA CURCAS* IN AN AGROFORESTRY SYSTEM

BY

SIMON ABUGRE

MSc. AGROFORESTRY, KNUST, KUMASI

APRIL, 2011

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A Thesis submitted to the, Department of Agroforestry, Faculty of Renewable Natural Resources, Kwame Nkrumah University of Science and Technology, Kumasi in partial fulfillment of the requirements for the degree of

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IN

AGROFORESTRY

BY

SIMON ABUGRE

M.Sc. (Agroforestry), KNUST, Kumasi

Faculty of Renewable Natural Resources

College of Agriculture and Natural Resources

APRIL, 2011

DECLARATION

I do declare that except references to other peopleøs work which has been duly cited, this work submitted as a thesis to the School of Research and Graduate Studies of the Kwame Nkrumah University of Science and Technology, Kumasi for the degree of Doctor of Philosophy in Agroforestry is the result of my own research.

Mr. Simon Abugre	é é é é é é é é é é é é é	é é é é é é .
(Student)	Signature	Date
Dr. Charles Oti Boateng	é é é é é é é é é é é é é	é é é é é é é é
(Supervisor)	Signature	Date
Dr. K. Twum-Ampofo	é é é é é é é é é é é é .	é é é é é é é é é
(Head of Department)	Signature	Date

ABSTRACT

Jatropha curcas is gaining importance as a potential biofuel crop in Ghana. Already skeptics are talking about the impact of the crop on food crops. It is important that the compatibility of *J. curcas* in agroforestry systems is investigated to provide answers to some of the potential problems being advanced. Experiments were conducted to determine the compatibility of *J. curcas* on the growth and yield performance of *Zea mays*. To determine the growth and yield of *Z. mays* under *J. curcas* hedgerows, an experiment using a Randomized Complete Block Design (RCBD) with three hedgerow spacings of 2 m x 1 m, 3 m x 1 m, 4 m x 1 m of *J. curcas* and a control (No hedgerow) was conducted. This was replicated 3 times. The results of the study showed that *J. curcas* spacing had no significant effect (P Ó0.05) on plant height, plant diameter, number of leaves and number of nodes/plant of maize in the first year. In the second year, however, increases in plant height of 17.19%, 22.39% and 23.38% were realized for 3 m x 1 m, 4 m x 1 m and the control (No hedgerow) respectively with respect to 2 m x 1 m. Diameter at first node however, increased by 19.69%, 16.87% and 18.46% for control, 3 m x 1 m and 4 m x 1 m respectively with respect to 2 m x 1 m. Maximum grain yield of maize was 4.47 tons/ha in the first year at the control treatment, which differed significantly from the 2 m x 1 m, 3 m x 1 m, 4 m x 1 m treatments. Chemical properties of the soil did not record any significant decline after two years of cultivation for pH, organic carbon, total nitrogen, organic matter, exchangeable cations, total exchangeable bases, exchangeable acids and base saturation. The highest Land Equivalent Ratio (LER) was recorded at 4 m x 1 m for both years, making it the most suitable plant spacing for *J. curcas* with maize while the highest economic returns were obtained at 4m x 1m and 3m x 1m spacing. The influence of storage period, fertilizer and spacing on the growth and yield of *J. curcas* propagated from seed were evaluated in a second experiment using two different designs. Seeds of *J. curcas* were stored for 1 to 12 months, sown on beds in a RCBD,

replicated four times and their viability and germination energy tested. The results showed a progressive decline in germination from 98% after one month to 52% when stored for 12 months. The highest germination energy was obtained during the first two months of storage. Fertilizer and spacing effects were also evaluated in a split plot design in RCBD and replicated three times. Three plant spacings (D1=1m x 1m; D2=2m x 1m; D3=3m x 1m) and two fertilizer application levels (F0: 0kgNPK/ha, F1: 150kgNPK/ha) were used. Fertilizer and spacing interaction did not significantly (P Ó 0.05) affect yield components of *J. curcas*. The fertilizer treatment however, had a significant effect on yield components and increased seed and fruit yield by 56.4% and 51.75% respectively. Spacing did not significantly affect seed yield. A third experiment on the variation in seed sources of *J. curcas* and polybag size on the growth of seedlings was laid out using a split plot design in RCBD with 3 replicates. The results showed significant variation in seed weight from the various seed sources but no differences in seed length and seed width. Seedling growth of *J. curcas* was highest when larger polybag size was used, however, it did not differ significantly from medium polybag size. Based on the results obtained medium polybag size would be ideal for raising seedlings. In a fourth experiment the decomposition trend of *J. curcas* leaves was assessed by placing 80 g fresh leaves in a 0.30 m x 0.30 m nylon litter decomposition bags of 2 mm mesh size under closed and open canopies. The total quantity of litter produced in a year at different spacings were 2.27 ton/ha, 1.10 tons/ha and 0.79 tons/ha for 1 m x 1m, 2 m x 1m and 3 m x 1m, respectively. The month of November had the highest litter fall (508.8 kg/ha) for 1 m x 1 m. *J. curcas* under open canopy had 97-99% of leaf litter decomposing by the end of the experimental period and a half-life of 25 days. Open canopy had the highest decomposition constant (k) of 0.020. In a final experiment the effect of aqueous extracts from leaves and roots of *J. curcas* on four traditional crops (*Phaseolus vulgaris, Zea mais, Lycopersicon lycopersicum* and *Abelmoschus esculentus* was examined. Aqueous extracts at concentrations of 2%, 4%, 6%, 8% and 10% applied to the test crops affected all the crops. Extracts at higher concentrations of *J. curcas* had a strong inhibitory effect on germination, radicle and plumule length of all the test crops. The inhibitory effect suggests the presence of allelochemicals that could inhibit the growth of the crops.

Generally, it can be concluded that *J. curcas* is compatible with maize in an alley cropping system but closer spacing of planting *J. curcas* can reduce maize yields. Management practices such as pruning could be applied to get the optimum benefit from the system.

DEDICATION

I dedicate this thesis to my wife Janet Anafo Anaba, my daughters Lilian Awinpanga Abugre and Bernice Asaknaba Abugre who supported me during the period of the study. I also dedicate this work to the memory of my father Pastor John Abugre Azure and my mother Mary Asaknaba Abugre for their support and encouragement.

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CHAPTER ONE

1.0 INTRODUCTION

1.1 Description of *J. curcas*

The physic nut *(Jatropha curcas*, Linn.), a genus of family Euphorbiaceae, is believed to be a native of Mexico and Central America (Heller, 1996). It was introduced into Africa and Asia and is now cultivated worldwide. *J. curcas* was most likely distributed by Portuguese ships via the Cape Verde Islands and Guinea Bissau to other countire of Africa and Asia (Heller, 1996). It is a multipurpose, deciduous, small tree (or large shrub), reported to be cultivated in drier sites of Central and Western parts of India (Jongschaap *et al*., 2007). *J. curcas* is a prominent species with a wide variety of uses. Seeds, leaves and bark are used in traditional medicine and for veterinary purposes. The oil has a strong purgative action and is also widely used against skin diseases and to soothe rheumatic pains. The leaves are used against cough and as an antiseptic after birth (Heller, 1996). In India, pounded leaves are applied near horsesô eyes to repel flies. Mexicans grow the shrub as the host for the lac insect. Ashes of the burned root are used as salt substitute (Morton, 1981). Agaceta *et al*. (1981) conclude that it has strong molluscidal activity. Duke and Wain (1981) list it for homicide, piscicide and raticide as well. The latex was strongly inhibitory to watermelon mosaic virus (Tewari and Shukla, 1982).

Ranging from tropical very dry to moist through subtropical to wet forest life zones, the physic nut is reported to tolerate annual precipitation of 250 mm to 1500 mm and annual temperature of 18.0^{o}C to 28.5^{0}C (Heller, 1996). It grows readily, from cuttings or seeds. Cutting strike roots so easily that the plant can be used as an energy-producing living fence post. In Ghana, *J. curcas* can grow in all parts of the country owing to its robust nature. Production levels in Ghana are reported to range between 3 ï 5 tons/ha/year and has three main the fruit bearing periods (Amoah, 2006).

1.2 Justification for the study

In recent years energy conservation and its alternative production has acquired significant importance in the wake of the world energy crisis. Since the oil crisis of the 1970ôs and recognition of the limitations of world oil resources, most of the oil importing countries including Ghana have been highly motivated to develop alternative sources of energy to meet their domestic needs from natural resources. Increasing industrialization in the developing world is leading to a spiral increase in the demand of fossil fuel. In addition, the green-house gas emissions from fossil fuel are taking a heavy toll on the environment and contributing to global warming. Vehicular emissions in particular, have led to major environmental consequences, since non-renewable fuels contain atmospheric pollutants like nitrous oxides, carbon monoxide, sulphur oxides and lead. In Ghana, the countryôs overall import bill at the end of December, 2005, reportedly amounted to US$ 5, 343 million. This represented an annual increase of 24.4% over the US$ 4, 297.3 million registered at the end of 2004 and the second highest annual rate of increase over the past five years (CEPA, 2006). According to the bank of Ghana, the countryôs oil imports (mainly crude and petroleum products) increased in value by 45.4% by end of December, 2005; this was followed by a 31% increase in the first half of 2006 compared with 19.7% of the corresponding period of 2005 (CEPA, 2006). These developments are attributed largely to high crude oil prices on international Markets (CEPA, 2006).

The directive 2009/28/EC of the European parliament and of the council on the promotion and the use of energy from renewable sources has affirmed EUǒs ambitious targets with respect to renewables (DNV, 2010). The directive superceded the original bill of 2007, endorsed a mandatory 2020 target of 20% of all energy use through renewable energy sources. The agreement specifies that by 2020, 10% of transport fuel, with a 5.75% intermediate target for 2010, needs to be from renewable sources including biofuels, hydrogen and green electricity (Warren, 2009). In addition, the mandate obliges EU memebers to ensure that biofuels offer at least a 35% carbon emissions savings compared to fossil fuels by 21010 and as 50% by 2017 (DNV, 2010).

Developing a reliable source of renewable energy is therefore attracting a major global attention. *J. curcas* has been found to be a highly promising species which yields oilseed as a source of energy in the form of bio-diesel. It has a short gestation period, it is hardy and produces high quality oil. The oil can be used in soap and candle industries and its by-product glycerin can be used in the pharmaceutical industry. The clear oil obtained from the seed has been used for illumination and lubrication, and more recently as a biofuel (Heller, 1996). The absence of sulphur dioxide (SO_2) in the exhaust from diesel engines run on *J. curcas* oil shows that the oil may have less adverse impact on the environment (Kandpal and Madan, 1995).

Recent food shortages reported in the world has been attributed to the conversion of agricultural lands into bio-fuel production (Compete, 2009). This is probably the result of converting agricultural land into plantations for the production of biofuel. The use of *J. curcas* in sole cropping plantations is therefore not sustainable as it would affect food production (Compete, 2009).

Agroforestry is increasingly being recognized as a vital land use system in solving the apparent contradictions between development and environmental agenda. The use of *J. curcas* in combination with food crops would provide the most viable option for the production of biodiesel without affecting food production. Currently, *J. curcas* is used in boundary planting or live fencing in most communities in Ghana. Farmers therefore have some knowledge about this plant species. It would therefore be acceptable to farmers than a completely new species. Sufficient information on genetic variation of species is lacking despite its uses. Such information may help in early evaluation of criteria for selection of some traits both in nursery conditions, which may be related to subsequent performance in the field.

Information on the most appropriate planting distance and fertilizer levels on yield of *J. curcas* is limited in Ghana. The effect of the plant on soil physical and chemical properties is also limited. For the country to start planting *J. curcas* in plantations such information would be vital to provide a sustainable farming system in Ghana.

1.3 Objectives of the study

To address these questions, the following research objectives were considered in the study. The broad objective of this study was therefore to determine the compatibility of *J. curcas* in an alleycropping system so that it could be recommended as one of the species that could be used to reduce rural poverty.

The specific objectives of the study were to:

1. Determine the growth and yield performance of *Zea mays* in alleys of *J. curcas* hedgerows.

2. Determine the influence of fertilizer and spacing on growth and development of *J. curcas*.
3. Determine the effect of seed source variation and polybag size on early growth of *J. curcas*.
4. Assess the litter fall and decomposition trend of *J. curcas* leaves on soil nutrient pool.
5. Evaluate the allelopathic behaviour of *J. curcas* on four (4) traditional crops of Ghana.

1.4 Research questions considered

The research questions addressed in the study were:

1. Would the growth and yield of maize be affected when grown in alleys of *J. curcas* hedgerows?
2. Can the use of fertilizer and manipulation of spacing affect the yield and growth of *J. curcas*?
3. Do seed sources vary significantly so that high yielding species can be obtained and propagated?
4. Would leaf litter decomposition of *J. curcas* affect soil nutrient pool?
5. Does *J. curcas* exhibit allelopathic properties?

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1.1 Origin and distribution of *J. curcas*

A number of scientists have attempted to identify the origin of the Physic nut, but the origin remains controversial. Martin and Mayeux (1984) identified the Ceara state in Brazil as a centre of origin but without giving any evidence. Dehgan and Webster (1979) cited Wilbur (1954) as follows: it was without doubt part of the flora of Mexico and probably of Northern Central America before the arrival of Cortez, and it most likely originated from there. According to other sources, the Physic nut seems to be a native of Central America as well as of Mexico where it occurs naturally in the forest of coastal regions (Aponte, 1978). It is highly probable that the centre of origin of the physic nut is in Mexico since it is not found in natural vegetation in Africa and Asia but only in cultivated form (Heller, 1996).

From the Caribbean, this species was probably distributed by Portuguese Seafarers via the Cape Verde and former Portuguese Guinea (now Guinea Bissau) to other countries in Africa and Asia (Heller, 1996). Nevertheless, the Portuguese transported it to the old world. The Javenese, among other names, call it Chinese castor oil. The Malays call it by a name meaning Dutch castor oil. It is regarded in most countries in Africa as well as in the East, as the "Castor oil plant", which shows that it was brought in and planted for the oil. Further, it is widely known as the "hedge castor oil plant, showing where it was planted, namely in hedges (Heller, 1996).

J. curcas from the family euphorbiaceae is now found abundantly in many tropical and sub-regions throughout Africa and Asia. Jatropha is a genus of approximately 175 succulent, shrubs and trees; some (*J. curcas*) are deciduous. Though native to America, the species is almost pan tropical now, widely planted as a medicinal plant. It is listed, e.g., as a weed in Brazil, Fiji, Honduras, India, Jamaica, Panama, Puerto Rica, and Salvador (Holm *et al*., 1979). It bears the following common names: Arandi, Physic nut, Barbados nut, Purging nut, Castor oil plant, Dutch castor oil and Biodiesel tree. The species has its natural distribution area in the northeastern part of South America. The plant scientific classification is as follows:

Kingdom: Plantae

Division: Magnoliophyta

Class: Magnoliopsida

Order: Malpighiales

Family: Euphorbiaceae

Subfamily: Crotonoideae

Tribe: Jatropheae

Genus: Jatropha

Species: *J. curcas*

2.1.2 Environmental requirements of *J. curcas*

J. curcas is a plant that sheds its leaves during the dry season. It is therefore adapted to arid and semi-arid conditions. Its distribution shows that it survives in drier regions of the tropics with an average annual rainfall of between 300 and 1000 mm (Heller, 1996). It also occurs mainly at lower altitudes (0 ï 500 m) and is adapted to higher temperatures. The areas considered as centres of origin and from where the material were taken for provenance trials showed average annual temperatures above 20 ^{o}C and up to 28 ^{o}C (Heller, 1996). It grows on well-drained soils with good aeration and is well adapted to marginal soils with low nutrient content (Heller, 1996).

J. curcas grows almost anywhere, even on gravelly or stony soil. It grows in semi-arid and arid conditions (Makkar *et al.*, 1997; Openshaw, 2000) and in tropical humid areas, like Guatemala (>4,000 mm/year) and the northern parts of Vietnam and in Thailand. It can be used to reclaim marginal soils by exploring the soil with its root system. It can therefore recycle nutrients from deeper soil layers (Spaan *et al*., 2004). Under such conditions its oil production is not proven to be commercially viable (Francis *et al*., 2005). Chaudharry *et al*. (2007) and Ogunwole *et al*. (2007) demonstrated that *J. curcas* significantly improved soil structure by 6-30% and reduced soil bulk density by 20%.

The organic matter derived from leaves shed around the base of the plant enhances earth-worm activity, which improves the fertility of the soil. *J. curcas* can withstand severe heat and can withstand long periods of drought by shedding most of its leaves to reduce transpiration. It is also suitable for preventing the shifting of sand dunes. In Cape Verde, where rainfall is as low as 250 mm a year, *J. curcas* is able to survive. Optimum rainfall requirements range from 600 mm to 800 mm although some areas in India report good crop yields with rainfall of 1380 mm/year (Heller, 1996).

2.1.3 Botanical features of *J. curcas*

It is a shrub with smooth gray bark. It grows between 3-5 metres in height, but can attain a higher height under favourable conditions. It has large green to pale-green leaves, alternate to sub-opposite with three to five lobes. The petiole length ranges between 6-25 mm. The inflorescence is found in the leaf axil. Flowers are formed terminally, individually, with female flowers usually slightly larger (Jongschaap *et al*., 2007). Under conditions where continuous growth occurs, unbalance of pistillate or staminate flower production results in a higher number of female flowers. A higher number of female flowers give more number of seeds. It may produce throughout the year if soil moisture is good and temperatures are moderate (Jongschaap *et al*., 2007).

J. curcas is a monoecious shrub, with staminate (male) flowers and pistillate (female) flowers on the same inflorescence (raceme). The inflorescence is a panicle with the female flowers (about 10-20%) at the apices of the main stem and branches of the inflorescence. Male flowers are more numerous (about 80-90%) and occupy subordinate positions on the inflorescence. There is a strong correlation between reproduction and vegetative growth, revealed by the total number of flowers produced and the total length of the branches bearing the inflorescence at their tips (Aker, 1997).

Flowering is one of the most important crop phenological stages for *J. curcas* oil production, as the number of female flowers and their fertilization determines how many fruits and seeds develop eventually. Male flowers open for a period of 8-10 days, whereas female flowers open for 2-4 days only (Prakash *et al.*, 2007). Nutrient limitation seems to provoke the end of flowering (Aker, 1997). Continuous flowering results in a sequence of reproductive development stages on the same branch, from mature fruits at the base, to green fruits in the middle, and flowers at the top of the branch. Flower abortion may be as high as 60% depending on soil water and nutrient availability (Kumar and Kumari, 2007). Pollination of physic nut is by insects

(Dehgan and Webster, 1979). Heller (1992) observed that staminate flowers open later than pistillate flowers on the same inflorescence. After pollination, a trilocular ellipsoidal fruit is formed. The exocarp remains fleshy until the seeds are mature. The seeds are black, 2 cm long and 1 cm thick.

2.1.4 Growth and yield of *J. curcas*

The growth of *J. curcas* is rapid and forms a thick live hedge after only a monthôs planting. It starts yielding from the second year onwards and can grow for fifty (50) years (Henning, 1998). This was again confirmed by Takeda (1982) who stated that the physic nut can reach an age of about 50 years. It quickly establishes itself and will produce seeds round the year if irrigated. Mali has about 10,000 km of *J. curcas* hedges with a growth rate of 2.00 km per year, which represents a potential of 1,700 litres of oil per year (Henning, 1998). The average length of these hedges, in these areas of Mali where they are most prevalent is between 2 and 15 km per village, with a maximum of up to 40 km per village (Henning, 1998).

Rooting pattern is significantly influenced by propagation method. Plants originating from seeds and directly sown into the soil normally develop a rooting system with a thick primary tap root and 4 lateral roots and with abundant secondary roots (Heller, 1996; Severino *et al*., 2007), where as plants propagated by cuttings only develop secondary roots. Growth containers in nurseries may hamper the initial growth of the seedlings if the container volume is insufficient. This is caused by reduced space for root expansion and not by lower availability of nutrients in the substrate (De Lourdes *et al*. 2007).

Seed size (small, medium, large) significantly influence various variables of the seedling such as: seedling height, rooting depth, stem diameter, number of leaves and dry matter of green biomass (1.5, 1.8, 2.1 g/ seedling) (Jongschaap *et al*., 2007). Optimum growth seems possible if rainfall is between 1,200 to 1,500 mm/ year and well distributed. Each inflorescence yields a bunch of approximately 10 or more ovoid fruits (Jongschaap *et al*. 2007).

With good moisture conditions, germination needs 10 days. The seed shell splits the radicle emerges and four peripheral roots are formed soon after the development of the leaves; the cotyledons wither up and fall off (Jongschaap *et al*., 2007). With good rainfall, nursery plants bear fruit after the first rainy season, with directly seeded plants bearing for the first time after the second rainy season. With vegetative propagation, the first seed yield is higher.

Comparative research on the influence of different propagation methods on survival and vegetative development was conducted by Kobilke in Cape Verde and by Heller (1992) in Senegal. The survival rate at Sao Jorge, Cape Verde was significantly higher than that obtained using corresponding methods in Senegal. Both vegetative cultivation methods and methods of generative pre-cultivation were more successful than direct seeding. Heller (1992) compared direct seeding, transplanting of seedlings and direct planting of cuttings of different diameters and differences in seed yields were detected. The first seed yield of cuttings of 730 mm diameter was significantly higher than that of pre-cultivated plants. Thitithanavanich (1985) investigated the root formation of physic nut cuttings of different diameters (1, 2, 3 cm) and lengths (15 and 30 cm) in the nursery. Thicker cuttings formed more roots than the thinner ones. Cuttings of 30 cm length developed more roots and their survival rate was higher than cuttings of 15 cm length. Factors responsible for the survival of direct seeding (seeding time, seeding depth) were studied by Heller (1992). Based on yearly averages, the lower survival rates for direct seeding (19.8%) are striking, whereas the same provenance seeded in polyethylene bags for provenance trials showed a germination of 68%. The survival rate depended not only on sowing time and depth of sowing but also on the trial year (Heller, 1992).

Yield is a function of water, nutrients, heat and the age of the plant. Many different methods of establishment, farming and harvesting are possible (www. Jatrophaworld.org.2007). Seed production ranges from about 2 tons per hectare per year to over 12.5 tons / ha/ year, after five years of growth (www. Jatrophaworld.org.2007). Although, not clearly specified, this range in production may be attributed to low and high rainfall (www. Jatrophaworld.org.2007). According to Gaydone *et al.* (1992) seed yields approached 6-8 tons/ha with 37% oil. They calculated that such yields could produce the equivalent of 2,100-2,800 litres fuel oil/ha. According to Saxena (2006) a well established plantation of *J. curcas* could produce on good soil, an average of about 5 tons seed/ha/ year giving 1500 kg/ha oil and 2500 kg/ha seed cake. However, under marginal conditions a yield of 1.5 tons seed/ha can be expected (Saxena, 2006). The production of seeds is about 0.80 kg per metre of hedge per year, with an oil yield of 0.17 1itres (Henning, 1998). Seed yield of *J. curcas* is also highly variable within plantation stands, varying for example from 0.2 to more than 2 kg per tree (Francis *et al.*, 2005). In young *J. curcas* plantations of 1-2 years, low yields are usually recorded.

J. curcas is known to grow and produce with a minimum water availability of 500 to 600 mm/year with realistic yield of probably less than one ton seed/ha (Euler and Gorriz, 2004). In Brazil, at different plant spacing and with drip irrigation, yields were 335 kg seed/ ha after 12 months, 190 kg seed ha^{-1} after nine months and 56 kg seed/ha after seven months (Saturino *et al.*, 2005). In India, experiments on marginal soils yielded 0.60 to 1.45 tons seeds ha^{-1} after two and a half years (Ghosh *et al*., 2007). Yields were reported to range from 3.2 to 4.1 tons seeds ha^{-1} for the first year after planting at six different locations of rain fed marginal lands in Utter Pradesh (India) (Lal *et al*., 2004).. In Indonesia, the first yearǿs yield of plantation resulted in 3.0 tons seeds ha^{-1} (Manurung, 2007). Openshaw (2000) anticipated yields of 7.5 tons fruits/ ha/year for an established stand under good growth conditions with sufficient water, but without presenting the scientific basis.

In the initial growth phase after establishment of a plantation, when there is no competition for radiation, water and nutrients between plants, seed yield per plant is negatively correlated with plant density (Chikara *et al*., 2007). An additional branching in low density situations may increase the number of fruits per unit area considerably. Depending on crop growth conditions, such as water, nutrient availability and the absence of pests and diseases, maximum yields of 7.8 tons seeds ha^{-1} are projected for mature stands (Jongschaap *et al*. 2007). Depending on the geographical distribution, *J. curcas* stands may reach maturity and full production in about 3-4 years after planting. Younger stands have appreciably lower yields due to inefficiencies in radiation interception and the assignment of dry matter to standing biomass instead of the harvestable parts, the fruits and seeds; decreasing productivity has been reported for aging stands.

2.1.5 Diseases and Pests of *J. curcas*

The toxic characteristics of *J. curcas*, caused by constituents in leaves, stems, fruits and seeds may protect it against diseases and pests, but certainly not all. In plantations, especially under well humid conditions, serious problems have been reported with fungi, viruses and the attack of insects (Sharma and Sarrat, 2007). Some of the diseases that infect the crop include ócollar rotô caused by *Macropphomina phaseolina* or *Rhizoctonia bataticola*) at juvenile stages or by water-logging at adults stages. Leaf spots (caused by *Helminthosporium tetramera* or *Pestalotiopsis spp*), root rot (caused by *Fussarium moniliforme*) and damping off (caused by *Phythoptora spp*) also infect *J. curcas* (Jongchaap *et al*., 2007).

The Commonly known pests of J. curcas are *Agrotis ipsilon*, *Spodoptera litura*, *Locusta migratoria*, *Ostrimia furnacalis*, *Helicoperva armigera* and *Dichocrosis punctiferalis* (Fact, 2010).

2.2 Uses of *J. curcas*

J. curcas is known to have a wide range of uses. These include:

2.2.1 Renewable energy

Since the oil crisis of the 1970s and recognition of the limitations of world oil resources, renewable energy has received special attention. Most of the research was carried out with the aim of making available to farmers possibilities for diversifying in view of the increasing oil prices. Another argument for the cultivation of oil crops for energy purposes is the increasing global warming or green house effect. When these fuels are burned, the atmosphere is not polluted by carbon dioxide, since this has already been assimilated during the growth of these crops. The CO_2 balance therefore remains stable (Ginwal, 2004). In a GTZ project carried out in Mali, it was demonstrated that physic nut oil was competitive with imported diesel especially in remote areas, where fuel is often not available (Lutz, 1992). Quedrago *et a*l. (1991) compared the performance of rapeseed and physic nut oil in diesel engines. The results showed that neither of these fuels was superior to the other.

J. curcas seeds are used for making biodiesel fuel in India and is being promoted as an easily grown biofuel in hundreds of projects throughout India and the third world . It is used to produce the non-edible Jatropha oil, for making candles and soap, and as feedstock for the production of biodiesel. The oil is used as an illuminant in lamp, as it burns without emitting much smoke. The cakes remaining after the oil is pressed can be used as feed in digester and gasifiers to produce biogas for cooking and in engines. In the rural areas in Mali, Lister-type engines are used to drive grain mills and water pumps. These inexpensive pre-combustion chamber diesel engines of Indian origin require only the addition of a fuel filter to be able to run on pure Jatropha oil, thus eliminating the need for gasoil entirely. Furthermore, at maximum load conditions the Jatropha oil gives even better results than gasoil because of its high oxygen content (Henning, 1998). Based on tests conducted by the Jatropha project in Mali, the oil can also be successfully used as a lubricant in engines (Metzler, 1996).

In equivalent terms, the energy needed to produce Jatropha oil in mechanical presses amounts to about 10% of the oil obtained. *J. curcas* oil can be produced inexpensive and therefore cheaper than gasoil (Henning, 1998).

2.2.2 Food and fodder

J. curcas cake can be used as fodder for animals. It is also used as food for the tusser silkworm (Salish, 2007 www.svlele.com. Accessed 3rd October, 2010). According to Ochse (1980) the young leaves may be safely eaten by animals.

2.2.3 Soil improvement and protection

The oil cake of *J. curcas* is rich in nitrogen, phosphorous and potassium and is therefore a very good organic fertilizer comparable to that of chicken manure (Henning, 1998). *J. curcas* used as living fences to control unwanted animal access to fields, they also reduce wind erosion and, if planted across slopes to fix small earth or stone dams, they help control water erosion. The roots of the plant grow close to the ground surface, anchoring the soil like miniature dikes or earthworm bunds. These dikes effectively slow surface run off during intensive downpours which are common, thus causing more water to penetrate into the soil to improve soil water conservation (Henning, 1998). Preliminary studies have shown that *J. curcas* is a very promising species for rehabilitating degraded areas and protecting the land from wind erosion when introduced in dry areas within the framework of watershed management (Saxena, 2006). Physic nut is widely cultivated in the tropics as a living fence in fields and settlements. According to Budowski (1987), it is one of the hedge plants frequently found in El Salvador. In Ghana it is one of the main shrubs or trees planted as hedge. In Madagascar, it is used as a support plant for vanilla. Physic nuts plants are planted around houses to guard against misfortunes in the South ï East of Piaui (Brazil) (Emperaire and Pinton, 1986). Moreira (1970) applied physic nut seed cake at different rates to different crops in pots in field trials. Applications showed phytotoxicity expressed as reduced germination, when high rates of up to 5 tons/ha were applied. Phytoxicity to tomatoes seeded in the field was reduced by increasing the time difference between application and seeding. Fruit hulls and seed shells can be used as a burning material.

2.2.4 Medicine

The seeds, leaves and bark of the physic nut are used in traditional medicine and for veterinary purposes. The oil has a strong purgative action and also widely used against skin diseases and to soothe pain such as that caused by rheumatism. A decoction of leaves is used against cough and as an antiseptic after birth. Branches are used as a chewing stick in Nigeria (Isawumi, 1978). The sap flowing from the stem is used to arrest bleeding of wounds.

Physic nut is a remedy for burns, convulsions, cough, dermatitis, diarrhoea, dysentery, eczema, fever, gonorrhea, herpia, jaundice, paralysis, pneumonia, rash, rheumatism, scabies, stomach ache, syphilis, tetanus, tumors, ulcers and yellow fever (Duke and Wain, 1981). Colombians and Costa Ricans apply the latex to burns, ringworm and ulcers. Barbadians use the leaf tea for marasmus. In Panama, it is reported that *J. curcas* can be used to treat jaundice. Venezuelans take the root decoction for dysentery (Morton, 1981). The leaves are regarded as anti-parasitic and applied to scabies, rheumatism and tumours. The latex is used to dress sores, ulcers and inflamed tongues (Perry, 1980). Root is used in decoction as a mouth wash for bleeding gums and toothache. Otherwise used for eczema, ringworm, and scabies (Perry, 1980; Duke and Ayensu, 1984). Four anti-tumour compounds including jatropham and jatrophone have been reported to be obtained from other species of Jatropha (Duke and Ayensu, 1985).

Extracts from physic nut fruits showed pregnancy terminating effect in rats (Goonasekera *et al.*, 1995). The seed oil extracts of Physic nut seeds were used to control various pests with successful results in many cases (Heller, 1996). Aqueous extracts of physic nut leaves were effective in controlling Sclerotium sp., an *Azolla* fungal pathogen (Garcia and Lawas, 1990).

Ground physic nut showed molluscidal activity against the host liver fluke, a disease which is widely distributed in the Phillipines (Agaceta *et al*., 1981).

The leaves of *J. curcas* are used as food for the tusser silkworm Jongschaap *et al*., 2007). Duke and Wain (1981) listed it for hormicide, piscide, and raticide. Tewari and Shukla (1982) found the latex to be strongly inhibitory to watermelon mosaic virus. A 100% mortality rate was obtained against mosquito when petroleum extract of *J. curcas* leaves were used as a larvicide (Karmegam *et al*., 1997). The wood was used as a (poor quality) burning material in Cape Verde.

2.2.5. As green manure

In a green manure trial with rice in Nepal, the application of 10 tons of fresh physic nut biomass resulted in a yield increase of 11%, with 23% with *Adhatoda vasica*, 17% for *Albizzia lebbek* and 14% with *Hdarrhwa antidysenteria* compared with unfertilized rice which had a yield of 4.11 tons/ha (Sherchan *et al*., 1989).

2.3 Constituents and toxicityof *J. curcas*

Depending on the origin either oleic or linoleic acid content is higher. The seed oil belongs to the oleic or linoleic acid group, to which the majority of vegetable oils belong (Rehm and Espig, 1991). It is an irritant which can cause acute abdominal pain and nausea within half an hour after ingestion. Depression and collapse may occur especially in children. Two seeds can have a strong purgative effect while four to five seeds can cause death, but the roasted seed is said to be nearly innocuous.

The bark, fruit, leaf, root and wood are all reported to contain HCN (Duke, 1983). Seeds contain the dangerous toxalbumin curcin, rendering them potentially toxic. The seed is reported to contain 6.6 g H_2O, 18.2 g protein, 38.0 g fat, 33.5 g total carbohydrate, 15.5 g fibre, and 5.5 g ash (Duke and Atchley, 1984). The toxicity of the seeds is mainly due to the following seed component: a toxic protein (Curcin) and diterpene esters. Curcin is similar to ricin, the toxic protein of the castor bean (*Ricinus communis*) (Heller, 1996). Curcin hinders protein synthesis (Stirper *et al*., 1976). Diterpenes have been isolated from the seeds (Adolf *et al.* 1984) and roots (Naengchonong *et al*., 1986). The detoxification of *J. curcas* organic material is a complicated process and has so far been successful only at the laboratory. The prospect for successful penetration of the seed market with a detoxified product appears small. The toxicity of *J. curcas* is based on several components (phorbol, esters, trypsin and inhibitors) that are present in considerable amounts in all plant components (including the oil) which make complete detoxification a complicated process.

2.4 Economics of planting *J. curcas*

Average oil yields of between 2 t/ha and 6 t/ha for seed can most likely be attained only on soils with irrigation, pruning, fertilization and sufficient exposure to sunlight. Seeds yields will have to be more clearly distinguished in all reports to allow any reliable economic calculation. To attain higher yields, higher inputs are needed which in turn result in increase production costs and thus higher oil prices. Processing cost for expeller and bio-diesel production will also be higher than assumed. If bio-diesel production is to profit from sale of the nutrient rich press cake (at $0.09/kg, which is almost the same price assumed for the whole fruit), to keep the price of processing low, then inputs into nutrients and fertilizer on the *J. curcas* fields will have to be further increased (www.iesafoundation.com). Bio-diesel needs an attractive price for its raw materials to be able to compete with petro-diesel and rural energy sources. As long as alternative incomes from other crops, labour and even reforestation efforts continue to be considerably higher, the bio-fuel programme is bound to stagnate. If other targets such as soil improvement, reforestation, poverty alleviation etc. are to be combined with commercial bio energy production to make it attractive, they need to be accounted for and brought in line with market based economic cost figures, to reach at prices that allow production and consumption on a sustained basis. To this end, transparent, long-term market regulations or subsidies will have to be designed and established (www.iesafoundation.com).

2.5 *J. curcas* production in Ghana

J. curcas plantations in Ghana cover over 1,534 ha (Hagan, 2007). Traditionally, the plant has been used as a fence around homesteads and gardens because it is not browsed by animals; the fruits and seeds are not edible. According to the World Bank, a total of seventeen (17) commercial biofuel developments have been identified in the country (Schoneveld *et al*., 2010). Table 2.1 shows some of the major stakeholders in the cultivation and utilization of *J. curcas* in Ghana. The Ghana Governmentôs interest in promoting the cultivation and use of jatropha for biodiesel production is based on the plantôs ability to grow in a wide range of environments, and also the potential to create jobs for a large number of people (Ahiataku-Togobo and Ofosu-Ahenkorah, 2009). The reported yields of *Jatropha* range from extremely low to high. The Anuanom Industrial Bio product Limited (AIBPL) ï Ghana, estimated that the wild genetic resources in Ghana can yield seeds between 3-5 t/ha/yr and has three main fruits bearing periods; four months cycle for each year (Amoah, 2006).

Table 2.1: Major investments in *J. curcas* plantations in Ghana

Name of institution/company	Land area under cultivation (ha)	Funding sources
B1 Ghana	700	Private investment
ADRA/UNDP	800	UNDP/GEF/ADRA
New Energy	6	Donor funding
Gbimisi Women Group	4	UNIFEM/UNDP-GEF
AngloGold Ashanti Ltd	20	Corporate Fund
Valley View University	4	University Funds
Total	1534	

Source: Hagan (2007)

2.6 Potentials of Bio fuels

The *J. curcas* L. plant is currently receiving a great deal of attention (Kumar and Sharma, 2008). It has been recognized as a plant that is easily converted to biodiesel with good product properties (Agarwal, 2007). The growing global biodiesel market has attracted investors and project developers to consider *J. curcas* L. biodiesel as a supplement for fossil resources and a means to reduce green house gas emissions. By promoting the integrated utilization of the Jatropha plant, the Jatropha system can provide direct financial benefits to the rural economy.

Bio fuels are energising activities on many policy fronts, which may offer opportunities to pursue poverty reduction, environmental protection and development goals both domestically and globally. There are both synergies and trade-offs between these goals and levels (Dufey, 2007). Brazil represents one of the most advanced and attractive markets for biofuels. It was one of the first countries to introduce ethanol on a large scale as a replacement for gasoiline in the 70ós (Ugarte, 2009). Today Brazi mandates that gasoiline have 20 -25 % ethanol at the pump. In 2008, a legislation promoting the production of bio-diesl through tax incentives, with a focus on small producers, and fixing utilization target of 3% for 2008 and 5% by 2012. Brazil is one of the largest exports of biofuels worldwide (Ugarte, 2009). Argentina has set an ambitious goal to replace 5% of the diesel and gasoline used in the transportation sector by biofuels (Warren, 2009). It has guaranteed a minmum price level for ethanol and biodiesel, which will promote the development of sugar cane and soybean industries (Warren, 2009). Canada has also passed legislation mandating the use of 2% biodiesel by 2010 and introduced a number of tax incentives such as tax exemption of 40% for biodiesel production and consumption (Ugarte, 2009). India has set a very aggressive target for ethanol and biodiesel of 10% by 2012 which require a 13 fold increase in installed capacity to meet such objectives (Ugarte, 2009). Thailand has set 10% biofuels target by removing import tarrifs on flex-fuel vechicle as a mechanism tp promote high ethanol blends (DNV, 2010).

Woldwide biodiesel production reached 3,524 million litres in 2005 and expected to reach 11,000 million litres by 2010. Currently world ethanol is 55,000 million litres and is expected to reach 70,000 million litres in 2010. In both cases, demand is expected to exceed supply, therefore there is the potential for new players such as Ghana to engage in the biofuel industry (Camiati, 2007). The IEA Bio energy Task 40 reports that Africa has the largest bio energy potential in the world (Smeets *et al*., 2004). Though bio energy is not a new concept, it has resurfaced now due to security of supply of fuels caused by a looming peak (energy resource depletion) and increasingly expensive fossil fuels which make bio fuels competitive (Sinkala, 2007). Thus, bio fuels are a golden opportunity for developing countries, regarded as central for sustainable development and poverty reduction.

Critics of the bio energy drive have, however, argued that the scale of production that would be expected to meet global and national demands would have devastating impacts that are social, economic and environmental in nature (Dufey, 2007). There are fears that the bio fuel agenda will compete with the growing of food crops and thus lead to food insecurity. There are also fears that governments are promoting bio fuels and making decisions without adequate policy and institutional framework to guide their implementation.

According to Bio energy report (2007) promotion of the bio fuels industry in developing countries has the capacity to propel such countries to achieve the Millennium Development Goals through poverty reduction (especially job creation and economic enhancement), health impact and climate change.

2.7 Energy Crops

Energy crops are a type of biomass from which bio fuels are made. Energy crops are specifically grown to produce some form of energy, which may be generated through direct combustion or gasification of the crops to create heat, or by converting them to liquid fuels such as ethanol for use in vehicles (MBEP, 2002). There are basically two types of energy crops, herbaceous and woody. Herbaceous energy crops are mostly types of grasses which are handled like hay while woody energy crops are short rotation woody crops which include many types of trees and shrubs such as jatropha (MBEP, 2002).

Energy crops have the following characteristics; high energy savings and greenhouse gas reductions, non-food crop, recycle their nutrients, no annual cultivation, all parts of the plant can be used as feed stock, longer growing season and high yields per hectare (Karp, 2009). A study in the SADC region identified the following as key energy crops for bio fuel production; palm oil, sweet sorghum, sugarcane, sunflower, soybean, jatropha and cassava (Takavarasha *et al*.,2005). These crops were ranked according to their potential in the production of bio fuels, employment creation level and production costs, yield and impacts on food security, foreign exchange savings and energy balance. The study revealed that the total production levels of these enrgy crops in SADC were oil palm (1,516 Mt), sunflower (749.9 Mt), soybean (335.8 Mt), maize (19,757 Mt), sorghum (1,697 Mt), sugar cane (43,602 Mt) and cassava (39,441 Mt) (Takavarasha *et al*.,2005). Jatropha areas were ranked low because the crop is not yet commercially grown.

In Ghana, the production level of J. curcas as an energy crop is between 3 ï 5 tons/ha/year (Amoah, 2006).

2.8 Integration of Energy Crops into Agroforestry

According to FAO (2009), negative environmental impacts of bio energy production, in particular those related to carbon, soil and water resources can be mitigated through good agricultural practices such as minimum tillage, integrated pest and soil management, multiple cropping, appropriate crop choices and crop rotations. The use of these practices is believed to reduce the threat to biodiversity, particularly soil diversity, through retention of crop residues and diversified rotations. All these practices are encompassed in improved agro forestry systems. Thus, it can safely be concluded that for sustainable environmental management, energy crops should be integrated into improved agro forestry systems which combine feed stock production with crop production and feeding livestock on biomass not used for energy production or soil cover. This system can minimize waste and increase the overall productivity of the system for food and energy production (FAO, 2009). Effective implementation and management of agroforestry systems can be a solution to some of the potential problems which can result from bio fuel production systems due to the fact that agroforestry will help to optimize the use of land resources to stabilize the environment, provide stake products, trees and food.

2.9 A general overview of Agroforestry

2.9.1 Definition

Agroforestry is a collective name for land-use systems and technologies where woody perennials (trees, shrubs, palms, bamboos etc) are deliberately used on the same land-management unit as agricultural and/or animals, in some form of spatial arrangement or temporal sequence. In agroforestry systems there are both ecological and economic interactions between the different components (Lundgren and Raintree, 1982). The above definition, though not perfect in all respects, was increasingly used by the International Centre for Research in Agroforestry (ICRAF) now World Agroforestry Centre (WAFC) publications and thus achieved wide acceptability (Nair, 1993). A strictly scientific definition of agroforestry should stress two characteristics common to all forms of agroforestry and separate them from the other forms of land use namely:

- The deliberate growing of woody perennials on the same unit of land as agricultural crops and / or animals, either in some form of spatial mixture or sequence.
- There must be a significant ecological and/or economic interaction (positive and / or negative) between the woody and non woody components of the system (Nair, 1993).

Agroforestry is credited with improving the utilization of space by improving recycling of nutrients and organic matter. This translates into improved soil chemical, physical and biological characteristics with a reduction in the use of chemical fertilizers and improved infiltration of rain water. Higher aggregate biomass production is obtained from an agroforestry mixture than monoculture (Nair, 1993). Microclimate extremes are reduced as is soil erosion. Limited resources can be used more efficiently in the following manner: Efficient sunlight utilization by multistoried levels, soil nutrients recycle by deep roots, retaining of moisture by mulch and land improvement by sustaining soil fertility (Nair, 1993). Agroforestry thus provides a more favorable environment for sustained cropping, the creation of habitat diversity and provides a more continuous flow of more products over time (Cameron *et al*. 1991).

The practice, however, has disadvantages. Most important of these is the increased competition of trees with agricultural crops for water, nutrients and light. This competition could lead to reduced yields of both trees and associated crops. The usable crop area is reduced due to tree alley/plots, which could also act as a habitat for pests. Allelopathic effects by trees could reduce crop yields. More importantly, agroforestry systems are usually labor intensive, which could be a deterrent to the adoption of the practice. There is also the fear that certain species may become invasive and provide favorable conditions for the habitation of pests (Nair, 1993). It is however, increasingly accepted that the advantages of agroforestry, particularly the environmental aspects, clearly outweigh the disadvantages, and that many of the disadvantages can be eliminated or minimized by manipulating management practices (Nair, 1993).

2.9.2 Background of Agroforestry in Ghana

The National Agroforestry Policy recognized the fact that an organized and co-ordinated approach was required if agroforestry was to play a role in the promotion of sustainable agricultural development. In the light of this, the Government of Ghana, with assistance from the UNDP and FAO through project GHA/88/007 initiated a national programme to support an Agroforestry Unit (AFU) within the Crops Services Department of the Ministry of Food and Agriculture (MOFA), and to establish a National Coordination Network between the Agroforestry Unit, the Government, and NGOøs. To ensure effective policy implementation and monitoring three main stratified institutions were put in place. They were:

- National Agroforestry Committee
- Agroforestry Technical Sub-Committee
- Regional and District Agroforestry Committees

Other related institutions included the National Research Institutions, Universities, MOFA and the Forestry Services Department. Three main strategies or courses of action were adopted to support the policy. These were research (adaptive trial and demonstrations), training and exension education (Anim-Kwapong, 2004).

2.9.3 Agroforestry Research in Ghana.

Agroforestry research in Ghana is mainly applied research. Institutions involved in agroforestry research include Cocoa Research Institute of Ghana (CRIG), some Institutes within the Council for Scientific and Industrial Research (CSIR), various Universities, MOFA, and other organizations such as NGOs and the Ghana Irrigation Development Authority (GIDA). The CSIR institutes (Forestry Research Institute of Ghana, Crops Research Institute, Soil Research Institute, Savannah Agricultural Research Institute) and GIDA conduct both strategic and adaptive research whereas MOFA only carries out adaptive research. The universities undertake more strategic applied research than basic and fundamental research (Anim-Kwapong, 2004).

Agroforestry research is primarily grouped under two main themes, biophysical and socio-economic and policy issues. Research into biophysical aspects outweighs that of the socio-economic and policy issues. The biophysical research tends to have narrow and specific (not cross cutting) subject matter and is aimed at the academic rather than poor farmers and their livelihood realities. Most of the research takes place onï station. The various technologies being developed or adapted fall under alleycropping, multipurpose trees (MPT) production on croplands, fuelwood production, protein banks, live hedges and home gardens. The specific technologies under MPTs on croplands include dispersed planting, line planting and boundary planting and in situ live staking of yams (Anim-Kwapong, 2004).

In developing, testing and disseminating appropriate agroforestry technologies to farmers, field investigations, trials and demonstrations were used by the National Research Institutions, Universities, MOFA and Forestry Services Division of the Forestry Commission. To scale up farmer adoption rates, NGOs and individuals were supported and encouraged to establish their own nurseries by MOFA and Forestry Department. These individuals and groups were provided with technical and material assistance, including seeds and polythene bags. In addition, training programmes were organized for those interested in complicated seedling production like grafting and budding of fruit trees. To ensure the success of this strategy and to encourage the privatization of nursery departments, seedlings subsidies were gradually removed in 1992 (Anim-Kwapong, 2004). Further extension services in the Agroforestry Unit led farmers through demonstrations on selected farmersô field and the farmers were provided with inputs to demonstrate agroforestry systems or techniques suitable for their particular locality (Anim-Kwapong, 2004).

2.9.4 Training and extension education in Agroforestry

Agroforestry training focused on formal education in the Universities. The Kwame Nkrumah University of Science and Technology (KNUST) run courses in agroforestry to train professional capable of promoting the practice of Agroforestry in the field. Other public universities such as the University of Cape Coast and the University For Development Studies; and the Agricultural Colleges under the MOFA also incorporated the study of agroforestry into their curriculum. Appropriate on the job training sessions, workshops and seminars aimed at up-grading the knowledge and skills of personnel engaged in agroforestry activities were organized by MOFA. The Ministry of Food and Agriculture and NGOs undertook the task of disseminating the concepts and techniques. Staff of the Agroforestry Unit in MOFA served as Subject Matter Specialist and facilitated adaptive trials throughout the country (Anim-Kwapong, 2004).

2.9.5 Agroforestry Development in Ghana

The objectives of many agroforestry projects in the late 1980s were to establish tree seed nurseries in order to provide readily available seedlings for farmers willing to adopt agroforestry technologies. This was in line with the objectives of the National Agroforestry Policy, which was aimed at establishing and maintaining 350 demonstration centers, 450 nurseries and 30,000 ha of agroforestry systems nationwide (Anim-Kwapong, 2004). As at 1992, 119 demonstrations, 131 nurseries and 1,642 ha of agroforestry had been achieved (34, 33, and 5%, respectively) (Anim-Kwapong, 2004).

NGOs like the Ghana Rural Reconstruction Movement (GhRRM), Adventist Development and Relief Agency (ADRA), CARE-Denmark and Conservation International have been influential in supporting governmentô's effort in empowering farmers to engage in sustainable agriculture through agroforestry. ADRA supported the governmentô's effort in 1989 by launching the Collaborative Community Forestry Initiative (CCFI) programme that established nurseries and supported households with seedlings. Under this programme, 20 nurseries were established within 10 years, producing more than 4 million assorted tree seedlings including fruit trees like mangoes, cashew, citrus and guava. Woody tree species under nurseries included Teak (*Tectona grandis*), Eucalyptus (*Eucalyptus spp*.), Neem (*Azadirachta indica*) and Albizzia (*Albizzia lebbeck*) (Djarbeng and Ameyaw, 2002).

In 1994, GhRRM supported the publication of Agroforestry in Ghana: A Technology Information Kit. This loose-leaf information Kit has information on agroforestry techniques and served as a teaching and extension material for extension personnel and NGOs.

In 1994 two timber firms from Ghana and Denmark, Ghana Primewood Products Limited (GAP) and Dalhoff Larsen and Hornemam A/S established what later became known as a joint Forest

Management Project between farmers and the project organizers in South-Western Ghana. The objective of the project was to get farmers to actively incorporate tree on farm in an area gradually losing its forest cover (Asare, 1999). The project distributed fruit trees and timber species to farmers and encouraged them to incorporate them on their farms. ADRA in 1997 initiated a 5-year food security programme which promoted availability, access, and utilization of food produced through agroforestry. Eleven nurseries and an area of 9,920 ha were placed under production (Djarbeng and Ameyaw, 2002).

In 1998 Conservation International in collaboration with government and Farmer Associations in Ghana contributed to sustainable Cocoa farming through the promotion of cocoa agroforestry. The programme was to promote cocoa agroforestry as an integral land use, strategy to connect part of the remaining forest fragment through conservation corridors in the South-Western parts of the country. The Conservation International promoted participatory training and an extension methodology which created an enabling political climate to support agroforestry in the country. Through these activities farmers have diversified crop production, increased yields in cocoa and reduced encroachment into nearby forests (Asare, 2004).

2.9.6 Economic benefits of agroforestry

Support for agroforestry technologies has been spurred by the concern for environmental problems such as deforestation, desertification and soil erosion, and by aggregate shortages of household fuel wood supplies. Agroforestry interventions have been evaluated mainly for their purported effects on environmental factors or wood supply. Organizations responsible for promoting agroforestry, especially alley cropping among farmers have realised that farmer adoption of new practices and their willingness to extend existing practices is critically dependent on perceived financial and economic benefits at the household level (Scheer,1992).

Even though the economic performance is of utmost importance only a few projects have established systems to monitor it. In 1988-89, a review of technology evaluation of 108 agroforestry projects revealed that only 13% assessed economic costs or benefits, less than 33% assessed crop yields, 7% assessed labour requirements, and 23% formally solicited farmer evaluation of the technologies. Half of the projects assessed impact, but of these only 8% assessed the cost and benefit of technology adoption and 16% assessed changes in product supply (Scherr and Muller, 1991). Projects that do not carry out economic studies limit their value for cross-project comparison, particularly in semi-arid environments, there is much to learn from farmersô strategies with agroforestry. Economic research can shed more light in this area (Sullivan *et al.*, 1991).

According to Gittinger (1982) an economic analysis will enable recommendations of the best treatment combinations. The economic analysis consists of identifying and pricing costs and benefits from these cost and benefits. Three decision criteria can be determined, namely, the Benefit/Cost (B/C) ratio, Internal Rate of Return (IRR) and Net Present Value (NPV). The benefit-cost ratios require discounted values for benefits (returns) and cost and therefore a discount rate is necessary. Benefit-cost ratios are simply the ratios of discounted benefits to discounted cost. It is the monetary benefit per unit of money (e.g cedis) invested. Benefit-Cost ratios provide additional economic information useful to determine the 'best' agroforestry practice (David, 1988). The internal rate of return (IRR) can be used to measure economic performance of time-related investments. This particular rate of return is the rate, which results in the Net Present Value (NPV) being zero (0). It is the maximum rate of return possible. The key benefit of using IRR to compare agroforestry investments is that no specific time preference rate must be determined (David, 1988). Net present value is the difference between discounted costs and revenues at a specified discounted rate measured by the opportunity cost of capital. An investment is generally acceptable if its NPV is positive and unacceptable if its NPV is negative. Negative NPV implies that higher rates of return can be earned in alternative investments (Josef and Brehon, 1990).

Raintree and Turay (1980) reported that there were positive economic benefits for upland rice in a Leucaena/Rice alley cropping system in Sierra Leone. The main economic benefit was the net increase in profit as a result of less fertilizer and herbicides being used in the alley cropping system. The cost of production of rice was lower than in control plots. The Cost-Benefit ratio was therefore higher which implied higher profits for the alley cropping system than the control.

Singh *et al*. (1989) working in semi-arid India reported that alley cropping sorghum yielded nearly twice the income of the sole crop, thus giving farmers better economic benefits. They also found that the alley cropped Pigeon pea yielded almost seven times the income of the sole crop. In both cases the added economic benefit was derived from the Leucaena by-product, which was sold as fodder. Sumberg *et al*. (1987) reported that alley cropping maize among Leucaena hedgerows was more profitable than the monocropped maize. The additional benefits were derived from fuel wood and the higher maize yield in the alley cropped plots.

2.10 Alley cropping

A promising agroforestry technology for the humid and sub humid tropics which has been developed during the past decade is alley cropping (Nair, 1993). In many areas of humid Africa traditional farming is no longer sustainable due to shortening or disappearance of the fallow period resulting from rapid population growth (Kang *et al*., 1999). Alley cropping is also known as hedgerow intercropping and combines the regenerative properties of a bush fallow system with food crop production. Pioneering work on this technology was initiated at the International Institute of Tropical Agriculture (IITA) in Nigeria in the early 1980s (Nair, 1993). The concept of alley cropping was formalized at IITA where the term was defined as ñthe growing of crops, usually food crops, in alleys formed by trees or woody shrubs that are established mainly to hasten soil fertility restoration and enhance productivity (Nair, 1993). The trees and shrubs are cut back at crop planting and maintained as hedges by frequent trimming during the cropping (Wilson and Kang, 1981). The leaves and twigs from the trees are added to the soil as green manure or mulch.

Shrubs and trees retain the same functions of recycling nutrients, suppressing weeds and controlling erosion on sloping land as those in bush fallow. In addition, other tree products such as fuelwood and animal feed can be provided. It is a management-intensive system that can lead to increased yields and productivity of the land (Nair, 1993). Trees planted in rows are normally from 2 to 20 meters apart, usually with cash crops cultivated between the rows or in the alleys formed by the trees. Wide spacing between rows (e.g. 10 ï 20 m) may be used to avoid negative impact on the associated crops when the trees are permitted to grow to large sizes. During the cropping season, the trees are kept pruned ï mostly to a hedgerow ï and the leaves and green stems are applied to the soil surface or incorporated into the soil. The soil and micro-environments are enriched by fallen leaf material or mulch, directly affecting associated crops (Nair, 1993).

Hedgerows are preferred as shading of the cash crops is minimized and competition between the trees and crops is limited. Hedgerows can be allowed to grow out between cropping seasons to produce fuelwood. On sloping land, hedgerows are planted densely (5 ï 10 cm within rows) along the contours to form a barrier against soil erosion. Grass strips planted beside hedgerows will create an even more effective barrier. Cash crops used have included beans, maize, cassava, grasses, rice and pigeon peas. Animals/vehicles can be used for tillage and harvesting if the tree rows are planted far enough apart. Animals can feed directly off the trees if they are not pruned but this may entail damage to cash crops in alley. However, trees take up space, compete for light, moisture and nutrient with cash/pasture crops (Brewbaker *et al.*, 1985).

According to Nair (1993), alley cropping depends on nutrient recycling through decomposition of leaves from deep rooted and nitrogen-fixing trees, whereby yields and associated crops are perceived to be increased through different mechanisms including:

- Concentration of soil nutrient extracted from the deeper soil horizons and return of these nutrients to the soil surface.
- Fixing atmospheric nitrogen and contributing this nitrogen to the soil via leaf and fallen fruit litter, or the release of root debris and nodules. Trees used for this reason are therefore mainly leguminous (Nair, 1993).

Alley cropping is a low external input technology and the cost of externally procured inputs is low. Intensely populated rural areas where alley cropping is most appropriate labour is relatively cheap and readily available and so the cost of labour is low. In rural areas the opportunity cost of land is low as land is mainly used for the production of traditional crops, which are the main components of the alley cropping system. Therefore, with the low price for capital, land and labour, the total cost of production is expected to be low. A technology with low cash outflow and judicious use of labour is likely to have a greater attraction for small farmers (Sullivan *et al*., 1991).

2.10.1 Factors to consider in choosing tree species for alley cropping

Rachie (1983) detailed a number of attributes which should be considered when selecting a tree species for alley cropping. These include:

1. Ease of establishment from seeds or cuttings.
2. Rapid rate of growth of the tree species.
3. Ability to withstand frequent lopping.
4. Deep root system with different root distribution to that of crop.
5. Multiple uses such as firewood, fence posts and wood chips.
6. Ability to withstand environmental stress such as drought, water logging, extremes of temperatures etc.
7. High leaf: stem ratio.
8. Small leaves or leaflets.
9. Dry season leaf retention.
10. Free from pests and diseases.

2.10.2 Nutrient yield under hedgerow intercropping

The nitrogen contribution of woody perennials (that is the amount of nitrogen made available from the decomposition of biomass added to soil) is the most important source of nitrogen for agricultural crops in unfertilized alley cropping systems. Obviously, the amount of nitrogen added varies and largely corresponds to the biomass yield of trees, which in turn depends on the species and on management practices and site-specific factors. Nitrogen contribution may also vary according to the rate of nitrogen fixation and the turnover rate of nodulated roots (Nair, 1993). Torres (1983) estimated that the nitrogen yield of *Leucaena leucocephala* hedgerows, cut approximately every eight weeks, was 45 g per meter of hedgerows. If the hedges were planted 5 m apart; this amounted to 90 kg N $ha^{-1}yr^{-1}$. Higher nitrogen contribution has been reported from other field studies where the hedgerow species was *L. leucocephala* or *Gliricidia sepium* (Yamoah *et al*., 1986, Budelman, 1988). In a study conducted in Cote dȁIvoire, yields of 44, 59 and 37 kg ha^{-1} were obtained over a period of three months from *G. sepium, L. leucocephala* and *Flemingia macrophylla,* respectively (Budelman, 1988).

2.10.3 Criteria for selection of hedgerow species

In the selection of hedgerow species for alley cropping, Serrano (1988) considered the following as important criteria for determining whether or not an alley crop species is suitable: 1) species survival including pest and disease resistance; 2) nitrogen-fixing capacity; and 3) biomass and litter production. However, even if the hedgerow species possesses these excellent properties but cannot satisfactorily enhance or sustain the productivity of the ecosystem, such species may only be of marginal value for alley cropping. Enhancement of ecosystem productivity is primarily determined among other things, by the amount and decomposition characteristics of hedgerow pruning which the food crops may receive from the associated alley crops. Species ability to withstand repeated pruning plays an important role in this respect. Such parameters were included in a study conducted by Szoot *et al*. (1987). Their results indicated that *Inga edulia* produced 8.7 tons of biomass per hectare per year while *Cajanus cajan* yielded only 1.8 tons of pruning at the same production area and on the same time ï rate basis. The low biomass production by *C. cajan* was due to plant senescence. As to decomposition properties, the same researchers found that for Erythrina species, pruning can be observed even after three months and found it to be intermediate between that of Inga and that of *Cajanus cajan*.

2.10.4 Effect of hedgerow intercropping on soil properties

The concept of soil conservation has undergone significant change. It was synonymous with soil erosion control and control efforts were handled in isolation from other aspects of land management. Soil conservation now encompasses both erosion control and maintainance of soil fertility (Young, 1989). Lal (1989a) showed that erosion in plots tilled and alley cropped with gliricidia and leucaena was reduced by 73 and *83%* respectively compared with a tilled control treatment. Several studies (Kang *et al.* 1985, Lal 1989b, Kang and Ghuman 1991) have demonstrated significant positive effects of alley cropping on soil fertility parameters such as organic C levels, total N and extractable P levels over a range of climatic and soil conditions. The magnitude of these effects, however, varied with hedgerow species and management as this influenced the quantity and quality of prunings. Factors such as C:N ratio, lignin and polyphenol contents influence the decomposition rate of the mulch, the subsequent release of nutrients and their uptake by the crop. In a study in Nigeria, Yamoah *et al*. (1986) evaluated the relative potential of three leguminous shrubs (*Cassia siamea, Flemingia congesta* and *Gliricidia sepium*), with respect to changes on some soil properties in an alley cropping system with maize as the main food crop. Soil under Cassia yielded the highest content of nitrogen (N), phosphorus (P), potassium (K) and organic carbon after the second maize crop. The increase in these important nutrients was due to the large amount of pruning contributed by Cassia coupled with its slow rate of decomposition, which reduced nutrient loss through leaching. Even though maize removed some nutrients especially N, from the other plots, nutrient taken by the maize was replaced by pruning and fertilizer.

Onde and Jide (2009) also reported that *G. sepium* improved soil quality significantly in organic carbon content. Alley cropping with *Albizzia lebbeck* hedges offers farmers an option for reducing reliance upon chemical nitrogen fertilizer while improving soil organic matter levels (Rhoades *et al*., 1998).

One of the most important premises of alley cropping is that the addition of organic mulch, especially nutrient-rich mulch, has a favorable effect on the physical and chemical properties of soil, and hence on crop productivity. However, there are few reports on the long term effects of alley cropping on soil properties; of those that are available, most are from IITA, the institution with the longest record of alley cropping research. Okonkwo *et al*. (2009) showed that, over a two-year period, soil pH increased from 4.2 to 6.1 in alley plots with *C. cajan*. The organic matter increased from 1.01 g kg^{-1} in the pre-planting to 5.98 g kg^{-1} in the *C. cajan* alley plots over a two year period. Total nitrogen increased in all the alley plots with the highest nitrogen content of 2.31 g kg^{-1} in the *G. sepium* alley plots. Available phosphorus, exchangeable Ca and Mg increased significantly in the alley plots over the preplanting (Kang *et al*. 1989). Kang and Wilson (1987) reported that with continuous addition of *L. leucocephala* prunings, higher soil organic matter and nutrient levels were maintained compared to no addition of prunings. Atta-krah *et al*. (1985) also showed that soil under alley cropping was higher in organic matter and nitrogen content than soil without trees. Yamoah *et al*., (1986) compared the effect of *C. siamea, G. sepium,* and *F. macrophylla* in alley cropping trials, and found that soil organic matter and nutrient status were maintained at higher levels with *C. siamea* (which surprisingly, is not a N_2-fixing species). A study by Wang *et al.* (2010) indicated that nutrient loss in runoff was high especially the loss of nitrate and phosphate.

2.10.5 Effect of alley cropping on crop yields

Alley cropping is generally known to enhance crop yields. Oko *et al*. (2000) reported that alley cropping enhanced the growth and bunch yield of plantain. They further stated that the grain yield of cowpea was higher under alley cropping with hedgerow species. An eight year alley cropping trial conducted by Kang *et al*., (1990) in Nigeria on a sandy soil showed that, using *L. leucocephala* pruningôs only, maize yield could be maintained at óreasonableô level of 2 tons/ha as against 0.66 tons ha^{-1} without *L. leucocephala* pruningôs and fertilizer. Kang *et al*. (1981) indicated that an application of 10 tons ha^{-1} of fresh *L. leucocephala* prunings had the same effect on maize yield as the addition of 100 kg N ha^{-1}. A similar magnitude of response was obtained by Dofeliz and Nesbitt (1984) in the Philippines again with leucaena at 4 m row spacings. Mathews *et al*. (1992) also found a significant improvement in maize yields through alley cropping, when no fertilizer was applied. The incorporation of *L. leucocephala* pruning resulted in an increase of up to 95% in yield of maize, with a smaller improvement being produced by *F. congesta* (Mathews *et al*., 1992).

Chesney *et al*. (2010) reported that *G. sepium* was a more attractive alley cropping species than *L. leucocephala*. They obtained higher cowpea yields from *G. sepium* plots and attributed this to ease of establishment from cutting and higher production of biomass from *G. sepium*. The use of *G. sepium* was recommended to maximize crop yield and minimize the need for external nitrogen fertilizer. Studies conducted at IITA by Palada *et al*. (1992) found that better yield of vegetables in alley cropped plots were part due to the effect of the *L. leucocephala* hedgerow. Alley cropping with *L. leucocephala* reduced fertilizer requirement for vegetable production.

Results from other alley cropping trials are less promising. For example, in trials conducted on an infertile acid soil at Yurimaguas, Peru, the yields of all crops studied (Rice, cowpea and maize) in the experiment apart from cowpea were extremely low, and the overall yield from alley cropped plots was equal to or less than that from the control plots. Singh *et al.* (1989) reported that the yields of castor, cowpea and sorghum alley cropped with leucaena hedgerows spaced at 10 m for a period of 4 years were lower than in the control treatment. Yield declined from 30 to 150% of the sole crop yield as the distance from the hedgerows declined from 5 m to 0.3 m. These authors attributed much of the yield decline to severe moisture competition. Szott (1987) and Fernandes (1990) concluded from a study on productivity of shifting cultivation that, the main reasons for the comparatively poor crop performance under alley cropping treatments were root competition and shading. Lawson and Kang (1990) observed that larger amount of hedgerow biomass production was associated with significant decrease in crop yields due to increase hedgerow shading particularly with *L. leucocephala*.

2.11 The concept of Land equivalent ratio (LER)

Land equivalent ratio (LER) is ratio of the area under sole cropping to the area under inter-cropping at the same management level to give an equal amount of yield. LER is also the sum of the fractions of the yields of the intercrops to their sole crop yields (FAO, 1996). According to Willey (1979), the most generally useful single index for expressing the yield advantage is probably the LER. It can be expressed as:

$$LER = L_A + L_B = \frac{Y_A}{S_A} + \frac{Y_B}{S_B}$$

Where L_A and L_B are the LERôs for individual crops (called partial LERôs), YA and YB are the individual crop yield in intercropping system and SA and SB are their yield as sole crops (pure stand). According to Mead and Willey (1980) the advantages of LER are that it provides standardized basis so that crops can be added to form combined yield.

Various other indices have been suggested which are conversion of yield to money value, total protein content or calories. Undoubtedly economic indices have advantages but they have disadvantages that the monetary value, for example, is subject to market conditions, which are by no means constant. Again calorific value or protein content may appeal to a dietician but it does not enter into the consideration of peasant farmer, who is the one to be persuaded (Pearce and Gilliver, 1978).

There are two limitations of LER which are:

1. It is independent of yields levels, being a ratio, large values arise not only when the sole crop yields are small, but also when the inter-crop yields are large.

2. The LER values, being the sum of the ratios of two normal variates, follow Cauchyôs distribution and hence one of the assumptions of normality underlying the analysis of the variance fails.

However, for the second limitation, Oyejola and Mead (1982) have shown that there is more than one way to generate LER values from plot yield data and that non-normality is not serious, provided the mean yields of the sole crops (over replication) are taken for the purpose of standardization. Fisher (1977) favoured standardization within each block to reduce standard error and also skewness of the distribution of LERôs.

The following illustration makes LER calculation clear:

Treatment	Yield (Kg/ha)
Pigeonpea (sole)	30
Greengram (sole)	10
Pigeonpea + Greengram	22 + 6
Pigeonpea PLER (partial)	22/30 = 0.73
Greengram PLER (partial)	6/10 = 0.63

LER = 0.73 + 0.60 = 1.33

The LER is 1.33. This means that 33% more land would be required as sole crops to produce the same yields as inter-cropping (Lahiri, 1998). A LER of 1.0 indicates no difference in yield between the intercrop and the collection of monocultures (Mazaheri and Oveysi, 2004). Any value greater than 1.0 indicates a yield advantage for intercrop.

In a combined system of sunflower and peanut intercropping a LER of 1.45 was obtained (Sahoo *et al.*, 2003). Motha and De (1980) indicated that LER increased by 31% and 43% in the intercropping system of sorghum and maize with soybean as compared to monoculture of the ceraels, respectively. Obuo et al. (1998) evaluated four intra-row spacing for cowpea andsorghum intercropping and found the LER between 1.41 and 1.76 indicating high yield advantages from intercropping.

2.12 Definition and concept of decomposition

Decomposition is the process whereby formerly living matter is broken down into soil, nutrients and gasses. Decomposition is a dynamic stage of the carbon cycle, where carbon sequestered in living things is re-released in part into the atmosphere (Eberhardt and Elliot, 2008). According to Quigley (1998), decomposition refers to the natural breakdown of complex organic compounds into simpler substances. Decay occurs in dead plant and animal tissue and the substances released such as carbon dioxide, ammonia and methane are absorbed by green plants for nutrition beginning a new food chain. Without decay the essential building blocks of life would remain locked inside the dead tissue.

2.12.1 General theory of decomposition

Dead plants or animals, material derived from body tissues such as skin cast off during moulting, and matter derived from organisms in the form of excreta all gradually lose their form, due to both physical processes and the action of decomposers, such as bacteria and fungi. Decomposition, the process through which organic matter is decomposed, takes place in many stages. Materials like proteins, lipids and sugars with low molecular weights are rapidly consumed and absorbed by micro-organisms and organisms that feed on dead matter. Other compounds, such as complex carbohydrates are broken down more slowly. In addition, the purpose of the various micro-organisms involved is not to break down these materials but to use them to gain the resources they require for their own survival and proliferation, and they are merely breaking them down as part of that process (Quigley, 1998).

At the same time that the materials of plants and animals are being broken down, the materials (biomass) making up the bodies of the micro-organisms are built up by a process of assimilation (Quigley, 1998). When micro-organisms die, fine organic particles are produced, and if these are eaten by small animals which feed on micro-organisms, they will collect inside their intestines, and change shape into large pellets of dung. As a result of this process, most of the materials from dead organisms disappear from view, not present in any recognizable form, but is in fact present in the form of a combination of fine organic particles and the organisms using them as nutrients. This combination is termed detritus. In ecosystems on land, detritus is deposited on the surface of the ground, taking forms such as the humid soil beneath a layer of fallen leaves. In aquatic ecosystems, most detritus is suspended in water, and gradually settles. In particular, many different types of material are collected together by currents, and settle in slowly-flowing areas (Eberhardt and Elliot, 2008).

Detritus is mostly used as a source of nutrition for animals. In particular, many bottom-dwelling animals (benthos) living in mud flats feed in this way. Since excreta are materials which other animals do not need, whatever energy value they might have are often unbalanced as a source of nutrients, and are not suitable as a source of nutrition on their own. However, there are many micro-organisms which multiply in natural environments. These micro-organisms do not simply absorb nutrients from these particles, but also shape their own bodies so that they can take the resources they lack from the area around them, and this allows them to make good use of excreta as a source of nutrients. In practical terms, the most important constituents of detritus are complex carbohydrates, which are persistent (difficult to break down), and the micro-organisms which multiply using these absorb carbon from the detritus, and materials such as nitrogen and phosphorus from the water in their environment to synthesis the components of their own cells (Kulshrestha and Satpathy, 2001).

A characteristic type of food chain called the detritus cycle takes place involving detritus feeders (detritivores), detritus and the micro-organisms that multiply on it. When these detritus feeders take in detritus with micro-organisms multiplying on it, they mainly break down and absorb the micro-organisms, which are rich in proteins, and excrete the detritus, which is mostly complex carbohydrates, having hardly broken it down. At first this dung is a poor source of nutrition, but after several days, micro-organisms begin to multiply on it again, its nutritional balance improves, and so they eat it again. Through this process of eating the detritus many times over and harvesting the micro-organisms from it, the detritus thins out, becomes fractured and easier for the micro-organisms to use, and so the complex carbohydrates are also steadily broken down and disappear over time. What is left behind by the detritivores is then further broken down and recycled by decomposers, such as bacteria and fungi (Eberhardt and Elliot, 2008).

This detritus cycle plays a large part in the purification process, whereby organic materials carried by rivers is broken down and disappears, and an extremely important part in the breeding and growth of marine resources. In ecosystems on land, far more essential material is broken down as dead material passing through the detritus chain than is broken down by being eaten by animals in a living state. In both land and aquatic ecosystems, the role played by detritus is too large to ignore. The primary microorganisms that break down matter are called mesophilic (microorganisms thriving at medium temperatures). They produce a lot of heat that is why compost becomes warm after a while (Quigley, 1998).

2.13 Processes involved in decomposition

The main processes of decomposition are mechanical shredding, chemical decomposition, and leaching. Other variables that influence decomposition are time, water availability, substrate quality, C:N ratio, and physical factors. Decomposition is necessary to all ecosystems because it reincorporates nutrients in dead plants and animals and makes them accessible to plants (Magill, 1989).

2.13.1 Mechanical Shredding

Shredding is done by macroscopic organisms like beetles, termites and worms. They feed on the detritus and thereby break it into smaller parts. These smaller parts have greater surface area than the former larger pieces. The increased surface area allows more microbes to chemically decompose the detritus and exposes more detritus area to the processes of leaching (Magill, 1989). Every ecosystem has a unique set of shredders. When new shredders are introduced or old ones are somehow eradicated, the regular ratio of decomposed nutrients to un-decomposed nutrients changes (Fogel and Rogers, 1999).

2.13.2 Chemical Decomposition

Chemical decomposition or analysis is the separation of a chemical compound into elements or smaller compounds. It is sometimes defined as the opposite of a chemical synthesis. Chemical decomposition is often an undesired chemical reaction. The stability that a chemical compound ordinarily has is eventually limited when exposed to extreme environmental conditions like heat, radiation, humidity or the acidity of a solvent. The details of decomposition processes are generally not well defined, as a molecule may break up into a host of smaller fragments. Chemical decomposition is exploited in several analytical techniques, notably mass spectrometry, traditional gravimetric analysis, and thermogravimetric analysis (Eberhardt and Elliot, 2008).

Bacteria and fungi can chemically decompose detritus, changing it from organic to inorganic forms of nutrients. This provides nutrition for plants, because many plants cannot absorb nutrients in their organic states. Material is decomposed by anaerobic bacteria when there is not sufficient oxygen available for aerobic bacteria and fungi to function (Fogel and Rogers, 1999).

2.13.3 Carbon releases

Carbon can be released during decomposition in many different forms. Depending on local conditions, decomposition will release different amounts of carbon into the soil and the atmosphere. One of the forms in which carbon is released is methane. Methane is a major loss of carbon from an ecosystem, and is a contributor to the greenhouse effect in our atmosphere. Mineralization of carbon by anaerobic bacteria is a major source of the release of methane gas worldwide (Sergers, 1983). Neue (1983) stated that increasing water oxygen content through percolation limits methanogenesis since those bacteria require low oxygen to create methane.

2.14 Plant/leaves decomposition

Kulshrestha and Satpathy (2001) stated that leaves entering low order streams are subject to physical abrasion, microbial degradation and invertebrate fragmentation. Aquatic invertebrates feeding on leaves are known as shredders and their densities tend to be correlated with the spatial and temporal accumulation of organic matter in streams. Shredders discriminate among the variety of leaves normally found in the stream; this discrimination may be related to differences in leaf toughness, plant nutrient content of leaves and the presence of secondary compounds. Shredders also consume leaves preferentially after the establishment of a well-developed microbial community. This preference may be the result of changes in leaf matrix carried out by the microbial community or the presence of fungal hyphae with a higher nutrition value than the leaves themselves. The immediate consequence of invertebrate feeding on leaves is the incorporation of plant material into secondary production and the fragmentation of leaves.

The relative importance of fungi and invertebrates in the decomposition process depends upon the density of shredders, which, in turn, may depend on litter accumulation in streams. Therefore, the type of riparian vegetation has the potential to control the diversity and abundance of shredders and changes in riparian vegetation have the potential to affect the assemblages of aquatic invertebrates (Eberhardt and Elliot, 2008).

Leaves are decomposed by fungi, bacteria and many different species of invertebrate. Fungi unseen on the surface can spread through the entire forest floor, living on the dead leaves and twigs that have fallen from the trees above. They can extract many of the useful substances for their own benefit to rot down the dead plant material in the process. Many of the chemicals which remain after decomposition get dissolved in the soil and become nutrient for living plants. These nutrients can be taken up by the plantôs root in the soil and are used to help make new leaves, twigs, branches, roots, flowers and seeds (Wymenga, 1999).

2.15 Factors influencing decomposition

2.15.1 Time

One major component of decomposition is time. Without time there can be little or no decomposition. As litter decomposes its mass decreases exponentially with time. This relationship can be expressed numerically by an equation that is almost the same as exponential decay. $L(t) = L(0)e^{(-kt)}$. Where L(t) is the amount of litter left after time (t), L(0) is the initial amount of litter, (k) is the decomposition rate, and (t) is the time in years (Jeunes, 2005).

Time is not the only thing that affects decomposition. There are spatial patterns as well as physical factors to consider. Spatial considerations are things like the location of decomposers compared to the litter. Leaves and sticks break down quickly on the ground. They decompose faster if buried a few centimeters in the ground and slower if elevated or suspended in mid air. Dead leaves that stay on a tree will remain intact much longer than the leaves that fall to the ground and covered by other litter (Wymenga, 1999).

2.15.2 Physical factors

Physical factors such as temperature and water play key roles in decomposition rates. Like all living things bacteria and other decomposers have an optimal operating temperature. Far below this temperature, decomposition will be slow because most decomposers have a greatly lowered metabolism or cannot survive and die (Wagner, 1998). A nice hot area may have very fast rates. Normally the warmer it is the more bacteria will thrive. Tropical forests have very slow decomposition rates. Also, the wetter the soil the faster the decomposition rate of leaf litter. Water is typically a limiting factor for many of the organisms that affect decomposition. Too much water, however, causes decomposition rate to drop (Goulden, 2005).

2.15.3 Litter quality

The term ñlitter qualityò is commonly used in literature about organic matter decomposition to refer to nutrient content and comparative rate of decomposition of plant residues (Swift *et al*., 1979, Anderson and Ingram, 1993). Plant litter that is high in nutrients, especially nitrogen, and is decomposed rapidly, is traditionally considered to be of high quality, whereas woody residues and other lignified materials, such as cereal straw, are more resistant to decomposition and are considered to be of low quality.

A major factor that contributes to the rate at which matter or litter breaks down is the quality of the substrate. Some materials just break down more easily than others. Animal matter breaks down faster than plant matter (Botkin, 1993). Woody materials decompose slower than most other materials in the forest. The theory of the C: N ratio is a representation of this principle. This says that matter with a low C to N ratio will decompose faster than material with a high C:N ratio. This theory does not always hold true but does make for a good rule of thumb. This theory states that the nitrogen is normally the limiting factor for many organisms. With a higher amount of nitrogen (a low C: N ratio) these populations grow rapidly and to higher concentrations, because of the nutrient cycling through the decomposing leaves (Knops, 2003).

Leaves that have a higher C:N ratio decompose more slowly than those with lower ratios. The reason is that the oxidation of carbon by decomposers inhibits nitrification and the formation of soil. Lignin is also a factor in decomposition. It is resistant to decomposition, so leaves with higher levels take longer to decompose (Brown, 1978).

The lower the ratio, the more nitrogen is available and the quicker decomposition and mineralization. A ratio of 15:1 or higher may not have enough nitrogen available. This forces the microbes to pull in inorganic nitrogen from the soil, slowing mineralization down. Any ratio over 30:1 is considered extremely high and can result in some soil nitrogen deficiencies. The microbes, which tend to be more competitive than the plant, will completely exhaust the nitrogen resources in the soil. Depending on the C: N ratio, this could go on for a considerable length of time. With no added nitrogen, plant growth will completely halt. Nitrogen needs to be applied at higher rates just to ensure plant growth (Brady and Weil, 1999).

2.16 Nutrients and decomposition

Decomposition is one of the ways in which certain nutrients become available to plants to utilize for their survival and reproduction. Carbon is very essential as it plays an important role in photosynthesis. Other nutrients such as nitrogen (N) and phosphorus (P) also play important roles in plants growth. Nitrogen is a major component of proteins, nucleic acids and chlorophyll while phosphorus is an important part of energy biochemical reactions. These nutrients become available when organic matter is decomposed and reincorporated in the soil (Waring and Runing, 1998). According to Karmas (1970), the recycling of carbon and nutrients is a key process for the functioning of ecosystems and the delivery of ecosystem goods and services. Litter fall and decomposition are two essential means by which the nutrient pool in terrestrial ecosystems is maintained. Accumulated litter on the forest floor acts as an input and output systems of nutrients. This litter receives periodic contribution from the canopy and its subsequent decomposition is the route by which part of the carbon fixed by plants is incorporated either into the biomass of decomposers or reintegrated to the soil (Gartner and Cardon, 2004).

2.17 The role of soil nutrients

2.17.1 Physiological roles of soil nutrients

Soil nutrients play many complex roles in plant nutrition. While most of them participate in the functioning of a number of enzyme systems, there is considerable variation in the specific functions of the various nutrients in plant and microbial growth processes. For example, copper, iron and molybdenum are capable of acting as electron carriers in the enzyme systems that bring about oxidation-reduction reactions in plants. Such reactions are essential steps in photosynthesis and many other metabolic processes (Brady and Weil, 1999).

2.17.2 Role of phosphorus in plant nutrition

Brady and Weil (1999), stated that phosphorus is a critical element in natural and agricultural ecosystems throughout the world. The natural supply of phosphorus in most soils is small, and the availability of that which is present is very low. Inputs of phosphorus from the atmosphere and rainfall are negligible. Fortunately, most undisturbed natural ecosystems loose little of this nutrient because phosphorus does not form gases that can escape into the atmosphere, nor does it readily leach out of the soil with drainage water.

Phosphorus, Brady and Weil (1999) argue, is closely associated with animal and human activity. Bones and teeth contain large amounts of this element. Archaeologists study the phosphorus content of soil horizons, because they know that unusually high concentrations of this element often accumulate where humans have congregated and have discarded the bones of wild or domesticated animals. Phosphorus is so scarce in most soils that high concentrations are often an indication of past animal or human activity in the area.
At the extreme, lack of adequate available phosphorus is contributing to land degradation mostly in the lesser developed countries of Tropical and Subtropical regions. Phosphorus deficiency often limits the growth of crops and may even cause crop failure. Without adequate phosphorus, regrowth of natural vegetation on disturbed forest and savannah sites is often too slow to prevent soil erosion and depletion of soil organic matter (Brady and Weil, 1999).

Plant uptake of phosphate ions from the soil solution is curtailed by the slow movement of these ions to root surfaces. This is overcomed in part by the movement of roots to zones where the ions are held. Also, phosphate ions move to plant roots through symbiosis with mycorrhizal fungi. The microcospic threadlike mycorrhizal hyphae extend out into the soil several centimetres from the root surfaces. The hyphae are able to absorb phosphorus ions as the ion enter the soil solution, and may even be to access some strongly bound forms of phosphorus. The hyphae then bring the phosphate to the root by transporting it inside the hyphal cells, where soil-retention mechanism cannot interfere with phosphate movement (Brady and Weil, 1999). Once in the plant, a portion of the phosphorus is translocated to the shoots, where it becomes part of the plant tissues. As the plant shed leaves and their root die, or they are eaten by people or animals, phosphorus returns to the soil in the form of plant tissues, leaf litter, and waste from animals and people (Brady and Weil, 1999). Phosphorus is highly mobile in plants and when deficient it may be translocated from old plant tissues to young growing areas (Griffith, 2006). Cosequently, early vegetative responses to phosphorus are often observed. As plant matures phosphorus is translocated into the fruiting areas of the plant where high enrgy requirements are needed for the formation of seeds and fruits (Griffith, 2006).

2.17.3 Role of potassium in plant nutrition

Of all the essential elements, potassium is the third most likely, after nitrogen and phosphorus to limit plant productivity. Low availability of soil potassium also commonly limits plant growth and reduces crop quality. Even though most soils have large total supplies of this nutrient, most of that present is tied up in the form of insoluble minerals and is unavailable for plant use. Also, plants require potassium in such large amounts that careful management practices are necessary in order to make this nutrient available rapidly enough to optimize plant growth (Brady and Weil, 1999).

It is known to activate over 80 different enzymes responsible for such plant processes as energy metabolism, starch synthesis, nitrate reduction, photosynthesis, and sugar degradation. As a component in plant cytoplasmic solution, potassium plays a critical role in lowering cellular osmotic potentials, thereby reducing the loss of water from leaf stomata and increasing the ability of root cell to take up water from the soil. Generally a good supply of this element promotes the production of grains and large tubers (Dirk and Hagarty, 1984). Good potassium nutrition is linked to improved drought tolerance, improved winter hardiness, better resistance to certain fungal diseases, and greater tolerance to insect pests. Potassium also enhances the quality of flowers, fruits and vegetables by improving flavour and colour and strengthening stems (Brady and Weil, 1999).

Unlike phosphorus, potassium is present in the soil solution only as a positively charged cation, K^+. Like phosphorus, potassium does not form any gases that could be lost to the atmosphere. Its behavior in the soil is influenced primarily by soil cation exchange properties (Brady and Weil, 1999). It is found in comparative high levels in most mineral soils, except for those consisting mostly of quartz sand. In fact, the total quantity of this element is generally greater than that of any other major nutrient element. Yet the quantity of potassium held in an easily exchangeable condition at any one time is often very small. Most of this element is held rigidly as part of the primary minerals or is fixed in forms that are, at best, only moderately available to plants (Brady and Weil, 1999).

2.18 Nitrogen in plant nutrition

2.18.1 Nitrogen fixation by plants

Fitzpatrick (1986), stated that there are a number of free living bacteria including *Azotobacter*, *Clostridium, Pastorianum* and *Beijerinckia* species that are capable of utilizing atmospheric nitrogen to form their cell protein which upon the death of the organism is decomposed to ammonia to form part of the nitrogen available to plants or to take part in nitrification. Other microorganism capable of fixing atmospheric nitrogen includes some algae. Nitrogen is found primarily in organic forms in soils. It moves in soils and plants mostly in the anionic form (Dirk and Hagarty, 1984). The rate of biological fixation is greatly dependent on soil and climatic conditions. High levels of available nitrogen, whether from the soil or added in fertilizers, tend to depress biological nitrogen fixation (Brady and Weil, 1999). Plants make heavy investment required for symbiotic nitrogen fixation only when short supplies of mineral nitrogen make nitrogen fixation necessary (Brady and Weil, 1999).

2.18.2 Origin and distribution of Nitrogen

According to Brady and Weil, (1999), the atmosphere which is 78% gaseous nitrogen (N_2) in content appears to be a virtually limitless reservoir of this element. But the very strong triple bond between two nitrogen atoms makes this gas quite inert and not directly usable by plants or animals. Were it not for the ability of certain microorganisms to break this double bond and to form nitrogen compounds, vegetation in the terrestrial ecosystems around the world would be rather sparse, and little nitrogen would be found in soils. The nitrogen content of surface mineral soils normally ranges from 0.02 to 0.5%, a value of about 0.15% being representative for cultivated soils (Brady and Weil, 1999). A hectare of such a soil would contain about 3.5 mg nitrogen in the A horizon and perhaps an additional 3.5 mg in the deeper layers. In forest soils the litter layer (0 horizons) might contain another 1 to 2 mg of nitrogen. While these figures are low compared to those for the atmosphere, the soil contains 10 to 20 times as much nitrogen as does the standing vegetation (including roots) of either forested or cultivated areas. Most of the nitrogen in terrestrial systems is found in the soil.

Most soil nitrogen occur as part of organic molecules. Soil organic matter typically contains about 5% nitrogen; therefore, the distribution of soil nitrogen closely parallels that of soil organic matter because association with certain silicate clays or resistant humic acids help protect the nitrogenous organic compounds from rapid microbial breakdown, typically only about 2 to 3% of the nitrogen in soil organic matter is released annually as inorganic nitrogen. Unlike most of the inorganic nitrogen, the mineral forms of nitrogen are mostly quite soluble in water and may be easily lost from soils through leaching and volatilization. As it moves through the nitrogen cycle, an atom of nitrogen may appear in many different chemical forms, each with its own properties, behaviours and consequences for the ecosystem. This cycle explains why vegetation (and indirectly animals) can continue to remove nitrogen from a soil for centuries without depleting the soil of this essential nutrient. The biosphere does not run out of nitrogen because it uses the same nitrogen over and over again (Brady and Weil, 1999).

2.18.3 Soil organic matter

The organic matter in soils consists of the remains and decomposition products of both plants and animals. In spite of the very large soil fauna, it is usually very difficult to find their remains probably because they are vigorously decomposed by the microflora and microfauna. Occasionally one finds pieces of chitin, fragments of mollusk shells and eggs or cysts (Fitzpatrick, 1986). By far the greatest amount of organic matter in soils is derived from the above and below ground parts of plants (Fitzpatrick, 1986). Generally, leaves and needles constitute up to 80% of the litter, while roots make up most of the remaining 20% but may be as much as 50% in grassland.

Generally, in an aerobic environment, organic matter becomes more decomposed as it is more fragmented, but under anaerobic conditions, as in peat, there may be very large fragments of organic materials that are in a very advanced stage of decomposition and can easily be crushed between the fingers. Depending upon the nature of the organic material and the organisms involved in its decomposition it is possible to find that the degree of decomposition varies from place to place within the same plant fragment with some types of tissue decomposing before others. Generally, the order of increasing resistance is phloem, collenchyma, parenchyma, lignified tissue and epidermis (Fitzpatrick, 1986).

The levels of organic matter in soils influence a number of soil chemical and physical processes. Soil organic matter affects soil aggregation by binding individual clay particles together into micro aggregates and by clustering these into macro aggregates. Well aggregated soils demonstrate improved drainage, soil moisture holding and cation exchange capacities. In low external input cropping systems, the mineralization of organic matter contributes to soil fertility (Fitzpatrick, 1986).

2.18.4 Soil exchangeable calcium

Calcium is generally plentiful in the soil solution such that mass flow alone can usually bring sufficient amounts to the root surface (Brady and Weil, 1999). Levels of exchangeable calcium together with pH helps to determine which specific organisms thrive in a particular soil. Although in any chemical condition found in soils some bacterial species will thrive, high calcium and near- neutral pH generally result in the largest, most diverse bacterial populations (Brady and Weil, 1999).

Important ways by which calcium is removed from soil are through erosion, leaching and plant removal. The losses may be replaced by lime and fertilizer application. As the soluble calcium is removed from the soil by the growing plants or by leaching, the percentage base saturation and pH are gradually reduced (Brady and Weil, 1999).

2.19 Half-life

The half-life time of a quantity whose value decreases with time is the interval required for the quantity to decay to half of its initial value. The term Half-Life time was coined in 1907.

Half Life is a characteristic of each radioactive isotope. Depending on the isotope, its Half Life may range from a few fractions of a second to several billion years (Stern *et al*., 2003). According to Nye and Greenland (1960) half-life is the period in which half of the carbon in humus is oxidized.

2.20 The role of vegetation in improving soil chemical and physical conditions

2.20.1 Reduction of soil acidity

Several studies have proven that the bases released by litter decay can help reduce acidification (Young, 1997). However, other studies have shown that vegetation alone cannot reduce the acidity of strongly acidic soils. This is because the calcium which the trees supply via litter is insufficient to reduce acidity even by one pH point (Young, 1997). There are even cases where in the temperate zones especially, trees produce acid which can lead to appreciable soil acidification.

2.20.2 Increasing and sustaining levels of N, P, Ca and Mg in soils.

According to Young (1997), a large quantity of nutrients is believed to circulate between plants and the soil annually in forest ecosystems. It is observed that this circulation provides a closed cycle thereby providing equilibrium in the whole system. The nutrient recycling hypothesis, which states that by the inclusion of trees, agroforestry systems can achieve a condition intermediate between losses and increasing plant uptake, has identified certain processes which can help in achieving this. These include gains made by the system, by way of atmospheric rain and dust fertilizers (rain-dissolved nutrients and nutrient containing dust particles), organic additions (litter fall, compost, nitrogen fixation, deep capture by tap roots etc.). The pathways for losses have been identified as erosion, leaching and harvesting.

2. 21 The concept of allelopathy

Allelopathy occurs through the release by one plant species of chemicals which affect other species in its vicinity, usually to their detriment. This phenomenon has been observed for over 2000 years. The soil sickness problem in agriculture was specifically related to exudates of crop plants (Rice, 1984). However, intensive scientific research on this phenomenon only started this century. The term allelopathy was first introduced by a German scientist Molisch in 1937 to include both harmful and beneficial biochemical interactions between all types of plants including microorganisms. Rice (1984) reinforced this definition in the first monograph on allelopathy. Research on the recognition and understanding of allelopathy has been well documented over the past few decades (Rizvi and Rizvi, 1986). These include the symptoms and severity of adverse effects of living plants or their residues upon growth of higher plants and crop yields, interactions among organisms, ecological significance of allelopathy in plant communities, replanting problems, autotoxicity, problems with crop rotations, and the production, isolation and identification of allelochemicals in both natural and agroecosystems. Contemporary researchers have tended to broaden the context of allelopathy to include interactions between plants and higher animals (Rizvi and Rizvi, 1986), and have suggested that allelopathy may be part of a whole network of chemical communication between plants, and between plants and other organisms, and that such communication may contribute to plant defence (Lovett and Ryuntu, 1992).

Chemicals that impose allelopathic influences are called allelochemicals or allelochemics. They may be largely classified as secondary plant metabolites, which are generally considered to be those compounds (such as alkaloids, phenolics, flavonoids, terpenoids, and glucosinolates) which do not play a role in primary metabolic processes essential for a plant's survival, and are produced as offshoots of primary metabolic pathways. In contrast to primary metabolism, which comprises several hundreds of low molecular weight compounds, tens of thousands of secondary substances are known today, but only a limited number has been implicated as allelochemicals (Rice, 1984).

Allelochemics are present in virtually all plant tissues, including leaves, flowers, fruits, stems, roots, rhizomes, seeds and pollen. They may be released from plants into the environment by means of four ecological processes: volatilisation, leaching, root exudation, and decomposition of plant residues. Several chemicals can be released together and may exert toxicities in an additive or synergistic manner. The concentration of a single substance in field situations is generally below its inhibitory threshold. Allelopathic interferences often result from the joint action of several different compounds.

Biological activities of receiver plants to allelochemicals are known to be concentration dependent with a response threshold. Responses are, characteristically, stimulation or attraction at low concentrations of allelochemicals, and inhibition or repellence as the concentration increases (Lovett, 1990). These phenomena have been widely observed in allelochemicals from living plants, in allelopathic effects from decaying plant residues, and from the gross morphological level to the biochemical level, including other growth-regulating chemicals and herbicides.

When plants are exposed to allelochemicals, their growth and development are affected. The readily visible effects include inhibited or retarded germination rate; seeds darkened and swollen; reduced root or radicle and shoot or coleoptile extension; swelling or necrosis of root tips; curling of the root axis; discolouration, lack of root hairs; increased number of seminal roots; reduced dry weight accumulation; and lowered reproductive capacity. These gross morphological effects may be secondary manifestations of primary events, caused by a variety of more specific effects acting at the cellular or molecular level in the receiver plants (Rice, 1979).

As a scientific discipline, allelopathy is still relatively new. But it has already contributed to the solution of practical problems in agriculture and provided explanations for observed plant-plant interactions (An *et al*., 1998).

2.21.1 The historical basis of the concept of allelopathy

In the light of contemporary allelopathic research, the intuitively based statements of the early botanists stand up surprisingly well. The walnut tree is now understood to affect the growth of neighboring plants via juglone leached from the leaves, roots, and fruits (Davis, 1928). The declining yield of many crop species grown under continuous monoculture has been linked to the accumulation of allelopathic substances in the soil, especially through the mediation of microorganisms (Borner, 1960). Numerous plants cited as being injurious, such as *Erigeron* (Keever, 1950) thistle (*Cirsium*) (Bendall, 1975) and various crucifers (such as *Brassica nigra*) (Bell and Muller, 1973) have been found to posses marked allelopathic activity. Modern reviews of allelopathy commonly credit de Candolle with an insight that was not equaled by the technology of his era (Garb, 1961). In fairness to his detractors, his toxin theory of plant interactions was largely the by-product of an outdated and misconstrued notion of plant nutrition. His critics and earlier botanists had similarly erred in seeking a single factor responsible for plant growth, much as had the alchemists sought the legendary philosopher's stone. Taking all this into account and considering the forceful personality of Liebig, one can readily appreciate how, 130 years ago, Liebig's theories preempted and stifled those of de Candolle (Willis, 1985).

Today, with modern techniques of plant physiology and soil biochemistry, allelopathy has been shown to be a real but subtle factor in the dynamics of natural and agricultural plant communities (Willis, 1985). It is unfortunate that the single-mindedness characteristic of previous centuries still persists. The dichotomy between allelopathy and competition is exacerbated by the inherited bias toward the nutritional model of plant interaction fostered by Liebig, and is accentuated in the fact that in modern nutritional studies it is still basically unnecessary to consider plant-plant chemical interactions and their concomitant effects, whereas in allelopathic investigations the converse is regarded as axiomatic (Willis, 1985).

2.21.2 How plants keep other plants away

Allelopathy is a chemical process that plant use to keep other plants out of the spaces. There are several types of chemical allelopathy. In one kind, the plant that is protecting its space releases growth-compounds from its roots into the ground. New plant seedlings near the allelopathic plant absorb these chemicals from the soil and are unable to live. A second type of allelopathy is when the plant release chemicals that slow or stop the process of photosynthesis. An allelopathic plant may also release chemicals that change the amount of chlorophyll a plant has. When a plant's chlorophyll levels are changed, it cannot make the food it needs, and the plant dies (Bhatt *et al.*, 1994).

Allelopathic plants release allelochemicals in several ways including volatilization, leaching and exudation. In volatilization, some allelopathic trees release a chemical in the form of a gas through small opening in their leaves. Other plants absorb the toxic chemical and die.

Some plants store protective chemicals in the leaves they drop. When the leaves fall to the ground, they decompose. As this happens, the leaves give off chemicals through leaching that protect the plant. Through exudation, some plants release defensive chemicals into the soil through their roots. Those chemicals are absorbed by the roots of other trees near the allelopathic one. As a result, the non-allelopathic tree is damaged (Rice, 1984).

2.21.3 Mechanisms of action of allelopathetic plants

Generally there are hundreds of secondary metabolites in the plant kingdom, many of which are known to be *phytotoxic* (Einhellig, 2002). Allelopathic effects of these compounds are often observed to occur early in the life cycle, causing inhibition of seed germination and/or seedling growth. The compounds exhibit a wide range of mechanisms of action, from effects on alkaloids, photosynthetic and mitochondrial function, phytohormone activity, ion uptake, and water balance (phenolics). Interpretations of these mechanisms of action are however complicated by the fact that individual compounds can have multiple phytotoxic effects (Einhellig, 2002). The vast majority of allelopathy research attempts to have focused on direct negative plant-plant interactions caused by allelochemicals (Rice, 1984).

CHAPTER THREE
GROWTH AND YIELD OF MAIZE (*Zea mays* L.) cv. OBATAMPA IN HEDGEROWS OF *J. CURCAS*.

3.1 Introduction

The exploitation of bio-energy sources of fuel has recently been given much prominence by the scientific community and commercial entrepreneurs as a way to solve the energy crisis. Bio-diesel is the most valuable form of renewable energy that can be used directly in any existing unmodified diesel engine (Shekhawat *et al*., 2009). It is an alternative fuel that can be used in diesel engines and provides power similar to conventional diesel fuel. Biofuel can help reduce the countryǿs dependence on foreign oil imports. Recent environmental and economic concerns (Kyoto protocol) have prompted a resurgence in the use of biodiesel throughout the world. In 1991, the European Community (EC), proposed a 90% tax reduction for the use of biofuels, including biodiesel (Shekhawat *et al.*, 2009). Biofuels create new markets for agricultural products and stimulate rural development because they are generated from crops. They therefore hold enormous potential for farmers.

The long term challenge is the ability to supply feedstock to keep up with growing demand. The supply of feed stock from maize, soya beans will be limited by competition from other uses and land constraints. The key to the future of biofuels therefore is finding inexpensive feed stocks that can be grown by farmers. *J. curcas* proves is one of the many plants that hold great promise as a biofuel crop. *J. curcas* is more recently being cultivated as a bio-diesel plant. Soybean and rapseed have a relatively low oil yield compared with *J. curcas*. A yield of 375 kg/ha (700 gallons/ha) is reported for soybean in the United States. In Europe, yield for rape seeds is said to be 1000 kg/ha (1,850 gallons/ha) whilst in India, *J. curcas* is reported to have yielded 3000 kg/ha (5,565 gallons/ha).

The worldôs population has grown from almost five billion in 1980 to over seven billion in 2012 (US Census Bureau, 2012) and finite availability of fertile land makes meeting energy needs for this growing population difficult. Ghana had a population of about 12.4 million in 1984. This figure increased to 18.8 million in 2000 with a growth rate of 2.6%. In 2010, the population of Ghana increased to 24.6 million and this is a 30.4 per cent increase within the decade (Ghana Statistical Service, 2012). The increase in population could cause a corresponding rise in food and fuel consumption, straining the earthôs natural resources (FAO, 2003). In developing countries, the pressure on natural resources is more acute because nearly 70% are subsistence-based and live in rural communities (World Bank, 2004).

Maize (Zea mays L.) belongs to the family Poaceae (Gramineae) and the tribe maydeae. Based on area and production, maize is one of the most important cereal crops in Ghana. It is rich in calories and forms part of the staple diet of every Ghanaian. It is Ghanaôs number one staple crop followed by rice. The yield in Ghana is low compared to other maize producing countries. On average maize yield is estimated at 1.6 tons/ha (WABS, 2008). There is concern that the use of land for the cultivation of bio-fuels could further jeopardize Ghanaôs self- sufficiency in maize production. Increasing grain yield per unit area and increasing the corn cultivable area are recognized as better solutions to solving the gap between consumption and production. 13.6 million hectares of Ghanaôs 23.8 million hectares is suitable for Agriculture. Of this 35% is under cultivation (OCAR, 2002). Ghanaôs agriculture is predominantly small holder, traditional and rain-fed. Agricultural production is undertaken by about 2 million, predominantly small holder subsistence farmers who account for about 80% of food in the country (OCAR, 2002). The mean farm size is less than 1.2 hectares with a few exceeding two hectares (OCAR, 2002). In the midst of limited land for the cultivation of both maize and physic nut, it is surmised that the integration of these in an alley cropping could help provide an appropriate output from these plants.

A promising agroforestry technology for the humid and sub-humid tropics, which has been developed during the past decades, is alley cropping. Alley cropping also known as hedgerow intercropping has been the subject of intensive research at the International Institute for Tropical Agriculture (IITA) in Nigeria (Kang *et al*., 1981a and b). Currently it entails growing food crops between hedgerows of planted shrubs and trees, preferably leguminous species. It is a management-intensive system that can lead to increased crop yields and productivity of the land. This study was therefore designed to determine the appropriate hedgerow spacing to maximize grain yield of maize cv. Obatampa in a *J. curcas* hedgerow intercropping system.

3.2 Objectives

The specific objectives of the study were therefore to:

1. Determine the growth and yield of maize cv. Obatampa in alleys of *J. curcas* grown on ferric acrisol.
2. Assess the effect of *J. curcas* on soil chemical properties.
3. Evaluate the economics of using *J. curcas* in an alley cropping system.

3.3 Materials and Methods

3.3.1 Description of the study area

The experiment was laid out at Ayakumaso which is about 3 km from Sunyani. It lies between latitude $7^{o}55'$N and $7^{o}35'$N and longitude $2^{o}00'$W and $2^{o}30'$W (SMA, 1998) (Plate 3.1). The area has a tropical climate, with high temperatures averaging 23.9 ºC. Its mean monthly temperature varies between 23 ^{o}C and 33 ^{o}C with the lowest in August and highest in March and April, respectively. It has a double maxima rainfall pattern. Rainfall ranges from an average of 1000 mm to 1500 mm. The major rainy season occurs from April to end of July whilst September to October is the minor wet season. It has relative humidity of about 70%. The vegetation type is the dry semi-deciduous forest. The soil texture at the study site is silt loam and classified as ferric acrisols.

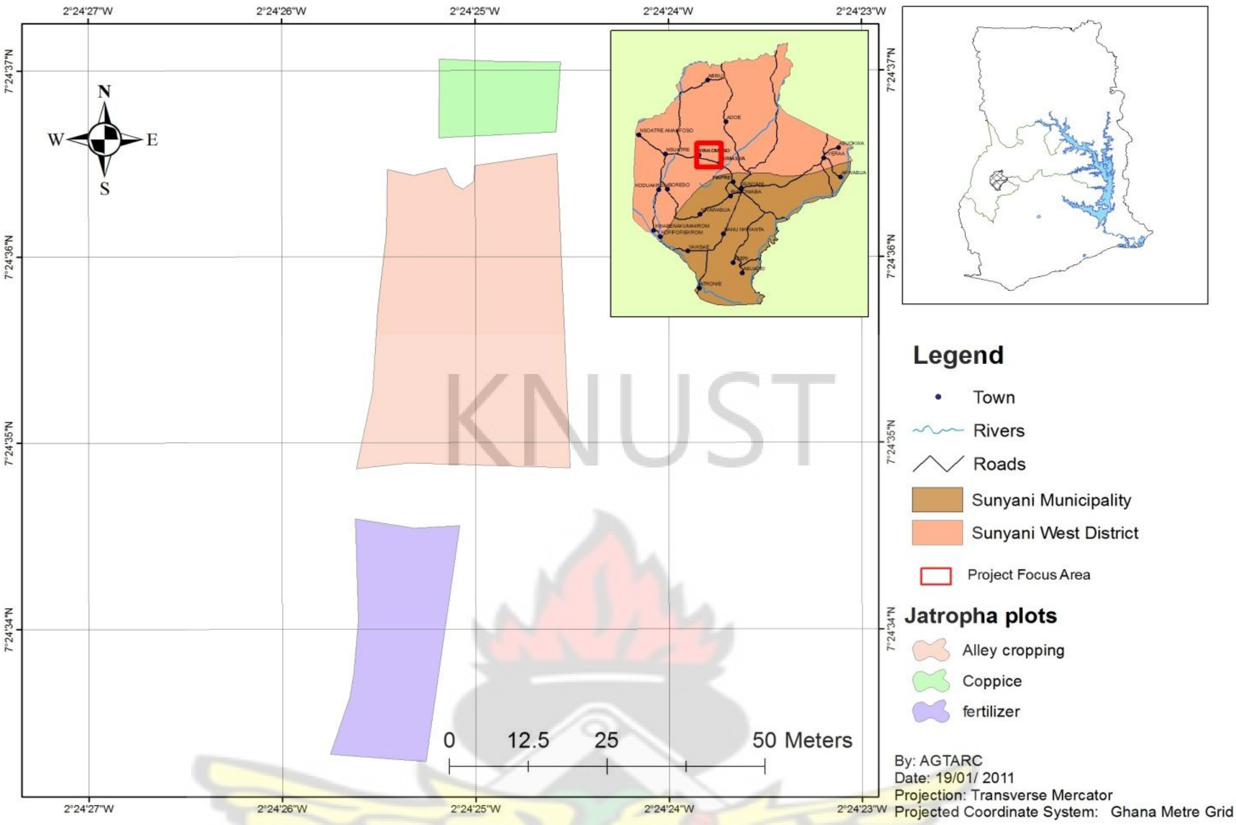

Plate 3.1: Map of the study area

3.3.2 Design of experiment

The experiment was laid using the Randomized Complete Block Design. Three hedgerow spacing treatments of 2 m x 1 m, 3 m x 1 m, 4 m x 1m of *J. curcas* and a control (No hedgerow) were used. These were replicated three times. Plot sizes for each treatment were 12 m x 5 m. The 2 m x 1 m, 3 m x 1 m, and 4 m x 1 m spacing had 6, 4, and 3 hedgerows, respectively. The alleys of *J. curcas* were established on the 1st of May, 2008.

3.3.2.1 Cultural practices

The test crop used in the alleys was Maize (*Zea mays*, var Obatampa) and sown at a spacing of 100 cm x 40 cm giving a population of 25,000 plants ha^{-1}. The planting date for the maize was 21st July, 2008 and repeated on the 25th July, 2009. Four (4) seeds were sown per hill and later thinned to two (2) plants per hill after germination. The lay out of the maize after planting with physic nut can be observed in plate 3.2 and 3.3.

Plate 3.2: Maize growing in alleys of *J. curcas*

Plate 3.3: Hedgerows of *J. curcas* grown with maize

About 50 kg of 15-15-15 fertilizer was applied as a starter fertilizer 7 days after sowing at 5 cm from the hills. Five bags of 50 kg were applied per hectare. Five weeks after sowing, maize was top dressed with urea fertilizer. 2.5 bags (50 kg/bag) of urea were applied per hectare. Using the No-till technology in land preparation, Round Up which contains glyphosate at 360 g/litre was used for the initial weed control at 180 ml of Round up per 15 litres of water in a knapsack sprayer. Hand weeding was done twice (3 and 5 weeks after planting) before harvesting.

3.4 Soil analysis

Three hundred grammes of soil samples were collected at a depth of 0 ï 30 cm prior to the establishment of the experiment and taken to the Soil Research Institute (SRI) for analysis. The samples were thoroughly mixed before the analysis. At the end of the experiment (2009), composite soil samples were again taken from each treatment. The soil samples were air-dried and analyzed for soil pH, Organic C, Total N, Organic matter, Ca, Mg, K, Na, T.E.B., Exchangeable acid and Base saturation.

3.4.1 Determination of soil pH

Twenty grams of soil were mixed with 50 ml distilled water and stirred at intervals for 30 minutes. The pH of the suspension was then measured with a pH meter.

3.4.2 Soil organic carbon

The percentage of organic carbon in the soil was determined by the LECO carbon analyzer. To get the organic matter level the percent organic carbon obtained was multiplied by the van Bermudan factor of 1.724.

3.4.3 Soil nitrogen (N)

Percent total N was determined by micro-kjeldahl digestion method. One gram (1g) each of the soil samples was digested in conc. H_2SO_4 using selenium catalyst. The compound formed was then titrated with 0.02NHCl.

3.4.4 Cation exchange capacity

This was determined by the sum of the exchangeable bases (Ca, Mg, K, Na) and exchangeable Al and H expressed in cmolc/kg(equivalent to meg/100 g).

$$CEC=TEB + EA$$

3.4.5 Exchangeable acidity

Exchangeable acidity (Al + H) was obtained by treating 10 g of soil with 100 ml of 1M KCl. The solution was shaken intermittently for one hour, centrifuged for 10 minutes and the solution filtered. Fifty mililitres of the filtrate was titrated with 0.05N NaOH using phenolphthalein indicator.

3.4.6 Available phosphorus and potassium

The available phosphorus (P) and potassium (K) were measured by putting 10 g of the soil samples into 50 ml Bray No.1 solution in stoppered bottles. The suspension was shaken for 10 minutes and filtered. A colour reagent and ascorbic acid powder were then added and the filtrate allowed to stand for 15 minutes. The level of phosphorus (P) was determined calori-metrically from the absorbance on a spectrophotometer at 660 mu wavelength. The level of potassium (K) was determined by measuring the emissions from a flame photometer. The concentrations of P and K (ppm) were then obtained by extrapolation from standard P and K curves.

3.5 Measurement of vegetative parameters of the test crop

Vegetative parameters such as plant height, plant diameter, number of leaves and stover weight were determined by randomly selecting 10 maize plants from each plot. The stover weight was determined after drying at 65 ^{o}C for 72 hours. Plant height was measured with a measuring tape and diameter was measured using the vernier caliper. At harvest, 10 maize plants from each plot were taken to determine yield and yield components.

3.6 Data Analysis

All data recorded were analyzed using the GEN-STAT package. The Analysis of Variance (ANOVA) was generated to determine if there were any significant differences between the treatments. The Fishers Least Significant Difference (LSD) was used to separate the means between the treatments at 5% probability level.

Land Equivalent Ratio is the sum of the relative yields of the components species. It was calculated by:

LER = Ci/Cs + Ti/Ts

Where Ci = Crop yield under intercropping

Cs = crop yield under sole crop

Ti = Tree yield under intercrop

Ts = Tree yield under sole system

3.7 Limitations of the study

Limitations for the study were:

- Data were collected for two years and therefore can only predict what is likely to happen in the third and subsequent years.
- The research did not take into consideration planting distances greater than 4 m between rows because the objective of the research was to make optimum use of land.

3.8 Results

3.8.1 Effect of *J. curcas* spacing on growth parameters of maize

The effect of *J. curcas* spacing on the growth of maize is shown in Table 3.1. Plant height, diameter, number of leaves, number of nodes per plant were not affected by *J. curcas* spacing in the first year. However, in the second year, significant differences (P < 0.05) in height and diameter of maize were obtained (Table 3.1). Spacing of 2 m x 1 m differed with the control, 3 m x 1m and 4 m x 1m treatments. An increase in plant height of 17.19%, 22.39% and 23.38% were obtained for 3 m x 1 m, 4 m x 1 m and control, respectively with respect to 2 m x 1 m in the second year. The control (No hedgerow) had the highest plant height (2.72 m and 2.48 m), diameter (20. 35 mm and 19.09 mm), number of leaves (11 and 10) and number of nodes (12.33 and 12.33) for the years 2008 and 2009, respectively (Table 3.1). Diameter growth in the second year was highest in 4 m x 1 m but it did not differ significantly from the control and 3 m x 1 m treatments. It increased by 19.7%, 16.9% and 18.5% for control, 3 m x 1 m and 4 m x 1 m respectively with respect to 2 m x 1 m. Stover weight was, however, significantly different (P < 0.05) in the first and second year. In the first year, significant difference was obtained between 2 m x 1 m and the other treatments. No significant effect was attained between the control (No hedgerow), 3 m x 1 m and 4 m x 1 m treatments. Similar results were obtained in the second year where the control and 4 m x 1 m treatments did not differ significantly (Table 3.3). However, these differed significantly from the 2 m x 1 m and 3 m x 1 m treatments (Table 3.3).

Table 3.1: Effect of *J. curcas* spacing on growth parameters of Maize.

Treatments (Hedgerow spacing)	Height (m)		Diameter at 1st node (mm)		Number of leaves		Number of nodes per plant	
	2008	2009	2008	2009	2008	2009	2008	2009
Control	2.72	2.48	20.35	19.09	11.00	10.00	12.33	12.33
2m x 1m	2.43	2.01	21.03	16.36	10.12	9.67	11.53	11.33
3m x 1m	2.51	2.36	21.22	19.12	11.00	10.33	11.63	11.39
4m x 1m	2.55	2.46	21.55	19.38	11.33	10.00	12.33	12.03
S.E.±	0.87	0.16	0.39	1.07	0.36	0.21	0.28	0.54
LSD (0.05)	NS	0.32	NS	2.70	NS	NS	NS	NS

**NS means Not Significant*

3.8.2 Effect of *J. curcas* spacing on yield and yield components of maize

The results showed significant differences in the yield of maize at different spacing of *J. curcas*. Maize yields ranged between 2.05 tons ha^{-1} and 4.47 tons ha^{-1} in the first year and 1.56 and 2.99 tons ha^{-1} in the second year. The differences in yield were significant in both years; however, the differences ($P > 0.05$) for 3 m x 1m and 4 m x 1 m treatments in both years were not significant (Table 3.3). There were no significant differences in 100 seed weight, number of rows/cob, number of seeds/row, weight of ear and weight of seed/cob in the first year (Table 3.2 and 3.3). In the second year, however, significant differences ($P < 0.05$) were observed for 100 seed weight, weight of ear, weight of seed/cob. The 100 seed weight was highest (25.17 g) at No hedgerow (control) but did not differ significantly from the spacing at 3 m x 1 m (23.73 g) and 4 m x 1 m (24.67 g) (Table 3.2). Significant differences were found between 100 seed weight at 2 m x 1m spacing and all other spacing. Weight of ear and weight of seed/cob showed the same trend for the second year. The maximum weight of ear of 228.1 g was recorded for the control while the lowest was 198.7 g for 2 m x 1 m. Weight of seed/cob was also highest (125.8 g) at No hedgerow (control) and lowest (99.30 g) at 2m x 1 m in the second year. In both cases, the highest results obtained from the control plot did not differ significantly (P Ó0.05) from 3 m x 1 m and 4 m x 1 m treatments (Table 3.3). Generally, yield and yield components of maize were lower in the second year.

Table 3.2: Effect of *J. curcas* spacing on yield and yield components of maize

Treatments	100 seed weight		Number rows/cob		Number seed/row	
	2008	2009	2008	2009	2008	2009
Control	43.00	25.17	14.67	14.22	35.00	30.56
2m x 1m	41.80	21.15	14.00	14.17	30.08	26.33
3m x 1m	41.88	23.73	13.67	14.58	31.62	27.67
4m x 1m	42.77	24.67	15.00	15.00	33.67	28.00
S.E.±	3.42	0.97	0.63	0.25	1.40	3.60
LSD (0.05)	NS	2.36	NS	NS	NS	NS

**NS means Not Significant*

Table 3.3: Effect of *J. curcas* spacing on yield and yield components of maize

Treatment	Weight of ear (g)		Weight of seed/cob (g)		Stover weight (tons/ha)		Grain Yield (tons/ha)	
	2008	**2009**	**2008**	**2009**	**2008**	**2009**	**2008**	**2009**
Control	267.2	228.1	202.8	125.8	11.99	8.95	4.47	2.99
2m x 1m	239.3	198.7	133.5	99.30	8.72	4.38	2.05	1.58
3m x 1m	242.3	217.1	164.3	112.5	11.77	4.88	2.82	2.00
4m x 1m	245.2	218.5	178.9	119.5	11.86	7.49	3.80	2.10
S.E.±	34.5	2.83	25.9	3.76	0.37	1.14	0.51	0.11
LSD(0.05)	NS	9.80	NS	13.03	1.28	3.95	1.77	0.38

**NS means Not Significant*

3.8.3: Soil textural class

Soil samples were taken from the experimental plot and its textural class determined. Table 3.4 shows the textural class for the site.

Table 3.4: Soil physical properties

Mechanical analysis	%
Sand	36.46
Silt	61.32
Clay	2.22
Soil type	Silt loam

3.8.4 Effect of *J. curcas* spacing and cultivation of maize on soil chemical properties

Data on soil chemical properties were analysed for year 2008 and 2009 after harvesting. The soil chemical properties were not significantly ($P > 0.05$) affected by *J. curcas* spacing and maize cultivation (Tables 3.6 and 3.7). Also, soil samples taken before the experiment, the control treatment (No hedge), 2m x 1 m, 3 m x 1 m and 4 m x 1 m treatments did not differ significantly (Tables 3.6 and 3.7). However, the results showed that before the experiment was carried out, the site had high proportion of total nitrogen, organic matter and exchangeable potassium as in the standard in Table 3.5. ECEC was however moderate. After two years of cultivating *J. curcas* with maize a similar trend was observed. No significant difference in soil chemical properties was observed.

Table 3.5 Soil nutrients (mineral content) and its ranking

Nutrient		Rank/Grade
Phosphorus P (ppm), (Blay -1)		
< 10.0		Low
10.0 ï 20.0		Moderate
> 20.0		High
Potassium, K (ppm); Exchangeable K (cmol) (+)/Kg		
< 50 ;	< 0.2	Low
50 ï 100 ;	0.2 ï 0.4	Moderate
> 100 ;	> 0.4	High
Calcium, Ca (ppm) / Mg = 0.25 Ca		
< 5.0		Low
5.0 ï 10.0		Moderate
> 10.0		High
ECEC (cmol) (+)/ Kg		
< 10.0		Low
10.0 ï 20.0		Moderate
> 20.0		High
Organic matter (%)		
< 1.5		Low
1.6 ï 3.0		Moderate
> 3.0		High
Nitrogen (%)		
< 0.1		Low
0.1 ï 0.2		Moderate
> 0.2		High

Table 3.6 Chemical properties of the soil after harvesting in 2009

Treatment	PH	Org. C.	Total N (%)	Org. Matter	Exchangeable cations me/100g Ca	Mg	K	Na
Before the experiment	5.43	2.75	0.24	4.74	10.80	3.61	0.75	0.13
Control	5.87	2.69	0.25	4.65	12.20	3.61	0.62	0.12
2m x 1m	5.68	2.99	0.26	5.15	8.73	8.39	0.83	0.17
3m x 1m	5.95	3.24	0.28	5.58	12.06	7.53	0.90	0.15
4m x 1m	5.75	2.76	0.24	4.76	9.66	4.19	0.79	0.15
C.V. (%)	4.98	9.00	9.14	8.99	29.94	14.78	8.05	10.35
S.E.±	0.29	0.26	0.023	0.45	3.19	0.825	0.064	0.015
LSD(0.05)	NS	NS	NS	NS	NS	NS	NS	NS

**NS means Not Significant*

Table 3.7: Chemical properties of the soil after harvesting in 2009

Treatments	T.E.B.	Exch. Acid (Al + H)	E.C.E.C. me/100g	Base saturation (%)	Available – Bray's P ppm	K ppm
Before the experiment	15.29	0.28	15.59	98.71	5.67	177.32
Control	16.55	0.15	16.53	98.68	4.59	167.40
2m x 1m	18.12	0.24	18.36	98.93	8.29	184.13
3m x 1m	20.64	0.13	20.80	99.37	8.60	217.61
4m x 1m	14.79	0.18	14.77	98.81	5.94	160.70
C.V. (%)	15.73	44.45	15.33	0.59	3.97	42.44
S.E.±	2.71	0.08	2.67	0.58	0.64	4.45
LSD (0.05)	NS	NS	NS	NS	NS	NS

3.8.5 Effect of distance of maize plants from *J. curcas* hedgerow on growth of maize

Distance of maize plant from hedgerow did not significantly (P > 0.05) influence the height, diameter, number of leaves, number of nodes and stover weight of maize in the first year (Tables 3.8 and 3.10). In the second year, however significant differences were observed for plant height, diameter and stover weight (Tables 3.8 and 3.10). In all cases, the distance of 1 m from hedgerow gave lower plant height, diameter, number of leaves, number of nodes per plant and stover weight than all treatments. Closer spacing of 1 m gave the lowest maize height of 2.30 m but it was not significantly different from 2 m spacing of hedgerow in the second year. Highest maize height of 2.45 m was at the control (No hedgerow). A similar trend was observed for diameter, number of leaves, number of nodes per plant and stover weight (Table 3.8 and Table 3.10).

Table 3.8: Effect of distance of maize plants from *J. curcas* hedgerow on growth of Maize.

Treatments (Distance from Hedgerow)	**Height (m)**		**Diameter at 1st node (mm)**		**Number of leaves**		**Number of nodes per plant**	
	2008	**2009**	**2008**	**2009**	**2008**	**2009**	**2008**	**2009**
Control	2.71	2.45	22.30	19.48	11.00	8.33	13.33	12.00
1m from Hedgerow	2.47	2.30	19.99	14.57	10.33	8.00	12.00	11.33
2m from hedgerow	2.48	2.43	20.86	18.54	11.67	9.00	13.67	12.67
S.E.±	0.78	0.03	1.18	1.24	0.66	0.38	0.88	0.47
LSD (0.05)	NS	0.15	NS	4.90	NS	NS	NS	NS

NS = Not Significant

3.8.6 Effect of distance of maize plant from *J. curcas* hedgerow on yield and yield components of maize

Yield and yield components were not affected by distance from hedgerow in the first year (Table 3.9 and 3.10). In the second year, however, 100 seed weight, weight of cob, weight of seed/cob and grain yield differed significantly ($P < 0.05$) between treatments. The highest grain yield (2.67 tons ha^{-1}) of maize was obtained by the control (No hedgerow) but did not differ from the yield from maize plants 2 m from the hedgerow where grain yield was 2.53 tons ha^{-1} (Table 3.11). Plants 1 m from hedgerows gave significantly lower values of 24.87 g, 205.7 g, 100.2 g for 100 seed weight, weight of cob, weight of seed/cob, respectively (Table 3.9 and 3.10).

Table 3.9: Effect of distance from *J. curcas* hedgerow on yield and yield components of maize

Treatments	100 seed weight (g)		Number rows/cob		Number seed/row	
	2008	2009	2008	2009	2008	2009
Control	46.30	25.97	14.17	14.60	32.67	31.51
1m from hedgerow	39.00	24.87	15.00	14.00	28.89	26.89
2 m from hedgerow	45.39	26.78	15.58	14.45	31.78	30.67
S.E.±	2.93	0.63	0.58	0.15	1.70	1.87
LSD (0.05)	NS	1.49	NS	NS	NS	NS

Table 3.10 Effect of distance of maize plants from *J. curcas* hedgerow on yield and yield components

Treatment	Weight of cob (g)		Weight of seed/cob (g)		Stover weight (tons/ha)		Grain Yield (tons/ha)	
	2008	2009	2008	2009	2008	2009	2008	2009
Control	384.3	296.2	204.6	121.9	21.12	7.83	2.99	2.67
1m from hedgerow	262.8	205.7	159.2	100.2	14.15	5.42	2.50	1.98
2 m from hedgerow	344.3	269.5	202.2	114.2	17.85	7.34	2.84	2.53
S.E.±	10.33	22.1	12.64	5.35	1.81	0.56	0.13	0.15
LSD(0.05)	NS	86.8	NS	21.00	NS	2.21	NS	0.61

3.8.7 Land Equivalent Ratio of cultivating *J. curcas* with Maize

One way to assess the benefits of growing two or more crops together or intercropping is to measure productivity using the Land Equivalent Ratio (LER). It was proposed to help judge the relative performance of a component of a crop combination compared to sole stands of that species. Using the LER as a measure of both beneficial and negative interaction between the crops, all the treatments were beneficial over that of the control (Table 3.11). The highest LER of 1.62 and 1.20 was attained at 4 m x 1 m for the year 2008 and 2009, respectively. Lowest LER of 1 was obtained at the control treatment for both years (Table 3.11).

3.8.8 Benefit/Cost ratio of intercropping *J. curcas* with maize

The study was to determine the financial feasibility of alley cropping of maize (*Zea mays*) with *J. curcas* in terms of their returns. Benefit/cost analysis was used to evaluate alley cropping relative to the existing cropping system. The benefit- cost ratio was calculated as total benefits by the total costs. The highest benefit-cost ratio of 2.70 and 1.88 were obtained for alley cropping width of 4 m x 1 m and 3 m x 1 m for 2008 and 2009, respectively. The existing cropping system (sole cropping of maize) had the lowest benefit-cost ratio in 2009 (Table 3.16). Generally, the control treatment (sole maize) had the highest revenue and highest cost of production compared to the other treatments. Alley cropping treatments had the lowest cost of production compared to the control, thus giving them better returns from investment (Table 3.12 and 3.13).

Table 3.11 Land equivalent ratio of the various treatments for year 2008 and 2009

Treatment	Crop	Partial LER	Total LER 2008	Crop	Partial LER	Total LER 2009
Control	Maize	4.47/4.47 = 1	1	Maize	2.99/2.99 = 1	1
2m x 1m	Maize	2.05/4.47 = 0.45	1.45	Maize	1.58/2.99 = 0.53	1.14
	Jatropha	0.5/0.5= 1		Jatropha	1.22/2.00 = 0.61	
3m x 1m	Maize	2.85/4.47 = 0.6	1.54	Maize	2.00/2.99 = 0.67	1.18
	Jatropha	0.47/0.5 = 1		Jatropha	1.03/2.00 = 0.51	
4m x 1m	Maize	3.80/4.47 = 0.8	1.62	Maize	2.10/2.99 = 0.70	1.20
	Jatropha	0.41/0.5 = 0.9		Jatropha	1.00/2.00 = 0.50	

**LER greater than 1 shows intercropping is advantageous, LER < 1 show disadvantage, LER = 1 show no effect.*

Table 3.12 Average cost of production per hectare at farm level in 2008

Treatment	Control GH¢	2m x 1m GH¢	3m x 1m GH¢	4m x 1m GH¢
Acquisition of land	100.00	100.00	100.00	100.00
Land preparation	150.00	150.00	150.00	150.00
Cost of seed (Maize)	40.00	20.00	25.00	35.00
Cost of seed (Jatropha)	-	20.00	15.00	10.00
Planting	25.00	25.00	25.00	25.00
Labour (weeding)	60.25	46.50	50.79	56.00
Fertilizer (N-P-K)	240.00	120.00	132.00	148.00
Sulphate of ammonia	220.00	110.00	121.00	136.00
Harvesting	25.00	21.00	24.00	27.00
Gathering	15.00	13.50	14.00	14.00
Transportation	35.00	35.00	35.00	35.00
Dehusking	35.00	32.00	30.00	33.00
TOTAL COST	**945.25**	**693.00**	**721.79**	**769.00**

Table 3.13 Average cost of production per hectare at farm level in 2009

Treatment	Control GH¢	2m x 1m GH¢	3m x 1m GH¢	4m x 1m GH¢
Acquisition of land	100.00	100.00	100.00	100.00
Land preparation	155.00	155.00	155.00	155.00
Cost of seed (Maize)	50.00	25.00	28.00	31.00
Cost of seed (Jatropha)	-	20.00	15.00	10.00
Planting	30.00	30.00	30.00	30.00
Labour (weeding)	67.50	55.50	58.20	62.00
Fertilizer (N-P-K)	260.00	130.00	143.00	160.00
Sulphate of ammonia	240.00	120.00	131.00	147.00
Harvesting	30.00	27.00	30.00	32.00
Gathering	15.00	13.50	14.00	14.00
Transportation	40.00	40.00	40.00	40.00
Dehusking	40.00	50.00	33.00	30.00
TOTAL COST	**1,027.50**	**766.00**	**777.20**	**811.00**

Table 3.14 Average Revenue per hectare at farm level for 2008 and 2009

Treatment	Yield (t/ha) (2008)	Revenue (GH¢) (2008)	Yield (t/ha) (2009)	Revenue (GH¢) (2009)
Control	4.47	2,279.00	2.99	1,584.70
2m x 1m(maize)	2.05	1,045.10	1.58	837.40
2m x 1m(Jatropha)	0.5	170.87	1.22	473.61
3m x 1m(maize)	2.85	1,453.00	2.00	1,060.00
3m x 1m(Jatropha)	0.47	160.62	1.03	399.85
4m x 1m(maize)	3.80	1,937.00	2.10	1,113.00
4m x 1m(Jatropha)	0.41	140.12	1.00	388.21

**Revenue on maize is estimated at a market value of GH¢509.8 0/ton and GH¢530.00/ton for 2008 and 2009 respectively. Revenue on jatropha is estimated at getting 331.8 litres from 1 ton of jatropha. A litre of diesel would cost 1.03 and 1.17 for 2008 and 2009, respectively.*

Table 3.15 Benefit/Cost ratio per hectare at farm level, year 2008

Treatment	Revenue margin (GH¢)	Production cost(GH¢)	Profit ratio(GH¢)	Benefit-Cost	Ranking
Control	2,279.00	945.25	1,333.75	2.41	2nd
2m x 1m	1,215.97	693.00	522.97	1.75	4th
3m x 1m	1,613.62	721.79	891.83	2.24	3rd
4m x 1m	2,077.12	769.00	1308.12	2.70	1st

Table 3.16 Benefit/Cost ratio per hectare at farm level, year 2009

Treatment	Revenue margin(GH¢)	Production cost(GH¢)	Profit ratio(GH¢)	Benefit-Cost	Ranking
Control	1,584.70	1,027.50	557.20	1.54	4th
2m x 1m	1,311.01	766.00	545.01	1.71	3rd
3m x 1m	1,459.85	777.20	682.65	1.88	1st
4m x 1m	1,501.21	811.00	690.21	1.85	2nd

3.9 Discussions

3.9.1 Effect of *J. curcas* hedgerow spacing on growth of Zea mays L.

Plant heights, number of leaves, number of nodes per plant were not significantly affected by *J. curcas* spacing in the first year. In the second year, however, differences were observed in plant height and diameter. Maximum plant height (2.48 m) in the control plants was highest and lowest at the 2 m x 1m (2.01 m). Diameter of maize stalks was highest at the 4 m x 1 m spacing (19.38 mm) and lowest at 2 m x 1 m (16.36 mm). The results suggest that the dense population of *J. curcas* at the 2 m x 1 m spacing may have accounted for the reduced plant height and diameter of the maize plants. This could be attributed to limiting supply of water and nutrients from the soil and other environmental resources at dense population of *J. curcas*. Since the maize component is smaller, its root will be confined to soil horizons that are also available to the roots of *J. curcas*, but the latter can exploit soil volume beyond the reach of maize. Therefore, the effects of nutrients and water competition will be more severe for maize culminating in reduced height and diameter. These findings are in conformity with results of Genter and Camper (1973) and Dimchovoski (1978) who observed reduced plant height in high plant populations. On the contrary, it had been reported that plant height and internodes length increased with increasing plant population because of competition for light (Enyi, 1973). Sharma and Adamu (1984) also recorded highest plant height in dense population of millet and sorghum. The highest plant height in 4 m x 1 m could be attributed to reduced competition for nutrient and space. Manipulating plant spacing would be important in reducing competition in alley cropping.

3.9.2 Effect of *J. curcas* hedgerow spacing on yield and yield component of Zea mays

Generally no significant differences were observed in the first year. Differences in yield and yield components of maize started emerging in the second year even though yield was generally lower than in the first year. The lower yields observed in the second year at the closer spacing of 2 m x 1 m could be attributed to competition for nutrients, space and water. Yield reductions involving one or all component in intercropping have been attributed to inter-specific competition for nutrients, moisture and/or space (Enyi, 1973; Okpara and Omaliko, 1995). Szott (1987) and Fernandes (1990) concluded that the main reasons for the comparatively poor crop performance under alley cropping treatments were root competition and shading. It is possible that in the second year *J. curcas* competed with maize for nutrients and water thus causing a reduction in yield and yield parameters at closer spacing (2 m x 1 m). Fernandes (1990) also noted that reduced crop yields, due to root competition between hedgerows and crops in the alleys, were detected at 11 months after hedgerow establishment, and that competition increased with age of the hedgerows as measured by steadily declining crop yields close to the hedgerows. This is corroborated by this study since, there were no significant differences in the first year but subsequently occurred in the second year.

The ITTA study by Lal (1989) showed that maize and cowpeas yields were generally lower under alley cropping than when grown as sole crops as observed in this study. It is significant to note that the control did not differ significantly from the wider spacing of 3 m x 1 m and 4 m x 1 m. Lawson and Kang (1990) reported that although 2 m hedgerow spacing gave higher biomass, the yield of maize was reduced in this hedgerow spacing compared to the 4 m hedgerow spacing. Also Verinumbe and Okali (1985) showed that competition for light was a more critical factor than root competition for intercropped maize between teak trees. Kang *et al*. (1981b) attributed low yields from maize rows adjacent to *Leucaena leucocephala* hedgerow to shade. Competition for light and nutrients can be minimized through pruning.

3.9.3: Effect of *J. curcas* spacing and cultivation of maize on soil chemical properties

The chemical properties of the soil did not decline significantly over the two-year period of establishment of *J. curcas* hedgerows and the cultivation of maize. This implies that *J. curcas* can be integrated into our land use system without a significant deterioration of soil chemical properties in the short term. Atta-krah *et al*. (1985) reported that soil under alley cropping was higher in organic matter and nutrient content than soil without trees. Yamoah *et al*. (1986b) compared the effect of *C. siamea*, *G. sepium* and *F. macrophylla* in an alley cropping trial, and found that soil organic matter and nutrient status were maintained at higher levels with *C. siamea*.

This study showed a higher organic matter content for the *J. curcas* hedgerow treatments over the non alleyed treatments even though these were not significantly different ($P > 0.05$). This increase although not significant could be due to the short duration of the study and the addition of leaf litter into the soil from the hedgerows. Lal (1989) also showed that, over a period of six years, the relative rates of decline in the status of nitrogen, pH and exchangeable bases of the soil were much less under alley cropping than under non-alley cropped. This was attributed to the nutrient cycling capability of *L. leucocephala* hedgerow, as there was evidence of a slight increase in soil pH and exchangeable bases during the third and fourth years after the establishment of the hedgerows. Could the slight increase in exchangeable bases in the *J. curcas* hedgerows be attributed to nutrient cycling capability of the plant? In this study, it was observed that there was an extension of *J. curcas* roots laterally. This may provide an avenue for the intercept of nutrients and recycling to the topsoil.

3.9.4 Effect of distance from *J. curcas* hedgerow on growth of Maize

Growth of maize was highest with increasing distance from the hedgerow of *J. curcas*. In the first year, no differences were observed between the treatments presumably because root extension and crown of *J. curcas* were not extensive enough to compete for resources with the test crop. Differences in the second year can thus be attributed to competition at closer spacing to the hedgerow. A number of findings support the hypothesis that reduced growth of maize closer to hedgerows could be a result of competition for resources and shading in the second year. Newman *et al*. (1998) reported that where shading occurs in tree based intercropping systems, a ǫparabolic effectô on crop height and yield had been observed within the intercropping agricultural crop. The apex of the parabola (i.e. the greatest growth) occurs in the middle of the crop strip with growth reduced nearest the tree hedge. They also observed that leaf weight and internode distances were also highest in the middle of the crop strip (Reynolds *et al*., 2007). Two crop species (corn and soybean) and two tree crops (hybrid poplar and silver maple) were examined for their potential competitive interactions. Of the two crops, corn was the most detrimentally impacted by tree competition (Reynolds *et al*. 2007). Working with temperate tree-based intercropping systems in China, Wu and Zhu (1997) also observed that inter-row spacing was a significant factor influencing tree shading. This study realized that maize growth closer to hedgerow reduced significantly which can be attributed to competition for resources.

3.9.5: Effect of distance from *J. curcas* hedgerow on yield of maize

Yield and yield parameters such as 100 seed weight, weight of cob, and weight of seed per cob and grain yield were significantly affected by distance from the hedgerow. Closer spacing from hedgerow (1 m) had the lowest yield and yield parameters. These results could be attributed to competition for resources at closer spacing since no reported difference was observed in the first year. Similar studies have also reported of decline in yield at closer spacing. Szott *et al*. (1991) found that yield generally increased with distance from hedges, suggesting that below-ground competition for water and nutrients reduce crops near the hedges. Goqerty (1994) showed that under conditions of 1.5 m spacing within rows and 6.8 m between rows, increased yields on a per hectare were observed. Newman *et al*. (1998) reported that the yields of corn and field beans were reduced by 63% and 68%, respectively, when intercropped with paulownias, a temperate tree species with relatively large crown. To avoid these yield losses Simpson (1999) suggested that the canopies of trees should be pruned to reduce shading and that trees should also be rootï pruned to reduce possible competition effects for soil moisture. To avoid decline in yield, maize should not be planted close to hedgerow of *J. curcas*.

3.9.6 Land Equivalent Ratio of cultivating *J. curcas* with Maize

The highest Land Equivalent Ratio (LER) attained at the hedgerow width of 4 m shows the beneficial effect of intercropping *J. curcas* and maize at this treatment. The results for the year 2008 (LER of 1.62) means that an area planted as monoculture (maize) would require 62% more land to produce the same yield as the same area planted to *J. curcas* and maize combination. According to Reyes *et al*. (2009) intercropping was highly advantageous for pepper and cardamon. Pepper intercropped with *Grevillea robusta* produced 3.9 times more than in monoculture and cardamon intercropped with grevillea and pepper yielded 2.3 times more than in monoculture (Reyes *et al*., 2009). The high LER showed a very clear benefit from intercropping *J. curcas* and maize at 4 m x 1 m hedgerow spacing. Jollife (1997) reported that, on average, mixtures are 12% more productive than pure stands, based on 202 direct observations, or 13% more productive, based on 604 estimates using yield-density relationships. It can be stated that a *J. curcas* and maize mixtures would be beneficial than planting maize as a monocrop.

3.9.7 Benefit cost ratio of intercropping maize with *J. curcas*

In terms of benefit/cost analysis, alley cropping system gave better returns than the monocropping system. According to Nair (1993) if the benefit-cost ratio is greater than one, the project is estimated to provide a positive return. Theoretically, the greater the ratio of benefits to costs the more attractive the undertaking. Generally, all the treatments had better returns. In 2008, the alley width of 4 m provided the highest benefit-cost ratio of 2.70 and in 2009; the alley width of 3 m had the highest benefit-cost (BC) ratio of 1.88. This amply demonstrates better returns from the alley cropping system. The high BC ratio obtained from the alley cropping treatments is as a result of reduced cost of weeding and fertilizer application. The reduction in weeding cost was due to the low biomass of weeds obtained in the alley cropping treatments. Jama *et al*. (1991) attributed weed reduction under closely spaced *L. leucocephala* alleys in Kenya to shading. In an alley cropping trial in Costa Rica, Rippin (1991) reported a reduction of weed biomass of over 50% in alleys of *E. poeppigiana* and *G. sepium* compared with non alley-cropped. The reduction in fertilizer cost was as a result of the density of maize per plot rather than nutrients incorporated by the *J. curcas* hedgerows. Fertilizer was applied only to maize plant rather than all components of the plot.

3.10 Conclusions

Hedgerow intercropping of *J. curcas* with maize could prove useful if a spacing of 4 m x 1 m is adopted. It should be noted that closer spacing of *J. curcas* could induce competition with the associated crop resulting in reduced yields. Even though alley width of 4 m spacing did not give the highest yield compared to the control, its highest land equivalent ratio implies it could be the most appropriate spacing. Soil chemical properties were not affected within the two years of cultivating *J. curcas* with maize. It implies that its use in alley cropping would not result in the deterioration in soil chemical status within a short term. The highest Benefit/Cost ratio was attained at the 4 m x 1 m spacing. In the midst of declining land area for the cultivation of *J. curcas* as a biofuel crop, its use in alley cropping at the appropriate hedgerow spacing could be exploited to produce the crop in Ghana.

CHAPTER FOUR

THE INFLUENCE OF STORAGE PERIOD, FERTILIZER APPLICATION AND SPACING ON GROWTH AND YIELD OF *J. CURCAS.*

4.1 Introduction

J. curcas is known to be a hardy plant and can thrive in the poorest rocky soils (Wiesenhütter, 2003). These poor soils do not provide the appropriate optimum yield desired to produce biodiesel. Low yield of 0.1 ï 1.10 tons/ha per annum had been reported in the production of *J. curcas* (CPJ, 2010). Low yields obtained in the traditional sector were mainly attributed to low soil fertility particularly N and P, moisture content and poor management (Mokwunye *et al*., 1996).

The success of *J. curcas* seed oil for biodiesel production lies in the sustainable and economically viable production of seeds at field level. Consequently, increased in the production of *J. curcas* can only be achieved by the application of inorganic fertilizers. Ojiem *et al*. (1996) reported that the use of inorganic fertilizers at 60 kg N and 60 kg P_2O_5/ha had a 3 ton grain yield per hectare advantage over where fertilizer was not used. Several investigations reported an increase in nitrogen (N) rate being associated with an increase in yield of different species of fruit trees (Koo *et al*., 1974). Ahad *et al.* (1992) found that the application of 2 kg NPK/apple tree gave more tree growth, fruit number and weight/fruit. Farmers thus need to increase their production by adopting appropriate strategies and techniques which will lead to sufficient and reliable yields without depleting the natural resource base.

Rapid population growth has resulted in a more intense land use pattern. Intensive cropping is becoming more common due to limited availability of land and increased population. The limited land therefore has to be allocated to uses other than the production of *J. curcas*. Adoption of optimum plant spacing is intended to harness solar energy, avoid root competition and efficient exploitation of water and nutrients. At the same time, the concept of high density is to maximize fruit productivity from the limited land resources (Nasir *et al*., 2006). It is therefore necessary to assess whether the use of inorganic fertilizer can increase significantly the yield of *J. curcas* and thus provide a sustainable supply of the produce. Reliable and viable seed supply is necessary to attain optimum yield of *J. curcas.* Mostly, farmers have to store *J. curcas* under room temperature (25 ^{o}C) and wait till the rains set in before it is planted. This period in storage could affect the germination percentage and germination energy of the seeds. It is not certain whether during this period, viable seeds can still be obtained for planting.

4.2 Objectives

This study sought to provide the appropriate period that seeds of *J. curcas* could be stored without losing viability.

The specific objectives of the study were to:

- Assess the effect of storage of seeds at room temperature on germination of *J. curcas* over a period of one year.
- Determine the effect of fertilizer and spacing on growth of *J. curcas*.
- Assess the effect of fertilizer and spacing on yield and yield components of *J. curcas*.

4.3 Materials and Methods

4.3.1 Study area

The study was carried out at Ayakumasu in the Sunyani West District of the Brong ïAhafo region. Details of Ayakumasu are presented under 3.2.1.

4.3.2 Germination test

Seeds were stored at room temperature (25 ^{o}C) for duration of 1 to 12 months. Germination beds were raised in a Randomized Complete Block Design (RCBD) with four replications. Each treatment had 100 seeds in each block to assess the percentage germination and energy of germination. A total of 400 seeds for each treatment were used for the experiment. For each month, the study ended on the 27th day when no further germination was observed. Seeds were considered to have germinated when the radicle was 1 cm above the soil.

4.3.3 Fertilizer and spacing experiment

A split plot design in Randomized Complete Block Design (RCBD) was used for the experiment. Fertilizer at 2 levels was the sub plot treatment and spacing at 3 levels was the main plot treatment. The fertilizer and spacing treatments used were:

<u>Fertilizer treaments</u>

No fertilizer = (F0; 0 kg NPK/ha)

Fertilizer = (F1; 150 kg NPK/ha)

<u>Spacing treatments</u>

1 m x 1 m (D1)

2 m x 1 m (D2)

3 m x 1 m (D3)

The experiment was replicated 3 times and data were collected over a period of 1 year (Plate 4.1). Seed length and seed width were measured with the Vernier caliper. Twenty seeds were randomly picked from each treatment for the measurement. Seed size was obtained by dividing the seed yield per hectare (g) over the number of seeds per hectare. Seed weight was measured using an electronic digital weighing scale.

Plate 4.1: Layout of Fertilizer and spacing experiment

4.4 Data analysis

Data for the study were analyzsed using the GENSTAT package. Significant differences between the treatments were determined from the generated Analysis of Varainace at 5% probability level. If treatements are different the Fishers LSD was used to separate the means.

4.5 Results

4.5.1: Germination trend of *J. curcas* over a year period

There was a decline in the germination percentage of *J. curcas* over the 12 month storage period (Fig. 4.1). Within the first month of storage of the seeds, germination was 98% and by the 12th month germination percentage had dropped to 52%. No significant difference in germination was realized within the first 2 months but after this significant differences emerged. The number of germinated seeds at first germination also declined with time (Fig. 4.2). The highest germination was at the first 2 months (Fig. 4.2) and the lowest number of seeds that germinated was at 12 months (Fig. 4.2). No significant differences were observed between the first and second month with respect to the number of germinated seeds at first germination (Fig. 4.2). The mean number of germinated seeds at first germination in the third month was 43.33 and it differed significantly from the first two months. In the fourth month, there was an increase in the mean number of seeds that germinated at first germination to 45 which also differed significantly from the first two months. However, no significant effect was realized between the third month and fourth month (Fig. 4.2). From the fourth month to the 12th month there was a gradual decline in the percentage germination (Fig. 4.1).

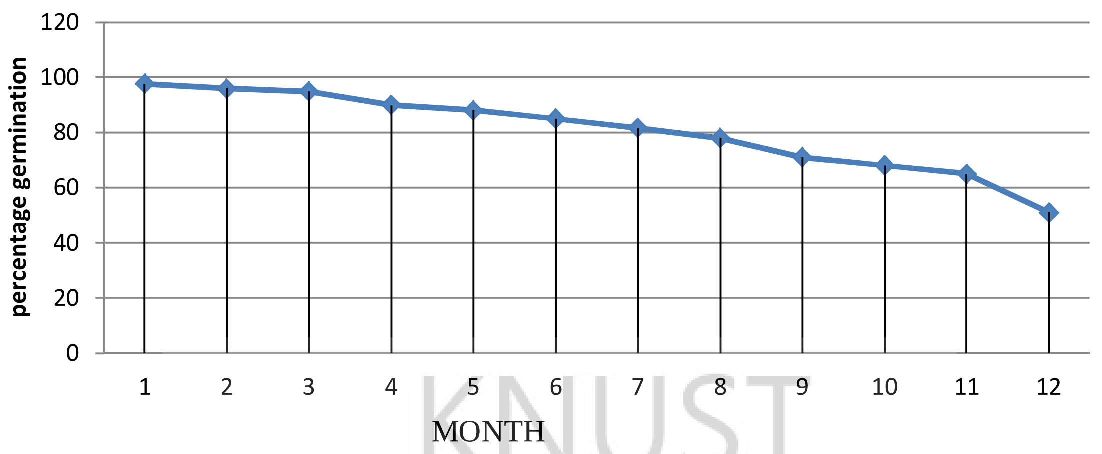

Figure 4.1: Trend in percentage germination of *Jatropha curcas* over a year

LSD (0.05) = 1.705

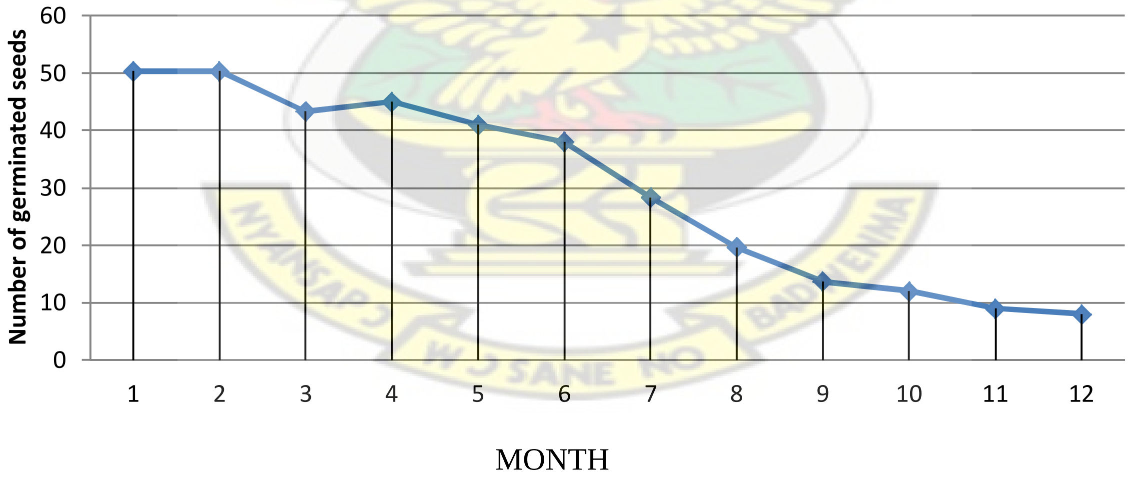

Figure 4.2 Number of germinated seeds at first germination

LSD (0.05) = 1.71

4.5.2 Fertilizer and Spacing on growth of *J. curcas*

Fertilizer and spacing interaction did not significantly affect the growth of *J. curcas*. Height growth of the crop was more pronounced in the fertilized soil compared to unfertilized soil, which were significantly different (P < 0.05) from each other (Table 4.1). The months of September and October showed very significant increases in height, with the least increase in height observed in the months of December and January (Table 4.1). Comparing the various spacing, the 1 m x 1 m (D1) had the highest increase in height compared to all the other spacing.

Table 4.1 Height of *J. curcas* over a year period as influenced by spacing and fertilizer interaction

Month	D1F1	D1F0	D2F1	D2F0	D3F1	D3F0	LSD (0.05)
August	0.219	0.17	0.25	0.17	0.22	0.17	0.06
september	0.67	0.47	0.58	0.45	0.52	0.5	0.17
October	0.97	0.79	0.99	0.72	0.98	0.89	0.77
November	1.3	0.98	1.2	0.87	1.24	1.12	0.65
December	1.32	1.07	1.35	1.06	1.3	1.13	0.38
January	1.38	1.1	1.41	1.08	1.39	1.22	0.41
February	1.42	1.2	1.51	1.12	1.45	1.36	0.42
March	1.69	1.4	1.68	1.45	1.67	1.56	0.38
April	1.75	1.5	1.71	1.54	1.7	1.59	0.037
May	1.81	1.66	1.87	1.65	1.78	1.65	0.38
June	1.83	1.7	1.93	1.7	1.85	1.7	0.39
July	1.86	1.74	2	1.73	1.94	1.74	0.44

The diameter of *J. curcas* showed a similar trend as in height (Table 4.2). It was observed that from December to January there was stagnation in diameter growth. Diameter growth was, however, highest in 3 m x 1 m and fertilizer at 150kg NPK (D3F1) treatment (Table 4.2).

Table 4.2 Table 4.1 Height of *J. curcas* over a year period as influenced by spacing and fertilizer interaction

Month	D1F1	D1F0	D2F1	D2F0	D3F1	D3F0	LSD (0.05)
August	13.45	11.46	14.57	11.61	13.84	11.61	2.65
September	31.62	26.33	30.9	21.92	30.23	28.39	6.40
October	42.7	39.8	35.4	32.6	45.5	32.2	9.09
November	52.3	44.7	48.6	41.6	49.7	43.8	11.37
December	53.3	45.1	50.1	43.1	50.7	45.2	13.87
January	53.7	46.1	50.3	43.8	51.1	50.5	12.43
February	53.9	46.3	50.6	44.2	51.4	50.8	10.20
March	54.9	46.8	51.9	45.5	52.9	51.3	13.13
April	58.9	48.5	55.7	49.3	58.1	52.3	11.30
May	63.6	55.9	60.4	53.7	65.4	60.9	10.61
June	68.8	60.8	68.1	60.1	70.1	65.1	9.77
July	72.3	66.2	73	67.1	76.2	70.9	8.80

4.5.3 Fertilizer and spacing on yield and yield components

The interaction between spacing and fertilizer had no significant effect ($P > 0.05$) on number of seeds harvested, number of fruit harvested, weight of seed husk, seed length, seed size, seed width, seed yield and fruit yield. However, the fertilizer treatment did respond to all the above parameters mentioned except seed size which was not significant (Table 4.3a and 4.3b). Fertilizer treatment increased seed yield by 56.4%, fruit yield by 51.8%, number of seeds harvested by 54.9% and number of fruits harvested by 55.5%. Weight of seed husk, seed length and seed width were also increased at the fertilizer treatment by 39.2%, 1%, and 1.7% respectively (Table 4.3b). Spacing however did not significantly influence the number of seed harvested, number of fruits harvested, seed yield, fruit yield, weight of seed husk, seed length seed size and seed width.

Table 4.3a: Effect of fertilizer on yield and yield components of *J. curcas*

Treatment	Mean number of seed harvested per ha/month	Mean number of fruits harvested per ha/month	Mean seed yield per ha (kg)/month	Mean fruit yield per ha (kg)/month
No Fertilizer (F0)	53851	19499	44.5	62.8
Fertilizer (F1)	83400	30313	69.6	95.3
LSD (0.05)	13049.6	3846.4	10.57	12.76

Table 4.3b: Effect of fertilizer on yield and yield components of *J. curcas*

Treatment	Mean weight of seed husk (kg)/month	Mean seed length (mm)	Mean seed size (g/seed)	Mean seed width (mm)
No Fertilizer (F0)	18.6	17.51	0.76 a	11.05
Fertilizer (F1)	25.9	17.69	0.74 a	11.24
LSD (0.05)	3.48	0.17	NS	0.18

NS = Not Significant

4.5.4 Trends in yield and yield components in the first year of cultivating *J. curcas*

J. curcas yield trend varied within the year. Significant differences did emerge over the 12 month period. The highest seed yield, number of seeds, number of whole seeds, and weight of seed husk was attained in July. It did not differ significantly from the month of June and August in most of the parameters (Table 4.4a and 4.4b). However, the month of July and August differed significantly from the other months in number of seeds per hectare, number of fruits per hectare, seed yield per hecatare, seed size and seed width (Table 4.4a and 4.4b). Total seed yield of 693.5 kg/ha was obtained in the first year of cultivating *J. curcas*.

Table 4.4a: Trends in yield and yield components of *J. curcas* within a year

Months	Number of seeds per ha	Number of fruits per ha	Seed yield per ha (kg)	Fruit yield per ha (kg)
January	40104	15175	22.7	33.4
February	13763	5662	8.7	12.3
March	4183	1513	3.0	4.5
April	3445	1437	2.3	3.3
May	24375	9522	22.8	33.4
June	112839	42469	98.1	153.3
July	211317	76905	179.5	248.7
August	193809	69160	171.4	210.9
September	155878	55584	140.2	175.4
October	44193	15551	32.1	44.1
November	15	6	0.0	0.00
December	19581	5885 cd	12.7	21.2
TOTAL	823,502	298,869	693.5	940.5
LSD (0.05)	28052.5	10268.7	24.26	36.00

Table 4.4b: Trend in yield and yield components in a year

Months	Weight of seed husk /ha (Kg)	Seed length (mm)	Seed size (g/seed)	Seed width (mm)
January	10.5	16.57	0.58	10.43
February	3.6	16.99	0.64	10.65
March	1.4	17.44	0.69	11.14
April	0.9	17.57	0.80	11.09
May	13.3	18.76	0.89	11.37
June	55.2	18.89	0.91	11.66
July	69.2	18.79	0.79	11.40
August	39.1	17.62	0.88	11.55
September	35.3	17.59	0.89	11.56
October	12.0	19.57	0.69	11.65
November	0.00	17.55	0.54	10.34
December	8.5	17.40	0.69	10.86
LSD (0.05)	13.48	0.34	0.19	0.24

4.6 Discussions

4.6.1 Germination of *J. curcas* seeds within one year of storage

According to Willian (1985) germination percentage is defined as the percentage of pure seeds which produce normal seedling or the number of seeds which germinate per unit weight of sample or per total number of seeds per test. The highest germination percentage obtained in the first 2 months in this study showed that, *J. curcas* seeds can be stored for two (2) months under room temperature without significantly losing their viability. From the second month there was a gradual deterioration of the seeds, culminating in a lower percentage germination of 52 by the 12th month. The high oil content of seeds may influence seed germination and vigour. Seeds with high oil levels such as *J. curcas* have often been associated with shorter longevity and faster deterioration than seed with high starch content (Copeland and McDonald, 2001). The ability of ñoilyò seeds to imbibe moisture and hold it tightly may contribute to more rapid deterioration of oily seeds compared to starchy seed of comparable moisture levels (Thomison, 2003). Seeds of *J. curcas* deteriorated over the 12 month period in storage presumably due to aging. This aging is manifested in the reduction of percentage germination, while seeds that germinated, produced weak seedlings. During aging seeds lose their vigour, germinability and ultimately viability (Trawatha *et al*., 1995). According to Grilli *et al*. (1995) membrane disruption is one of the main reasons of seed deterioration. As a result, seed cells are not able to retain their normal physical condition and functioning. The major causes of membrane disruption are increase in free fatty acid level and free radicals productivity. In this study, 50% of the seeds had germinated at first germination from seeds stored in the first 2 months. By the 12 month of seed storage only 8% germinated at first germination. This suggests that germination energy was high within the first 2 months and seedlings that are vigorous enough to establish will be obtained. Germination energy is the percentage number of seeds in a given sample which germinate under optimum or stated condition within a given period called the energy period. It is also the percentage of seeds in a given sample which germinate up to the time of peak germination. It is generally taken as the number of germination in a 24 hour period. According to Smith (1986) the concept of germination energy is based only on the theory that only those seeds which germinate quickly are likely to produce seedlings vigorous enough to survive competition in the open.

4.6.2 Effect of fertilizer and spacing on growth of *J. curcas*

There was no significant interaction between fertilizer and spacing with respect to the growth of *J. curcas*. Plant height was higher at closer spacing, but did not show any significant difference from the other treatments. Fertilizer addition was essential in promoting the growth of *J. curcas*. The application of fertilizer to the plants improved the fertility of the soil by making available essential elements required for improved nutrition and healthy growth of the plants. Patolia *et al.* (2007) in an experiment with *J. curcas* found that 60 kg N/ha applied at planting and one year thereafter, increased plant height by 23% whilst 30 kg N/ha P_2O_5/ha increased plant height by 17%. This explains why rapid growth (height and diameter) was observed for *J. curcas* on the fertilized plots.

Seasonal conditions which occurred in the various months also affected growth of the *J. curcas.* Significant increase in height was observed in September and October whiles the least increase in height occurred between December and January. This is because favourable rainfall figures recorded during the period could have accounted for the increased height. Rainfall is very essential for the growth of plants especially where irrigation is not undertaken. Water is one of the factors of growth of plants and dissolves soluble nutrients essential for their uptake. Water also transports nutrients to various parts of the plant to enhance growth. On the other hand, the least increase in height recorded in December and January can be attributed to the fact that these months mark the dry season of Ghana.

4.6.3 Effect of fertilizer and spacing on yield and yield components of *J. curcas*

The interaction of fertilizer and spacing treatments did not have any significant effect ($P > 0.05$) on yield and yield components. It was only the fertilizer treatment that influenced ($P < 0.05$) the yield and yield components of the crop except seed size. Donadio *et al*. (1995) had reported that size and quality of Pera oranges was not influenced by different planting densities. Fertilizer treatment increased seed yield by 56.4%, fruit yield by 51.75%, number of seeds harvested by 54.87% and number of fruits harvested by 55.45%. The marked effect of NPK on yield may be due to the stimulating effect of NPK on the vegetative growth characters which form the basis for flowering and fruiting. The higher yields have shown the importance of moderate application of fertilizer to *J. curcas*. The erroneous impression that the crop is hardy and can therefore be cultivated in degraded areas should be looked at if the ultimate objective is to get higher quantities of seeds. Low nutrient availability under nutrient deficient soils limits productivity unless fertilizers are applied. Spacing did not significantly influence yield and yield parameters. However, Peter *et al*. (1975) reported that high tree densities are better during early life of the orchard with high initial yield.

4.7 Conclusions

J. curcas seeds can be stored at room temperature for two months without losing their viability significantly. Within a year of seed in storage, germination can be reduced by 52%. Germination energy was high in the first 2 months. Fertilizer and spacing interaction, and spacing only did not significantly ($P > 0.05$) affect the growth and yield of *J. curcas*. Application of 150 kg NPK increased the yield of *J. curcas* seeds by 56.4%. It can be concluded that, to increase yield of the crop soil amendment in terms of fertilizer addition would be essential. Growth and yield of *J. curcas* increased progressively and attained the highest height of 10.96 m and yield of 179.5 kg/ha in July.

CHAPTER FIVE

SEED SOURCE VARIATION AND POLYBAG SIZE ON EARLY GROWTH OF *J. CURCAS*

5.1 Introduction

Ghanaôs effective participation in the bio fuel industry is important but must be based on sound research including the screening of seed source to determine possible competitive advantages that might be inherent in the different seed sources. Possibly *J. curcas* can become one of the most important crops in our agro-forestry systems as it satisfies not only economic and environmental concerns but also soil improvement. It is also simple to cultivate. Localized energy production to meet community need is possible in a *J. curcas* project as exemplified by GTZ in Mali (Henning, 1998).

The basis of any meaningful agricultural production or forest resource establishment are the seed and the nursery, and it is known that phenotypic and genotypic as well as broad sense variability exists in every plant species. This offers a breeder or a researcher ample scope to undertake screening and selection of seed source for desired traits which can lead to the improvement of the species (Kumarsukhadeo, 2006). The species has a wide range of adaptability for climatic and edaphic factors and grows well even on marginal lands enduring drought, alkalinity of soil and thus, serves as best source to green up barren wastelands (Tewari, 1994). The wide geographical and climatic distribution physic nut is indicative of the fact that there exists a tremendous genetic diversity (Ginwal, 2004). Since *J. curcas* is widely distributed in Ghana the species is expected to have considerable phenotypic variation. The presence of phenotypic diversity is crucial for improving any plant species. An understanding of the magnitude and pattern of genetic diversity in plants has important implications in breeding programmes and for conservation of genetic resources. The objective of this study was to understand the existing seed source variations which could form a basis of selecting the best for subsequent cultivation in the field.

5.2 Objectives

The objectives of the study were:

1 To determine the seed source variation of *J. curcas*.

2. To determine the effect poly bag sizes on seedling growth and root development of the crop.

5.3 Materials and Methods

5.3.1: The study area

The investigation was carried out at the nursery of the Faculty of Forest Resources Technology, Kwame Nkrumah University of Science and Technology, Sunyani Campus. It is located between 7.35^{o}N and 2.34^{o}W, at an elevation of 360 m. The soils are of ferric acrisols and the vegatation type is of moist semi-deciduous forest. Its mean monthly temperature varies between 23 ^{o}C and 33 ^{o}C with the lowest in August and highest in March and April, respectively. It has a double maxima rainfall pattern. The major rainy season occurs from April to end of July whilst September to October is the minor wet season. It has relative humidity of about 70%.

5.3.2: Methodology

The study was carried out from December, 2008 to March, 2009. Seeds were collected from seven localities across Ghana covering the major ecological zones (Wet evergreen, Dry semi-deciduous, Moist semi-deciduous and Guinea savanna zones). In each ecological zone, a specific community was selected randomly for the study. In the selected communities, seeds were collected randomly from homegardens. Seeds collected were quickly transported to the Facultyof Forest Resources Technology and air-dried at room temperature of 25 ^{o}C. The specific localities were**:**

1. Agotime Kpetoe, Volta Region (Dry Semi-Deciduos, fire zone) - (1)
11. Juaboso, Western Region (Wet evergreen) - (2)
111. Kumasi, Ashanti Region (Moist Semi deciduous forest) - (3)
1V. Fiapre, Brong Ahafo Region (Dry semi-deciduous) - (4)
V. Tamale, Northern Region (Guinea savanna) - (5)
V1. Koforidua, Eastern Region (Moist Deciduous forest) - (6)
V11.Wa, Upper Western Region (Guinea savanna) - (7)

5.3.3: Seed characteristics

The variation in seed and seed characteristics were investigated as follows. From each seed lot, 50 seeds were drawn at random and measured for their maximum length and width in millimeters using electronic vernier caliper. For the measurement of seed weight 5 replicates of 100 seeds each were used and expressed as weight of whole seeds.

5.3.4: Seed germination

Hundred seeds from each location were randomly picked for the germination trial at the nursery. The Randomized Complete Block Design was used for the experiment. In each experimental unit, 100 seeds from each location were randomly placed in the block. The experiment was replicated 3 times. Seeds were considered germinated when the radicle had emerged 1cm above soil (Czabator, 1962). Seed germination was recorded and quantified as germination percentage.

5.3.5: Growth measurement of seedlings

Seeds were collected from the various sources within two weeks, air dried and nursed in three different poly bag sizes filled with well mixed soil. One hundred and forty four (144) polybags were prepared in this way for the study.

The factors under examination were seed source and polythene bag (polybag) size. A split plot design in RCBD with three replications was used. The main plot treatments of poly bag size were Large (L): (16 cm×19.80 cm), Medium (M): (13 cm×17.80 cm), Small (S): (10.30×13 cm). The sub-plot treatments was the seed sources from Kpetoe (1), Juaboso (2), Kumasi (3), Fiapre (4), Tamale (5), Koforidua (6), Wa (7). In each sub plot 35 seedlings were laid.

Data on five (5) seedlings from each poly bag size group were taken each month. Seedling traits in the nursery were recorded for plant survival percentage at four (4) months. Seedling height in centimeters (cm), collar diameter in millimeters (mm), number of leaves per plant, above and below ground biomass in grams per seedlings was also measured. Root biomass was also determined by carefully washing the seedlings to retrieve majority of the root system. After taking all the necessary measurement on the fresh seedlings, the seedlings were dried in an oven at 65 ^{o}C for 72 hours for dry weight measurement. Uprooting of weeds and watering were done as and when necessary.

5.3.6: Analysis of data

The data gathered was analyzed using the GenStat package. The Analysis of Variance (ANOVA) was used to determine if the treatment means were significantly different at 5%. The Fishers Least Significant Difference was used to separate the means between the treatments.

5.3.7 Limitation of the study

Seeds could not be collected from the various seed sources the same day. This was done within two (2) weeks.

5.4: Results

5.4.1: Seed characteristics

Weight of seeds from the various sources did not differ significantly from each other except the lot from Kpetoe which differed significantly ($P < 0.05$) from the rest. No significant differences were observed for seed length and seed width (Table 5.1). Seed weight and seed length had a positive correlation coefficient (r) of 0.758 whilst seed length and seed width had a negative correlation coefficient (r) of -0.722.

Table 5.1: Characteristics of seeds

Locality	Number	100 Seed Weight (g)	Seed Length (mm)	Seed Width (mm)
KPETOE	1	83.4 ± 1.15	19.7 ± 0.82	10.4 ± 1.14
JUABOSO	2	62.6 ± 1.6	17.8 ± 1.6	10.8 ± 0.88
KUMASI	3	74.9 ± 0.3	19.5 ± 0.55	10.5 ± 1.11
FIAPRE	4	67.3 ± 0.5	17.5 ± 0.5	11.2 ± 0.36
TAMALE	5	72.9 ± 1.3	18.3 ± 0.83	10.9 ± 0.6
KOFORIDUA	6	75.3 ± 0.32	18.2 ± 1.03	11.1 ± 0.35
WA	7	68.5 ± 0.95	18.8 ± 0.55	11.2 ± 0.5
P-value		9.4E-12	0.126	0.72
LSD (0.05)		12.88	NS	NS

± = *Standard deviation; NS = Not Significant*

5.4.2: Seed germination and survival

Seed from all sources recorded a germination percentage of more than 90%. The highest percentage germination of 98% was recorded for seeds collected from Juaboso and Fiapre while those from Tamale recorded the lowest germination of 94% (Table 5.2). Germination started on the fourth day and ended on the ninth day. No germination occurred from the tenth day onwards. Differences in germination percentage of seeds did not vary significantly among the various locations.

Table 5.2: Variation in germination percentages of seed sources

Locality	Number	Mean number planted	Mean number germinated	% Germination
KPETOE	1	100	96	96
JUABOSO	2	100	98	98
KUMASI	3	100	96	96
FIAPRE	4	100	98	98
TAMALE	5	100	94	94
KOFORIDUA	6	100	97	97
WA	7	100	96	96
P (0.05)			NS	0.27

Seedling survival was above 90% percent in all 7 seed sources. Kpetoe, Kumasi, Fiapre, Koforidua, and Wa recorded 96% survival, while Juaboso and Tamale recorded 98% and 97% survival, respectively (Table 5.3). The survival percentage recorded did not show any significant differences between the treatments.

Table 5.3: Variation in survival percentages of seed sources

Locality	Number	Number germinated	Number surviving	Number dead	% Survival
KPETOE	1	96	92	4	96
JUABOSO	2	98	96	2	98
KUMASI	3	96	92	4	96
FIAPRE	4	98	94	4	96
TAMALE	5	94	91	3	97
KOFORIDUA	6	97	93	4	96
WA	7	96	92	4	96
C.V. (%)					1.22
P-Value					NS

5.4.3: Interactive effect of seed source and polybag size on seedling growth

There were significant interactions between seed source and polybag size for plant height and diameter of seedlings (Table 5.4). The highest height (31.12 cm) of *J. curcas* seedling was recorded at Medium size and Fiapre (M4). However, it did not differ significantly from Large size and Kpetoe (L1), Large size and Tamale (L5), Large size and Koforidua (L6), Medium size and Koforidua (M6), Small size and Wa (S7), Small size and Kpetoe (S1), and Large size and

Wa (L7) at P > 0.05. Seedling height (17.83 cm) was lowest at small size and Kumasi (S3) (Table 5.4). A similar trend was observed with respect to diameter of seedlings. M4 was highest (14.11 mm) in diameter whilst S2 was lowest (2.25 mm) with regard to diameter (Table 5.4). Generally a positive correlation of 0.78 was attained between diameter and height of seedling.

Fresh weight of roots of seedlings differed significantly between the treatments (Table 5.4). L6 and M4 had the highest fresh root weight. These did not differ significantly from L1, L7, L5, M6 and M2. However, L6 and M4 did differ significantly from the others (Table 5.4). The least fresh weight of roots was in S2 (Table 5.4). With respect to the root dry weight of seedling, No significant differences was realized between the treatments on root dry weight basis (P > 0.05) (Table 5.4).

Table 5.4: Effect of Polybag size and seed source on growth of seedlings

Interaction of polybag size and seed source	Seedling height (cm)	Seedling diameter (mm)	Fresh weight of root (g)	Dry weight of root (g)
S1	23.75	12.27	5.52	1.04
S2	18.72	9.70	2.25	0.4
S3	17.83	9.94	2.62	0.46
S4	20.38	11.30	4.45	0.56
S5	21.35	11.42	3.45	0.61
S6	20.90	11.76	4.48	0.86
S7	24.15	13.28	6.03	1.35
M1	21.85	13.63	6.62	1.51
M2	21.05	14.13	8.45	1.86
M3	19.57	12.03	5.17	1.24
M4	31.12	16.39	14.11	2.63
M5	21.00	12.00	4.60	1.11
M6	24.52	13.99	10.03	2.12
M7	18.30	12.49	5.77	1.13
L1	28.47	15.71	13.00	1.97
L2	20.87	13.34	7.35	1.37
L3	20.85	13.92	7.60	1.40
L4	20.40	13.96	8.28	1.64
L5	27.35	14.44	10.22	1.78
L6	25.07	16.38	14.18	2.96
L7	23.52	13.85	11.91	2.24
SE±	2.01	0.80	1.77	0.44
LSD (0.05)	5.56	2.28	5.02	1.26

5.4.4: Effect of seed source on fresh and dry weights of root and shoot of seedling

The analysis of variance showed that no significant interactions were observed between the seed sources and polybag size with respect to dry weight of roots at $P < 0.05$ (Table 5.4). Seed source alone however significantly affected dry shoot weight of seedlings. Seeds from Wa produced the highest dry shoot weight (12.35 g) but did not differ significantly from Kpetoe, Fiapre, Tamale and Koforidua seeds (Table 5.5).

Table 5.5: Effect of seed source on fresh and dry weight of roots and shoots of seedling

Seed source	Fresh weight of root (g)	Dry weight of root (g)	Fresh weight of seedling shoot (g)	Dry weight of seedling shoot (g)
Kpetoe	8.38	1.50	49.29	11.03
Juaboso	6.01	1.21	32.92	8.04
Kumasi	5.13	1.61	29.14	7.30
Fiapre	8.95	1.61	49.23	11.69
Tamale	6.09	1.72	40.39	8.97
Koforidua	9.57	1.98	54.27	11.17
Wa	7.90	1.57	47.65	12.35
SE±	1.02	0.25	1.02	1.27
LSD (0.05)	2.90	0.72	2.90	3.61

5.4.5: Effect of poly bag size on fresh and dry weight of roots and shoot of *J. curcas* seedling growth.

The analysis of variance showed a significant difference between poly bag size on fresh and dry weights of roots and shoot (Table 5.6). Dry weight of roots and shoot increased with increasing poly bag size (Table 5.6). The highest dry weight of 1.91g and 11.48 g was attained by seedlings from the large poly bag size for root dry weight and shoot dry weight respectively (Table 5.6).

Table 5.6: Effect of polybag size on fresh and dry weight of root and shoot

Poly bag size	Fresh weight of root (g)	Dry weight of root (g)	Fresh weight of seedling shoot (g)	Dry weight of seedling shoot (g)
Small	4.11	0.76	30.75	8.37
Medium	7.82	1.66	44.11	10.39
Large	10.36	1.91	54.95	11.48
SE±	0.67	0.16	3.39	0.83
LSD (0.05)	1.90	0.47	9.58	2.36

5.4.6: Effect of polybag size on root length of *J. curcas*

It was also observed that poly bag size had a significant influence on the root length developed by seedlings. Root length of seedlings decreased drastically with reducing poly bag size. Seed source and poly bag size interaction did not have any significant effect on lateral and tap roots of seedlings. Seed sources only also did not differ significantly at $P > 0.05$ with respect to lateral and tap roots of seedlings. Lateral roots were longest in the large sized polybags but it did differ significantly from roots from the smaller sized poly bags only. Tap root length followed the same trend as lateral root length (Table 5.7).

Table 5.7: Effect of polybag size on lateral root and tap root length

Poly bag size	Mean lateral root length (cm)	Mean tap root length (cm)
Small	27.88	14.94
Medium	41.28	18.96
Large	45.62	22.31
SE±	2.61	1.24
LSD (0.05)	7.38	3.51

5.5 Discussions

5.5.1 Effect of seed source on seed characteristics

Results from the study did not show significant effects of seed source on seed characteristics although seed source from Kpetoe appeared to perform significantly better than from the other seed sources. The significantly higher 100 seed weight recorded by this treatment may have been due to the fact that it was the last to be acquired within the two week period and probably had high moisture content than the rest. Variation in *J. curcas* seed sources with respect to their morphological traits could be due to the fact that the species grow over a wide range of climatic condition ranging from tropical rain forest to the savanna. The amount of rainfall and its distribution in these areas also vary widely in the country. Populations in these areas may therefore experience remarkable differences in environmental condition.

Since the seeds were collected from different areas, differences observed in the parameters studied could be genetic in nature or modified as a result of exposure and consequent adaptation to the different environmental conditions prevailing in their areas of collection. Vakshaya *et al.* (1992) stated that differences observed in phenotypic values are genetic in nature because randomization, replication and uniform environmental conditions must have dealt with any outside effects that might influence the evaluation. Seed length and seed width did not vary significantly between the seed sources. Even though Kpetoe had the highest 100 seed weight; its seed length and width were not significantly different from the other treatments. Seed weight was observed to have a positive correlation with seed length. This accounted for the highest value in seed length for Kpetoe. A negative correlation was, however, obtained between seed length and seed width.

Turnbull and Griffin (1986) have reported that different varieties and provenances often perform differently when tested together under one site.

5.5.2: Effect of seed source on germination and survival of *J. curcas*

The results of the present study did not indicate variability in *J. curcas* with respect to germination and seedling survival. Genetic variation is manifested through provenance test designed to assess the degree and pattern of variation across species. Seed source variation in germination percentage and related traits may be ascribed to the differences observed in seed dimensions and weight (Rawat *et al*., 2006). Dunlap and Barnett (1983) observed that germination values varied considerably among seed sources and exhibited a random pattern, in which an index of combining speed and completeness of germination is a function of seed size and weight.

It was expected that since a significant effect was obtained for seed weight this would be manifested in significant effect on germination. In this study seed sources did not significantly influence germination. The differences observed in seed weight in Kpetoe could be explained by the time it was acquired. Survival of seedlings is an important factor to consider immediately after planting. At this time, the seedlings are highly susceptible to rapid changes in relative humidity, temperatures and light levels (Biber and Caldwell, 2008). Since no significant difference was observed in the survival percentage of the *J. curcas* seedlings, it is presumed that there is not much variation between seed sources.

5.5.3: Interactive effect of seed source and polybag size on growth of seedlings

The different sizes of poly bag also showed significant effect on growth, dry weights of roots and shoots. These findings are similar to that of Annapurna *et al*. (2004) who reported that larger containers produced better growth of *Santalium album* seedlings. A similar relationship has been reported between container volume and seedling height and biomass in *Pinus contorta* (Endean and Carlson, 1975), and in *Grevillea robusta* (Misra and Jaiswal, 1993). Increased seedling growth of 72ï 360% was observed in *Picea glauca, P. banksiana* when container volume was tripled (Sutherland and Day, 1988). The primary function of any container is to hold a growing medium, which in turn provides water, air, mineral nutrients and physical support. The highest growth in the larger polybags may be due to the content of higher volume of rooting media which could influence the nutrient status of the media. Similar results were obtained for lateral root and tap root of *J. curcas*. Smaller polybag size had decreased lateral root and tap root. This may have profound effect on the survival of transplanted seedlings later under field conditions.

5.6 Conclusions

The study showed variation in *J. curcas* with respect to seed weight. Seed germination, survival, seed length and width were not significantly different for the various seed sources. Since most of the parameters measured did not show any variation between the seed sources, it can be concluded that there is no wide variation in *J. curcas* from the various seed sources.

Larger polybags recorded the best performance in growth and should be considered in raising seedlings at the nursery. Root length was highly influenced by the polybag size, with the larger polybag sizes out-performing the others. Seedlings raised in large polybags are more likely to survive on the field than those in small polybags. Poly bag size of 13 cm x 17.80 cm (medium) is recommended for growth of *J. curcas* seedlings since it did not differ significantly from poly bag size of 16 cm x 19.80 cm (large).

CHAPTER SIX

LITTER FALL AND DECOMPOSITION TREND OF LEAF BIOMASS OF *J. CURCAS* IN OPEN AND CLOSED CANOPIES

6.1 Introduction

Decomposition is an important part of all life cycles both in the terrestrial and aquatic environment. Litter fall and litter decomposition are two essential means by which the nutrient pool in terrestrial ecosystems is maintained (Karmas, 1970). After leaves fall they build up on the forest floor creating a layer of nutrients and litter on top of the soil. This layer is important for the food chain as it acts as food for many microscopic beings, but it is even more important since it acts as a way for recycling the nutrients back into the soil. As the leaves decompose, the nutrients are released back to the soil where they help to feed vegetation in the surrounding area.

A comprehensive knowledge of the organic matter decomposition and nutrient release patterns from leaf litter can help to maximize soil sustainability and crop productivity (Mugendi *et al*., 1999). Planting tree species with high biomass production and rich in foliar and branch nutrient content can therefore play a major role in maintaining levels of soil organic matter in alley cropping systems (Young, 1997). To achieve this, however, it is anticipated that large tracts of farmlands would be put into *J. curcas* L. plantations which is likely to be unsustainable. It is suggested that the integration of *J. curcas* and annual crops is likely to be accepted by farmers and will be sustainable.

The success of any agroforestry system depends on the decomposition of leaves. Therefore understanding litter fall, decomposition and nutrient release pattern of *J. curcas* could help in its incorporation into the agroforestry system to improve nutrient synchronization with associated crops.

6.2 Hypothesis and specific objectives

The hypothesis for this study was: the incorporation of *J. curcas* with annual crops would not be sustainable in terms of litter fall and nutrient release into the system

The objectives of the study were therefore to:

i. Determine the quantity of litter produced by *J. curcas* L. plantations at different plant spacings.

ii. Assess the trend in decomposition of *J. curcas* leaves in closed and open canopies

iii. Estimate the nutrients remaining in the decomposed leaf litter overtime.

6.3 Materials and Methods

6.3.1 Study area

The experiment was conducted at Ayakumaso in the Sunyani West District. Details of Ayakumasu are in section 3.2.1.

6.3.2 Weather condition during the study period

Monthly rainfall figures and temperatures recorded during the study period are presented in Figures 6.1 and 6.2, respectively. From July to October, 2008 rainfall was relatively high and ranged from 81.5-154.4 mm. From November 2008 to December 2008, rainfall figures were relatively low, and were 40 mm for both months (Figure 6.1). Temperatures of between 28.7 -30.5^{o}C were recorded from July to October, 2008. The months of November 2008 to December 2008 recorded 31.3 - 33.5 ^{o}C (Figure 6. 2).

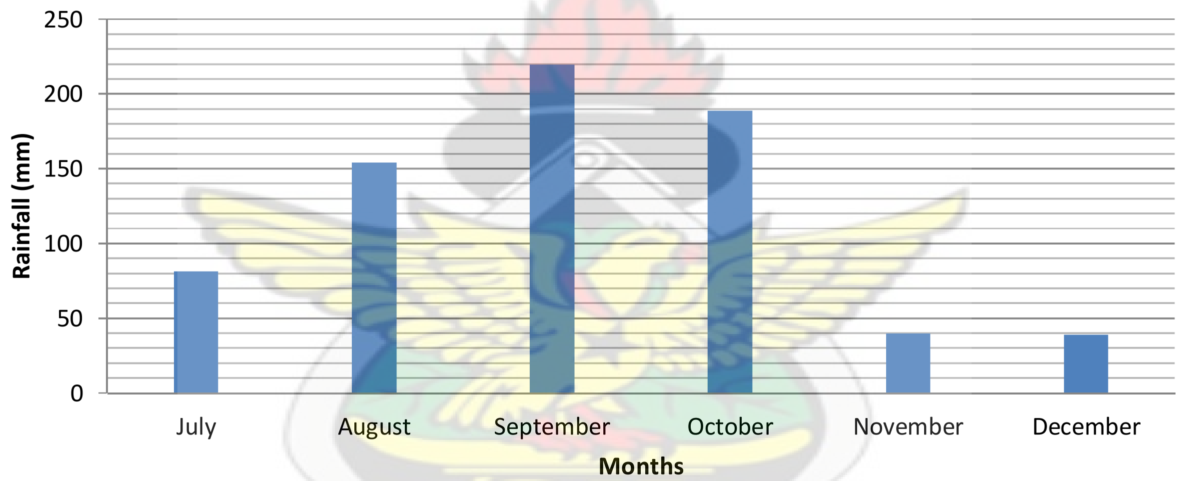

Figure 6.1 : Rainfall during the period of the experiment

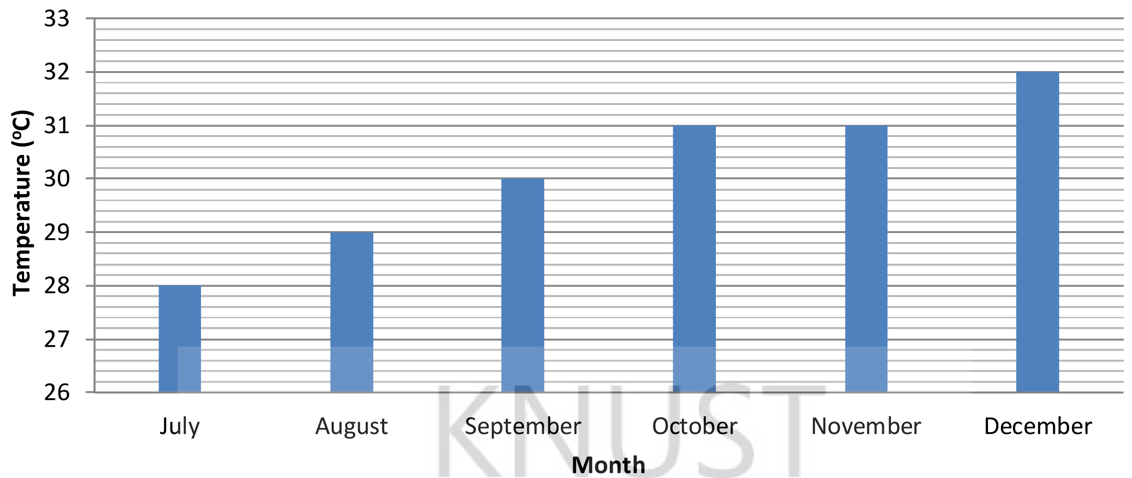

Figure 6.2: Temperature regime during the experiment

6.3.3 Methods

6.3.3.1: Litter collection from J. curcas

Litter collection was carried out from July 2008 to June 2009. This was from the plantation established for the spacing study. A total of fifteen (15) litter traps were placed for each treatment at various distances of 1 m x 1 m, 2 mx 1 m and 3 m x 1 m. Two milimetre nylon meshes size fitted to stakes fixed at 1 m x 1m in the ground were used as trap for litter. The traps were raised above the ground and placed beneath *J. curcas* canopies. Litter was collected every two weeks and dried in an oven at 65 ^{o}C for 72 hours. At the end of each month litter collected were added to get the litter fall for the month.

6.3.3.2: Decomposition of J. curcas litter

Decomposition of leaf litter of *J. curcas* was determined over a 5 month period from August, 2008 to December, 2008 under two different environments (closed canopy; 28 ^{o}C and open canopy; 30 ^{o}C). Freshly fallen (green) leaves of *J. curcas* were collected and placed in litter bags. Oven dry leaves were not used due to the risk of their rapid disintegration during the major rainfall, which may lead to accelerated rates of decomposition (Anderson and Ingram, 1993). Use of fresh leaves is also more representative of the natural decay process (Anderson and Ingram, 1993).

A total of 80 g of fresh *J. curcas* leaves were placed in 0.30 x 0.30 m nylon litter decomposition bags with a 2-mm mesh size. A total of 40 litter decomposition bags spaced 0.50 m apart were placed along a transect on the surface of the soil. The treatments were arranged in a Randomized Complete Block Design (RCBD) and replicated 4 times for closed canopy and open canopy.

At the time of placement of the litter decomposition bags, a set of leaves (4 replications) of *J. curcas* was collected to determine initial dry matter and moisture content (72 hrs at 65 ^{o}C). Samples of *J. curcas* leaves were also taken to the Soil Research Institute, Kumasi where the initial concentration of C, P, K, N, Ca and Mg were determined. The litter was oven- dried at 65 ^{o}C for 72 hours and then weighed. This material was ground in an electric mill and stored in air-tight containers at room temperature. Carbon was determined by LECO carbon analyzer. Total Nitrogen by the Kjeldahl method while Ca and Mg were estimated using the EDTA titration method. Potassium was estimated using the Atomic Absorption Spectrophotometer.

A total of 8 litter decomposition bags were collected on days 30, 60, 90, 120 and 150 for opened and closed canopies. On each of these dates, litter decomposition bag contents were carefully examined and all foreign materials including soil particles and leaves from weeds were removed. Soil was removed by brushing and briefly rinsing the leaves with distilled water. The remaining residue was dried for 72 hours at 65 ^{o}C. Dried leaves were weighed and recorded as residue remaining and expressed as a percent residue remaining of the initial dry matter weight.

6.4 Data analysis

The percentage of leaf litter remaining was obtained through calculation using the relation:

$\% LR = \frac{L_t}{L_o} \times 100$ Where,

LR = is the percentage of leaf litter remaining

Lt = is the amount of leaf liitter at each sampling time

Lo = is the initial weight of leaf litter

The method used is the same as that used by Anderson and Ingram (1993) in their decomposition experiment.

The samples in the litter bags were also analyzed at monthly intervals for the first four months for C, N, P, K, Mg and Ca to show the nutrient release pattern from decaying litter. Samples in the fifth month were so negligible and could not be sent to the laboratory for analysis.

Half-life of the species was calculated using the following formula;

$$T1/2 = T \log 2 / \log (L_o / L_t)$$

Where $T_{1/2}$ is the half-life of the species

T is the Elapsed Time

Amt B is the Beginning Amount

Amt E is the Ending Amount

The decay constant (k) was estimated by fitting the mass loss to single negative exponential models (Robertson and Paul, 2000) using the function $X_t = X_0e^{-kt}$, where X_t is the remaining litter weight at time t, X_0 is the initial litter weight, e is the natural logarithmic constant, k is the decay rate constant, and t is the time in days.

6.5 Results

6.5.1 Litter fall of *J. curcas* at different plant spacing

The total quantity of litter produced in a year at the three different spacings were 2.27 tons/ha, 1.10 tons/ha and 0.79 tons/ha for the 1 m x 1m, 2 m x 1m and 3 m x 1 m, spacings respectively. *J. curcas* exhibited two peaks of litter fall during the year (Fig. 6.3). The month of November had the highest litter fall for all the treatments. The highest litter fall of (508.8 kg/ha, 170.9 kg/ha and 151 kg /ha) were obtained from 1 m x 1 m, 2 m x 1 m and 3 m x 1 m respectively (Fig. 6.3). The second peak of litter fall in July followed a similar trend to the November results with 1 m x 1 m recording the highest value (Fig. 6.3).

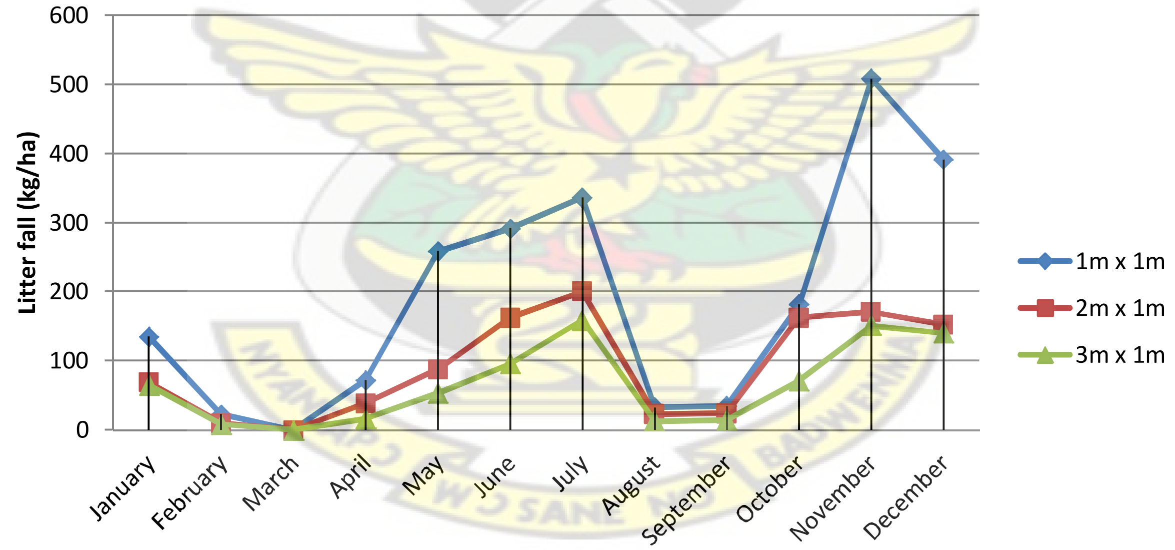

Fig. 6.3: Litter fall of *J. curcas* at different plant spacing in 2008

6.5.2: Initial dry matter, moisture content, lignin and tannin levels of *J. curcas* leaves

The initial composition of the *J. curcas* leaves were as follows:

Fresh weight: 80 g

Dry matter weight: 14.7g.

Dry matter (%): 18.38

Moisture content (%): 81.62

% lignin: 12.03

% Tannin: 2.90

6.5.3: Litter decomposition patterns of *J. curcas*

The results obtained for the opened and closed canopies revealed a significant loss of mass over time, which differed significantly between the treatments ($P < 0.05$). Remnant litter mass was significantly smaller under open canopy than closed canopy.

The lowest residual litter mass recorded from the open canopy, was significantly lower than that of the plant under closed canopy. It had 97-99% of the leaf litter decomposing at the end of the experimental period of five months (Figure 6.4). The initial 30 days saw a rapid decomposition of leaf litter. Subsequently, there was a gradual decline with time (Figure 6.4). Within the first 30 days leaf litter decreased by 52.4% and 57.8% in closed and open canopy respectively. These were more than half the initial leaf litter. The decomposition constant (k) for both open and closed canopy within the first 30 days were 0.024 and 0.029, respectively (Table 6.1). The regression analysis in figure 6.5 showed a coefficient of determination (R^2) to be 0.841 which implied that 84.1% of the variation in percentage leaf litter remaining could be explained by the closed canopy. Also 78.2% of the variation in percentage of leaf litter remaining could be explained by the open canopy (Fig. 6.6). On the contrary, rainfall had a weak relationship with the percentage of leaf litter remaining (Fig. 6.8). Temperature had a strong relation with the percentage ofleaf litter remaining (Figure 6.7).

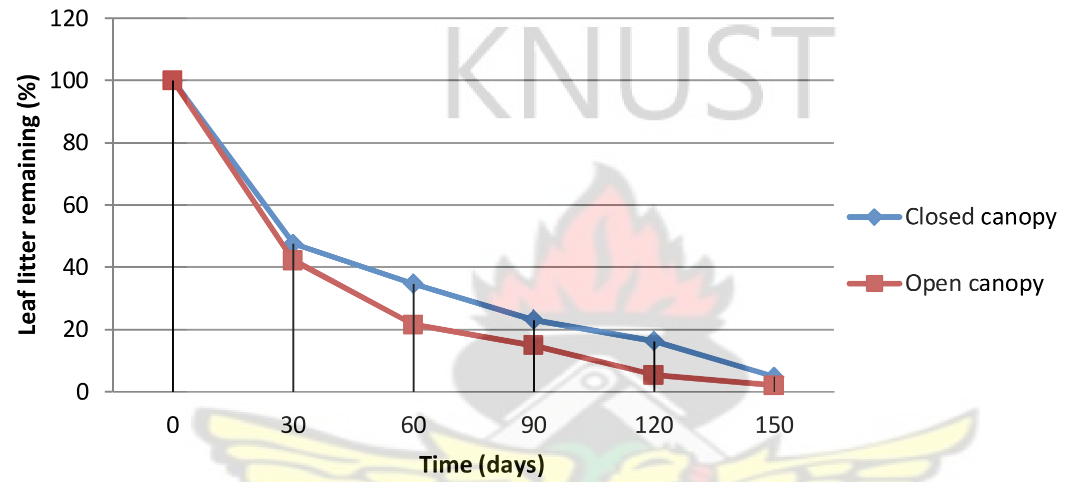

Figure 6.4: Trend of leaf litter decomposition of J. curcas

Table 6.1: Decomposition constant (k) of *J. curcas* leaf litter in open and closed canopies

Time (days)	open canopy	Closed canopy
30	0.024	0.029
60	0.017	0.025
90	0.016	0,021
120	0.015	0.024
150	0.020	0.026

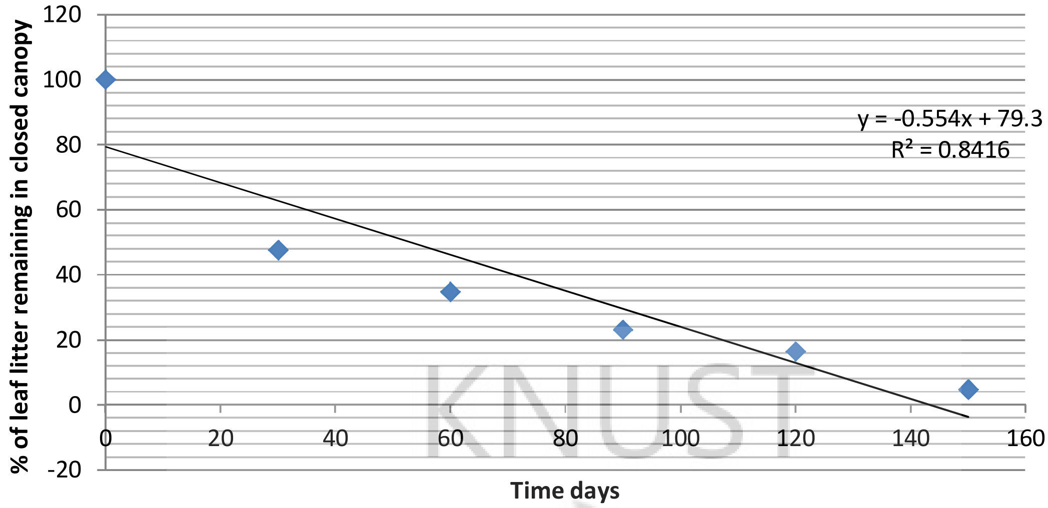

Figure 6.5: Regression analysis showing percentage leaf litter remaining in closed canopy at different sampling period

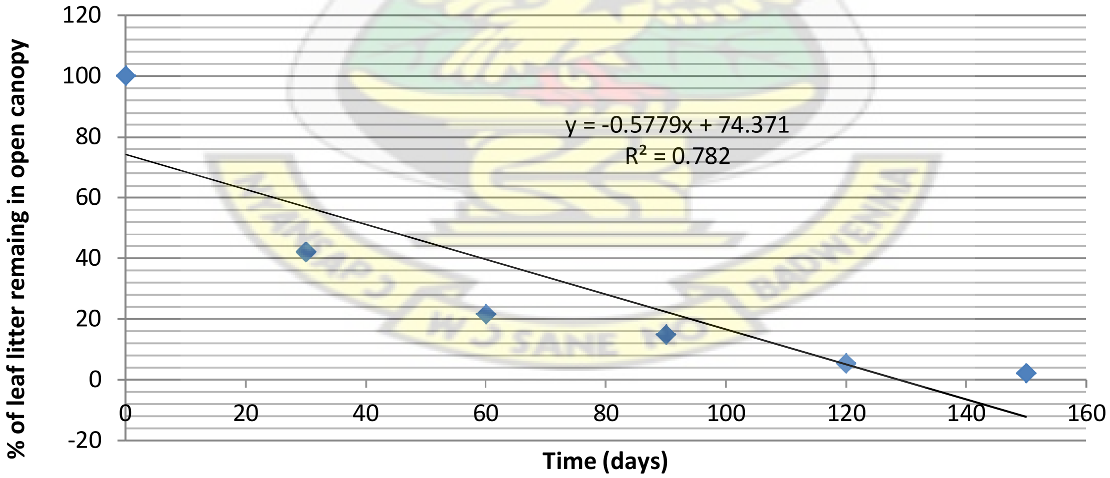

Figure 6.6: Regression analysis showing percentage leaf litter remaining in open canopy at different sampling period

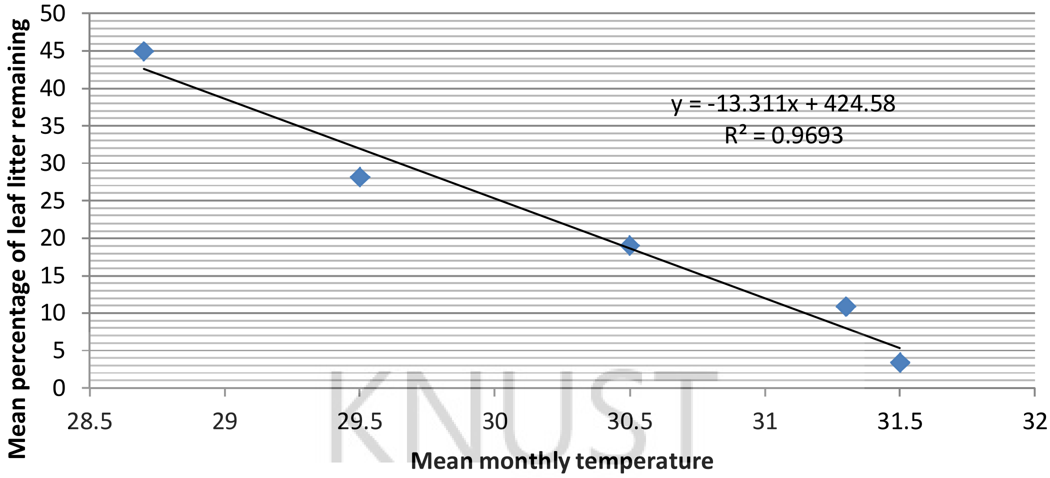

Figure 6.7 Regression analysis of mean monthly temperature and leaf litter remaining

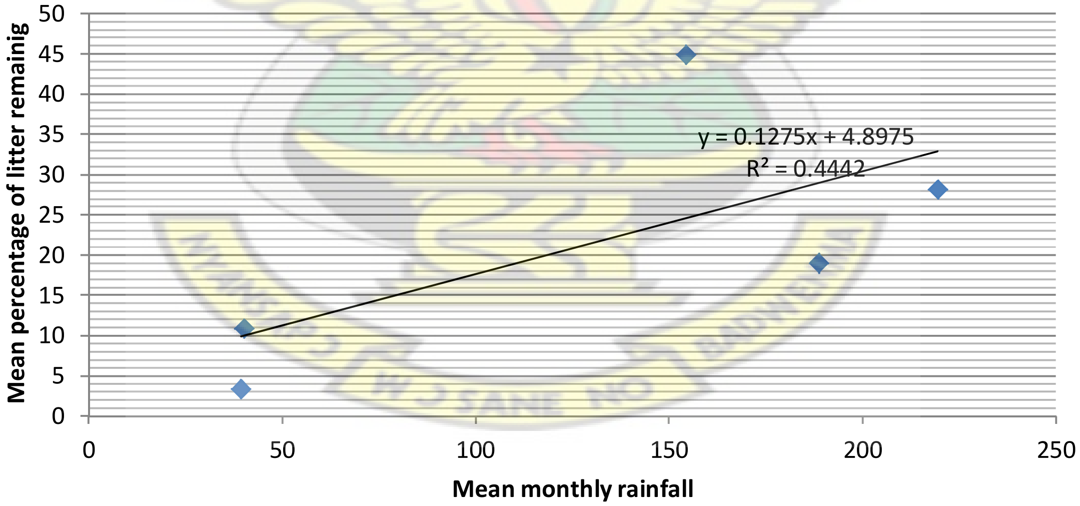

Figure 6.8 Regression analysis of mean monthly rainfall and leaf litter remaining

A negative correlation (r) of -0.98 was obtained between temperature and leaf litter remaining. On the otherhand, a positive correlation of 0.66 was recorded between rainfall and residual leaf litter.

6.5.4 Half-life and Decomposition constant of *J. curcas* leaf litter

From Table 6.2, the half-life of decaying leaves of *J. curcas* was 25 days in open canopy and 32 days in closed canopy. The decomposition constant for open and closed caopies were 0.020 and 0.0154 for bare soil and shade, respectively (Table 6.2).

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Table 6.2: Half-life of *J. curcas* leaf litter under open and closed canopy

Species	Area	Decomposition constant (k)	Half –life (days)
J. curcas	Open canopy	0.020	25
J. curcas	Closed canopy	0.0154	32

6.5.5 Nutrient dynamics in decomposed litter

Ca, Mg, P, K, N and C contents in the residual undecomposed leaf varied under the different environmental conditions. A higher proportion of the nutrients remained under closed than in open canopy. Ca, Mg, and K levels under the two environmental conditions declined with time. A pattern of an increase followed by a decrease was noticed for phosphorus under the closed canopy while it decreased gradually throughout the period for the open canopy except at 30 and 60 days. A decline in the percentage carbon was observed for both closed and open canopy (Table 6.3). The C/N ratio generally increased under the open canopy while it decreased under the closed canopy (Table 6.3). In the closed canopy, a similar trend to C/N ratio was observed for the C/P ratio (Table 6.3). The percentage of calcium remaining in residual litter increased at 30 days and then declined thereafter for both treatments until 90 days (Fig. 6.9). Magnesium exhibited a different pattern in open canopy. The percentage of magnesium remaining in the leaf litter had increased by 147% by 60 days but declined sharply thereafter till 90 days in the open canopy while it decreased gradually in the closed canopy through out the experimental period. Potassium in litter remaining for both open and closed canopies were similar and followed the same pattern through the period (Fig. 6.11).

Table 6.3: Concentration of C, N, and P in residual leaf litter of *J. curcas* in open and closed canopies

Time (days)	P%		C%		N%		C/N		C/P	
	Cl	Op	Cl	Op	Cl	Op	Cl	Op	Cl	Op
0	0.15	0.15	42.29	42.29	2.53	2.53	16.72	16.72	282	282
30	0.29	0.32	14.91	23.81	1.26	1.02	11.83	23.34	51.41	74.4
60	0.06	0.19	16.33	16.49	1.51	1.23	10.81	13.41	271.1	86.79
90	0.23	0.06	2.55	31.50	0.35	1.32	7.28	23.36	11.09	525
120	0.13	0.03	2.45	34.6	0.26	1.32	9.43	26.21	18.8	1153
LSD(0.05)	0.001	0.001	0.17	0.019	0.14	0.19	0.19	0.19	0.20	0.19

Op = Opened canopy Cl = Closed canopy

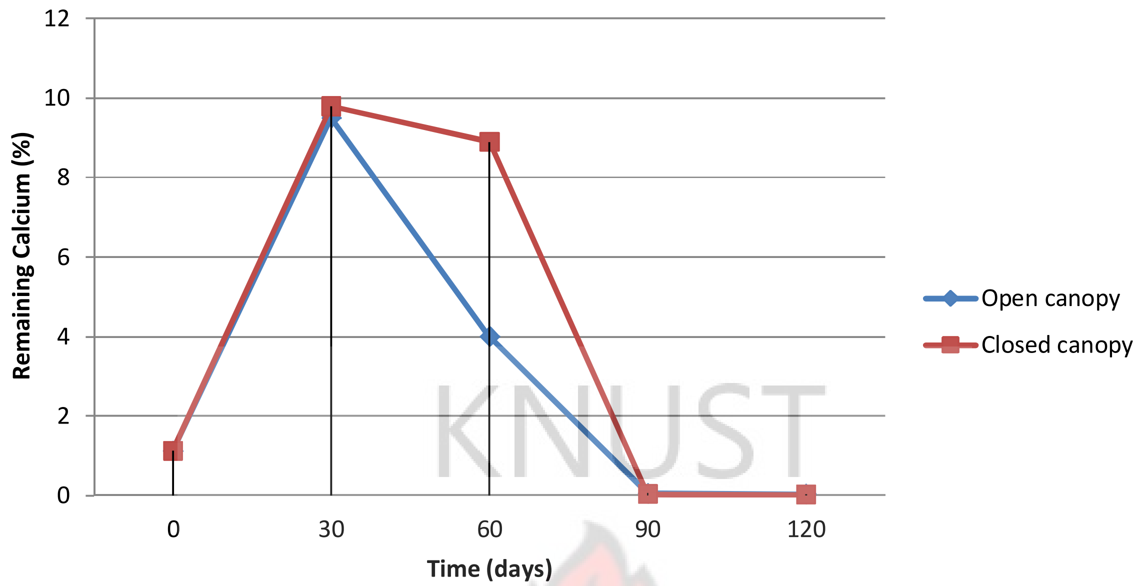

Figure 6.9 : Concentration of Calcium (Ca) in residual litter

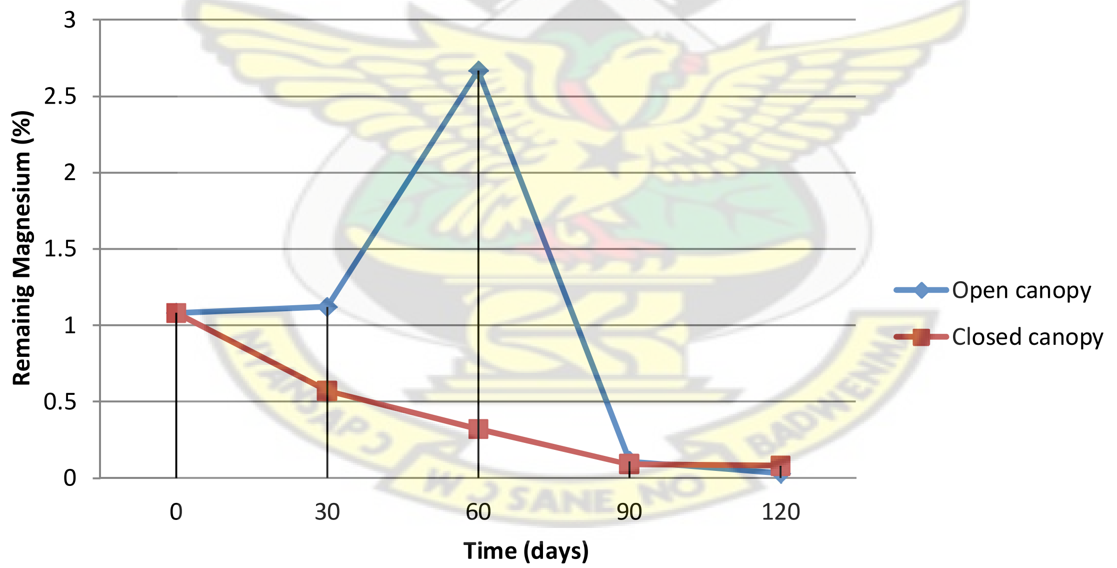

Figure 6.10. : Concentration of Magnesium (Mg) in residual litter

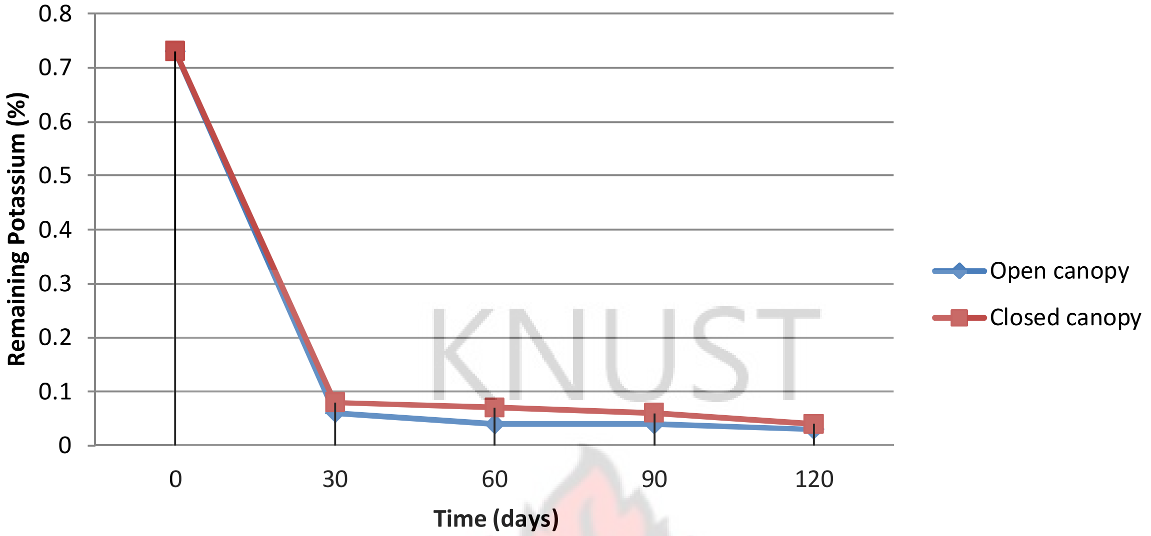

Figure 6.11 : Concentration of potassium (K) in residual litter

6.6 Discussions

6.6.1 Litter fall of *J. curcas*

Maximum litter fall occurred in the dry season. This characteristic of the plant shedding its leaves greatly reduced soil moisture extraction thereby, reducing competition with crops for water and nutrients during the period. The highest litter fall recorded in November is similar to that reported by Jamaludheen and Kumar (1999) and Isaac and Nair (2006) in which litter fall was associated with natural senescence of leaves induced by temperature and/or moisture. The high litter production during this dry period will ensure good soil cover and protection from excessive heat as well as maintaining nutrient cycling as highlighted by Montagnini *et al*. (1993). The total quantity of litter produced in a year at different spacing were 2.27 ton/ha, 1.10 tons/ha and 0.79 ton/ha for 1 m x 1m, 2 m x 1m and 3 m x 1 m, respectively. This quantity of litter fall was generally low compared to results obtained by Beer (1988) who reported annual litter fall rates of 2.9 ï 3.3 tons/ha for *Cordia alliodora*, 6.9 tons/ha for *Inga jinicuil* and 5.3 ton/ha for *Inga leptoloba*, all grown as shade trees for crops in humid tropical regions of Latin America at comparable densities of 185 ï 278 trees/ha. The synchronization of litter fall with annual crops in agroforestry associations would be essential to ensure the productivity of the system.

6.6.2 Pattern of leaf litter decomposition of *J. curcas* in closed and open areas.

The direct exposure of leaf litter to radiation exerted a significant effect on the decomposition processes in open areas. Open canopy always had the highest litter-mass losses and faster leaf-litter decay compared to those recorded in closed canopy. The results obtained suggest that direct exposure of leaf litter to solar radiation is important in the decomposition processes. Solar radiation in open canopy dehydrated plant material faster facilitating its mechanical destruction. This confirms the findings of Wagner (1998) that physical factors such as temperature influence decomposition. Like all living things, bacteria and other decomposers have an optimal operating temperature (25 ^{o}C ï 30 ^{o}C). Far below this temperature, decomposition will be slow because bacteria and other decomposers have a greatly lowered metabolism or cannot survive and die (Wagner, 1998). Botkin (1993) also stated that a hot area may have faster rates of decomposition. Normally the warmer it is the more bacteria will thrive. Similar results have been obtained in other experiments. Laura and Yolanda (2007) in an experiment on spatial variability in decomposition rates in a desert scrub of Northwestern Mexico found that leaf litter exposed to solar radiation decomposed faster than to those under the canopy of nursed trees.

It was also observed that leaf litter decayed faster during the wet period than during the dry period. Differences in water availability determined differences in decomposition trends and patterns of litter-mass losses. From August to October where the amount of rainfall was high, decomposition of leaf litter under open canopy was higher than under closed canopy (Figure 6.4). From November to January 2009 decomposition trends of *J. curcas* was slow under open canopy with those under closed canopy having slightly higher decomposition trends. This suggests that moisture plays a key role in decomposition rates. The wetter the soil the faster the decomposition of materials (Goulden, 2005). Water is typically a limiting factor for many of the organisms that affect decomposition. When the amount of water becomes too much however, decomposition rate slows down as was experienced under the canopy of trees during the wet period.

Rapid loss in weight during the first month of decomposition could be the result of microbial utilization of highly labile compounds of the substrate, such as non-structural carbohydrates. When these are depleted the rate of litter mass loss is also decreased (McClaugherty and Berg, 1987). In field studies Prescott *et al*. (1993) reported that the labile fraction of litter was rapidly metabolized by microorganisms or lost through leaching. Parson *et al*. (1990), however, explained that although some of the labile material may be water soluble, microorganism metabolism rather than leaching is responsible for the greatest part of mass loss. Reinerstsen *et al*. (1984) associated the more rapid decay immediately after residue burial with the decomposition of water-soluble organic contents while Hunt *et al*. (1988) explained the differences in decomposition pattern and rates among substrate are related to the amount of labile or rapid decomposing fractions (sugars, starches, proteins) and the recalcitrant or slowly decomposing fraction (cellulose, lignin, fats, tannins and waxes) present in the substrate. The rapid decomposition was due to lignin content (12.03%) of *J. curcas* litter. Lignin is a low quality substrate for decomposers thereby reducing their degradation. A threshold level of 150 g kg^{-1} lignin has been suggested above which decomposition is impaired (Mafongoya *et al.*, 1998).

6.6.3 Nutrient dynamics in decomposing litter

Different nutrients in decomposing litter have different pattern of release overtime and are retained with different strengths in litter structures (Girisha *et al*., 2003). One mechanism for this according to Rutigliano *et al*. (1998) is microbial immobilization. The nutrients that are limiting or non-limiting to microbial growth, determine their release dynamics. The nutrients which are limiting in amounts under conditions where Carbon:Element ratio is above the critical level will be retained resulting in immobilization, whereas elements in surplus where the Carbon:Element ratio is below the critical limit will be released during decomposition (Berg and Staff, 1981).

Nutrient dynamics of decomposing leaf litter showed nutrient contents of some materials in the residual litter to decline relative to the weight of litter. Potassium (K) released in both open and closed canopies were rapid. In the case of open canopy almost 92% was lost in the first 30 days. Potassium in plants occurs mainly in soluble ionic form (Tukey, 1970). It can therefore be easily leached from litter and losses may be accelerated by high rainfall. The release pattern observed in this study agrees with the review on potassium dynamics of decaying litter given by Stohlgren (1988); Toky and Singh (1993).

Phosphorus (P) concentration in decomposing leaf litter was irregular in both open canopy and closed canopy. Phosphorus was immobilized in litter during the first 30 days and mineralization occurred at 60 days. This resulted in an initial higher phosphorus concentration at 30 days followed by a decrease at 60 days. In decaying leaf litter, phosphorus may increase or decrease, the former being attributed to microbial immobilization (Bockheim *et al*. 1991). The factors known to control phosphorus availability patterns of organic inputs are total P, C:P ratios and N:P ratios (Vogt *et al*., 1986), which are highly variable in terms of the critical levels. Net mineralization ratio of P from organic matter usually begins at C:P ratios < 200 (Schlesinger, 1997). In the case of this study, C:P ratio was less than 200 except at 120 days (Table 6.3). This is probably due to phosphorus immobilization as a result of low initial P concentrations in plant residues as reported by Budelman (1988).

An initial decline in nitrogen (N) within the first 30 days was observed under both opened and closed canopies, which means a release of nitrogen into the soil. Nitrogen was immobilized at 60 days and declined afterwards. Nutrients such as nitrogen which are often limiting to microbial growth are immobilized when carbon supply is plentiful and nutrient concentrations are low and mineralized when carbon content decreases and nutrient concentration increases (O'Connell, 1988).

The pattern of magnesium (Mg) release from the litter material was different for open and closed canopies. Under open canopy, Mg had been immobilized by 60 days. The pattern of nutrient loss under closed canopy was however gradual. This indicates a complex interplay of different processes during the decomposition. The amount of nutrients released depends on the intrinsic material quality and amount of organic materials in the mulch (Cattanio *et al*., 2008).

Calcium (Ca) was immobilized at 30 days during the period of the study. Subsequently calcium was released into the soil. The period of immobilization was probably due to the luxury uptake of calcium as reported by Swift *et al*. (1979).

6.6.4 C:N ratio and decomposition of *J. curcas* leaf litter

The high decomposition rate obtained for *J. curcas* leaf litter is probably due to the relatively low C/N value (Table 6.3). Generally, organic matter with a low C to N ratio will decompose faster than a material with a high C:N ratio. Nitrogen is normally the limiting factor for many of the organisms. With a higher amount of nitrogen (a low C: N ratio) these populations grow rapidly and to higher concentrations, because of nutrient cycling through the decomposing leaves (Knops, 2003).

Decaying plant tissue has varying amounts of cellulose, lignin, and hemicellulose, all high sources of Carbon. Carbon is the primary food for microbes, providing energy for their life processes. As dead plant material is introduced to the soil surface, microbes begin the degradation process using available nitrogen to break down the carbon for food and releasing CO_2 and NH_4 as by-products. The microbes ingest nutrients and additional carbon and nitrogen through immobilization. The lower the ratio, the more nitrogen is available and the quicker the decomposition and mineralization. A ratio of 15:1 or higher may not have enough nitrogen available. This forces the microbes to pull in inorganic nitrogen from the soil, slowing mineralization down. Any ratio over 30:1 is considered extremely high and can result in some soil nitrogen deficiencies. The microbes, which tend to be more competitive than the plant, will completely exhaust the nitrogen resources in the soil. Depending on the C:N ratio, this could go on for a considerable length of time (Brady, 1990). Similar results have been obtained in several studies. In an experiment on the decomposition of *Erythrina peoppigiana* leaves in alleycropping systems in Costa Rica, Oelbermann *et al* (2004) found the decomposition rate of the species to be high due to its low C/N ratio.

K-value is primarily controlled by climate and litter quality. Higher k-values correspond to faster rates of decomposition, while lower values correspond to slower rates of decomposition. K-value is a function of temperature and moisture. Climates that are warm and wet have increased k-values. It is for this reason that the open canopy had a higher k-value and lower half life. Half life is influenced by the percentage lignin in the *J. curcas* leaves.

6.7 Conclusions

Litter production and decomposition are important pathways of biogeochemical nutrient cycling in agroforestry. The results of the study have contributed to our understanding of the litter dynamics of *J. curcas* in our agroforestry development activities. The total quantity of litter produced in a year at different spacing were 2.27 ton/ha, 1.10 tons/ha and 0.79 tons/ha for 1 m x 1m, 2 m x 1m and 3 m x 1 m, respectively. Decomposition trends were higher under open canopy and during the wet period than under closed canopy of trees. Leaf litter of *J. curcas* was reincorporated faster into the soil. It had 97 - 99% of the leaf litter decomposing at the end of the experimental period. Litter decomposition and nutrient release pattern of *J. curcas* was variable. Nutrients were immobilized when their concentration in leaf litter was low. The high decomposition rate of litter of the plant could be due to a low C:N ratio. Based on the results obtained *J. curcas* leaves could be an important source of nutrients.

CHAPTER SEVEN

EVALUATION OF THE ALLELOPATHIC EFFECT OF AQUEOUS EXTRACT OF *J. CURCAS* ON GERMINATION, RADICLE AND PLUMULE LENGTH OF CROPS

7.1 Introduction

J. curcas has been found to be a highly promising biofuel species since it is not used for human consumption. It has a short gestation period, hardy and high quality oil. The *J. curcas* oil is close to cottonseed and better than rapeseed, groundnut and sunflower (Gubitz *et al*., 1997), and gives no pollution when burnt. The absence of sulphur dioxide (SO2) in the exhaust from diesel engines run on *J. curcas* oil shows that the oil may have less adverse impact on the environment (Kandpal and Madan, 1995). Growing crops for biofuels is often critized because of the direct competition of land for food production. The recent price increases on world food markets are partly a result of this competition (Müller, 2008).

Agroforestry, which involves combining woody plants with annual or perennial crops or livestock, increases the biophysical and/or socioeconomic productivity of an agricultural enterprise (Bentley, 1985). It is suggested that the use of *J. curcas* in alleycropping could help reduce this scarcity of food. The failure of most crops in an agroforestry system has been attributed to an allelopathic effect of the tree species. This phenomenon is as a result of phyto-chemicals exuded by trees. These chemicals are largely classified as secondary metabolites (such as alkaloids, isoprenoids, phenolics, flavonoids, terpanoids and gluconolates) (Nazir *et al*., 2007). Swaminathan *et al.* (1989) reported that the potential compounds which are able to induce inhibitory effect on germination are identified as phenolic acids. The release of phenolic compounds adversely affect the germination and growth of plants through their interference in energy metabolism, cell division, mineral uptake and biosynthetic processes (Rice, 1984). Since *J. curcas* stem extracts contain phytochemicals like saponins, tannins, glycosides, alkaloids and flavonoids (Akinpelu, 2009; Igbinosa, 2009) of phenolic nature, the present study was carried to find allelopathic effects if any, from aqueous extract of *J. curcas* roots and leaves on some crops. This would enable us to establish *J. curcas* as a good intercrop in agroforestry system.

Studies with other species have reported that the response to allelochemicals may be concentration dependent (Ashrafi *et al*., 2008). Allelochemicals that inhibit the growth of some species at certain concentrations might stimulate the growth of the same or different species at different concentrations (Narwal, 1994). It is therefore necessary to identify concentration at which aqueous extracts of *J. curcas* would affect the germination and growth of crops.

7.2 Objecctives

The study was carried to:

1. Determine the effect of aqueous extract of *J. curcas* roots and leaves on germination and growth of some arable crops.
2. Identify the concentration at which aqueous extract of *J. curcas* would affect the germination and growth of the crops.

7.3 Materials and Methods

7.3.1: Study area

The experiment was carried out in a laboratory at the Forestry Research Institute of Ghana. The temperature condition during the period of the experiment was 28 ^{o}C.

7.3.2: Experimental procedure

Fresh leaves and roots of a seven year old *J. curcas* were collected from the Fiapre community (latitude $7^{o}21'40''$N and longitude $2^{o}20'50''$W) of Ghana and dried for a week. Aqueous extracts were prepared separately from dried leaves and roots. Ten (10) grams of the powdered sample from the leaves was added to 100 ml distilled water, shaken and left for 48 hours at room temperature (20 - 30°C). The extract was filtered through three layers of Whatman No. 1 filter paper and stored for use. The extract was considered as stock solution and diluted to different strengths (2%, 4%, 6%, 8% and 10%). The procedure was repeated for the preparation of root extract.

7.3.3 Laboratory bioassay

The procedure adopted is similar to that of Nazir *et al.*, (2007) and Maharjan *et al*. (2007). Seeds of *Phaseolus vulgaris* (Beans), *Zea mays* (Maize), *Lycopersicon lycopersicum* (Tomato) *and Abelmoschus esculentus* (Okra) were spread in sterilized petri-dishes lined with two layers of Whatman no. 1 filter paper (Plate 7.1). Each seed type in petri-dishes were saturated with 5 ml of extract corresponding to the different concentrations of *J. curcas* leaves (L) and roots (R) extract at (2%, 4%, 6%, 8% and 10%). Each treatment was replicated four times for each seed type. The total number of seeds tested varied with crop. For maize, (10 seeds x 4 replicates = 40 seeds), tomato (20 seeds x 4 replicates = 80 seeds), beans (15 seeds x 4 replicates = 60 seeds) and okra (10 seeds in four (4) replicates = 40 seeds). The petri dishes were kept under room temperature for one week. Moisture in the petri dishes was maintained by adding 1ml of the respective extracts water when necessary. Germination of seeds was counted after one week and radicle and plumule growth measured on the 7th day.

Plate 7.1: Allelopathy experiment conducted in the laboratory

7.4 Results

7.4.1: Effect of *J. curcas* leaves and root extract on germination of crops

The study revealed a significant effect ($P < 0.05$) of *J. curcas* leaf and root extract on the germination of crops. Lower concentrations of the extract from both leaves and roots seemed to promote germination of *P. vulgaris*. However, higher concentrations of the extract from the roots (R6% to R10%) and leaves (L6% to 10%) reduced the germination of *P. vulgaris*. No significant differences were observed between the control and the other treatments except for R8%, R10%, L8% and L10% (Table 7.1).

In *Z. mays* significant differences ($P < 0.05$) were observed between the treatments. Although a slight increase in germination with respect to the control was observed at L4%, L6%, L8%, L10%, R2%, R4% and R6% there was no significant difference between these treatments (Table 7.1).

In *L. lycopersicum* germination was influenced differently by the various concentrations of leaves and roots extracts of *J. curcas*. At L2% concentration, germination increased but did not differ significantly compared to the control (Table 7.1). Germination was lowest at R10% and it differed significantly from the control. L2%, L4%, L6% were not significantly different compared to the control.

With respect to *A. esculentus,* however, germination of seeds from the other treatments were significantly ($P < 0.05$) lower than the control. The highest reduction in germination of 97.92% was attained at L10% (Table 7.1). The coefficient of determination (R^2) of 0.96 obtained between germination percentage and concentration of leaf extract showed that 96% of variation in germination of the test crops could be explained by the concentration of leaf extracts (Figure

7.1). The root extract also showed that 98% of variation in germination of the test crops could be explained by the concentration of root extracts (R^2 = 0.986) (Figure 7.2).

Table 7.1: Effect of leaf and root extracts of *J. curcas* on the germination of crops

Treatments	***Phaseolus vulgaris* (%)**	***Zea mais* (%)**	***Lycopersicon lycopersicum* (%)**	***Abelmoschus esculentus* (%)**
Control	86.62 ^{ab}	95.00 ^{ab}	87.50 ^{bc}	79.95 ^{d}
L2%	93.33 ^{b}	95.00 ^{ab}	93.75 ^{c}	33.30 ^{bc}
	(+7.74)	(0)	(+7.14)	(-58.34)
L4%	84.97 ^{ab}	97.50 ^{ab}	86.25 ^{bc}	26.60 ^{abc}
	(-1.90)	(+2.63)	(-1.42)	(-66.72)
L6%	84.97 ^{ab}	100.00 ^{b}	80.00 ^{abc}	26.65 ^{abc}
	(-1.88)	(+5.26)	(-8.57)	(-66.66)
L8%	73.30 ^{a}	100.00 ^{b}	75.00 ^{ab}	11.64 ^{ab}
	(-15.37)	(+5.26)	(-14.28)	(85.44)
L10%	73.30 ^{a}	100.00 ^{b}	75.00 ^{ab}	1.66 ^{a}
	(-15.37)	(+5.26)	(-14.28)	(-97.92)
R2%	89.97 ^{ab}	100.00 ^{b}	86.25 ^{bc}	41.62 ^{c}
	(+3.86)	(+5.26)	(-1.42)	(-47.94)
R4%	88.30 ^{ab}	97.50 ^{ab}	87.50 ^{bc}	33.30 ^{bc}
	(+1.93)	(+2.63)	(0)	(-58.34)
R6%	84.95 ^{ab}	97.50 ^{ab}	73.75 ^{ab}	29.97 ^{bc}
	(-1.92)	(+2.63)	(-15.71)	(-62.51)
R8%	81.62 ^{ab}	90.00 ^{a}	73.75 ^{ab}	19.98 ^{abc}
	(-5.77)	(-5.26)	(-15.71)	(-75.00)
R10%	73.27 ^{a}	95.00 ^{ab}	66.25 ^{a}	16.65 ^{abc}
	(-15.41)	(0)	(-24.28)	(-79.17)
SED	7.84	3.385	6.55	11.82
C.V. (%)	13.2	4.9	11.2	50

R = Roots and L = Leaves

Values with similar letter(s) within a column are not significantly different at P = 5% by Duncan's Multiple Range Test (DMRT).

**The data in parenthesis indicate % reduction (-) or increase (+) over control.*

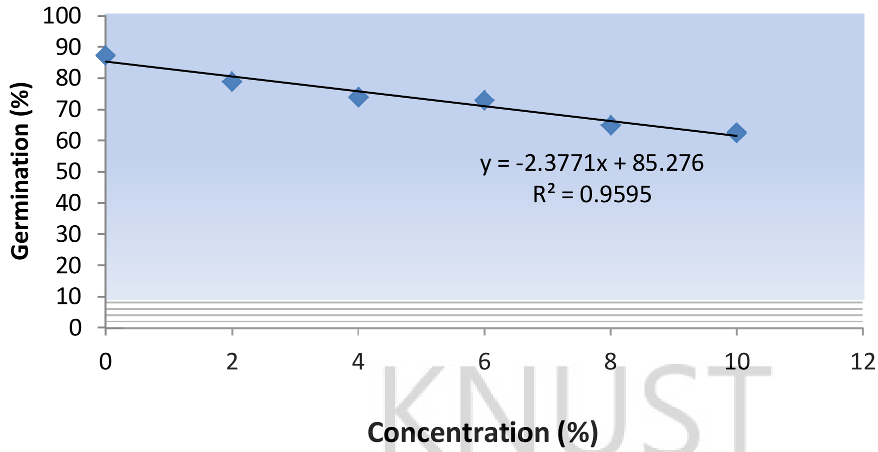

Figure 7.1: Regression analysis of variation in seed germination of all test crops with concentration of leaf aqueous extracts of J. curcas

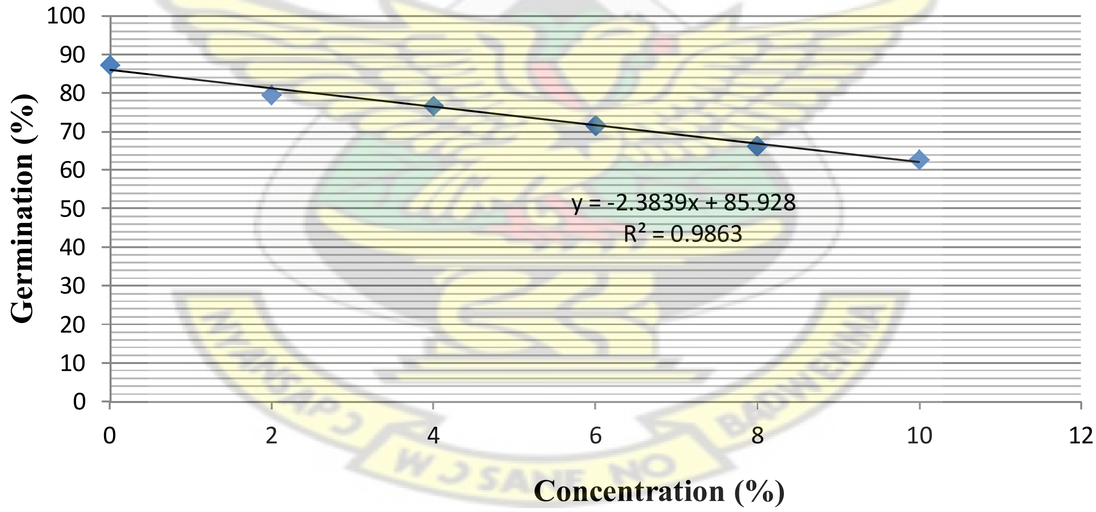

Figure 7.2: Regression analysis of seed germination of all test crops with concentration of root aqueous extracts of J. curcas

7.4.2: Effect of *J. curcas* leaves and roots extract on radicle length of crops

The lowest radicle length of *P. vulgaris* was at L10% and did not differ significantly from the L8% and L6% treatments but differed significantly from the others. The highest radicle length was realized at R8%. No significant differences were ($P > 0.05$) obtained between R8%, R6% and R10% compared to that of the control (Table 7.2). At R2% concentration of *J. curcas* aqueous extract, radicle length of *Z. mays* did not differ from the control. The lowest radicle length was obtained at higher concentration of the extracts (Table 7.2).

In *L. lycopersicum*, the highest inhibitory effect on radicle length was at L10% but this was not significantly different from that of L8% and L6%. Also the R10% and L4% treatments did not differ significantly in radicle length. All the other treatments were significantly lower than that of the control. None of the treatments showed a stimulatory effect (Table 7.2).

With respect to *A. esculentus*, radicle length was significantly lower in all the treatments compared to the control. The lowest radicle length or highest inhibitory effect was at L10%. This treatment however, did not differ significantly from L8%, L6% and L4%. Also, L4%, R8%, L2%, R10%, R6% and R2% did not differ from each other (Table 7.2). The regression analysis showed a coefficient of determination (R^2) to be 0.77. This implies that 77% of the variation in radicle length of the test crops could be explained by the concentration of leaf extracts (Figure 7.3). The coefficient of determination (R^2) in radicle length and concentration of root extract was 0.94 (Figure 7.4).

Table 7.2: Effect of leaf and root extracts of *J. curcas* on radicle length of crops

Treatments	*Phaseolus vulgaris* (cm)	*Zea mais* (cm)	*Lycopersicon lycopersicum* (cm)	*Abelmoschus esculentus* (cm)
Control	6.11^{efg}	15.12^{f}	8.14^{e}	2.65
L2%	4.74^{cd}	11.79^{de}	5.38^{d}	1.16^{bcde}
	(-22.42)	(-22.02)	(-33.90)	(-56.22)
L4%	3.99^{bc}	11.40^{de}	2.46^{b}	0.82^{abcd}
	(-34.69)	(-24.60)	(-69.77)	(-69.05)
L6%	3.12^{ab}	9.09^{cd}	1.18^{a}	0.68^{abc}
	(-48.94)	(-39.88)	(-85.50)	(-74.33)
L8%	2.61^{a}	5.24^{a}	0.75^{a}	0.28^{ab}
	(-57.28)	(-65.34)	(-90.78)	(-89.43)
L10%	2.08^{a}	5.95^{ab}	0.73^{a}	0.15^{a}
	(-65.95)	(-60.64)	(-91.03)	(-94.33)
R2%	5.17^{cde}	13.30^{ef}	6.03^{d}	1.70^{de}
	(-15.30)	(-12.03)	(-25.92)	(-35.84)
R4%	5.232^{cdef}	10.71^{cde}	5.24^{d}	1.92^{ef}
	(-14.40)	(-29.16)	(-35.62)	(-27.54)
R6%	6.54^{fg}	9.09^{cd}	3.97^{c}	1.34^{cde}
	(+7.03)	(-39.88)	(-51.22)	(-49.43)
R8%	6.58^{g}	10.44^{cd}	3.25^{c}	1.11b^{cde}
	(+7.69)	(-30.95)	(-60.07)	(-58.11)
R10%	5.66d^{efg}	8.31^{bc}	2.21^{b}	1.317^{cde}
	(-7.36)	(-45.03)	(-72.85)	(-50.56)
SED	0.58	1.21	0.3830	0.41
C.V.(%)	17.1	16.3	13.7	45

R = Roots and L = Leaves

Values with similar letter(s) within a column are not significantly different at P = 5% by Duncan's Multiple Range Test (DMRT).

**The data in parenthesis indicate % reduction (-) or increase (+) over control.*

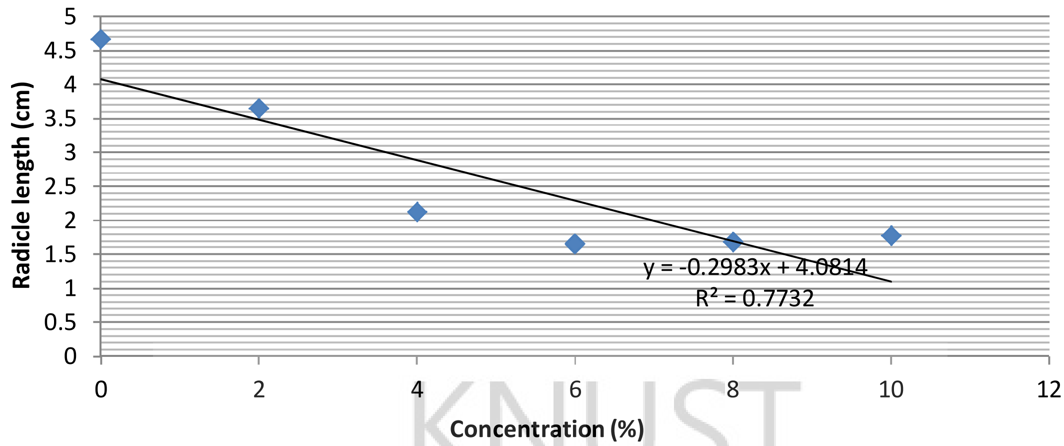

Figure 7.3: Regression analysis of radicle length of all test crops at different concentration of leaf aqueous extracts of J. curcas

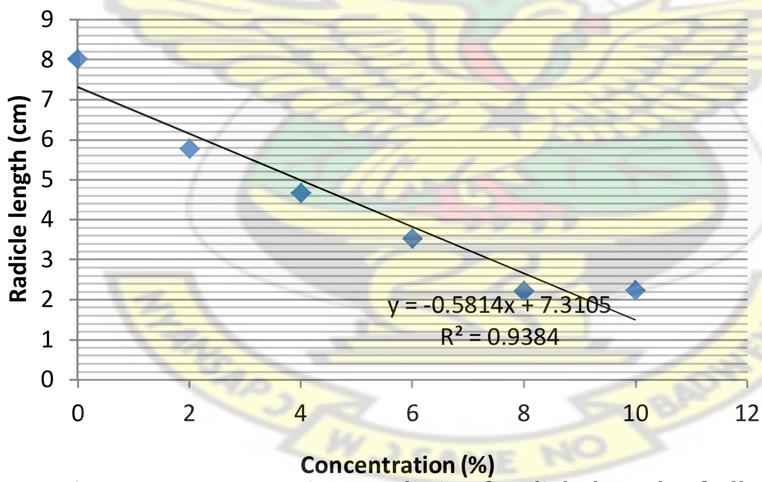

Figure 7. 4: Regression analysis of radicle length of all test crops at different concentration of root aqueous extracts of J. curcas

7.4.3: Effect of *J. curcas* leaves and roots extract on plumule length of crops

Generally, aqueous extracts of leaves and roots significantly reduced plumule length of *P. vulgaris* at all concentrations with the highest effect being recorded by L6%. No significant difference (P >0.05) was obtained for L4%, L10% and R10% (Table 7.3). In *Z. mays,* all the extracts significantly affected plumule length compared with that of the control while in *L. lycopersicum* the differences between the treatments R6%, R4%, R2%, L2% and the control were not significant. The least plumule length of *L. lycopersicum* was obtained at L10% (Table 7.3).

With respect to *A. esculentus*, the lowest plumule length was at L10% concentration of *J. curcas* extract, although the differences between this concentration and L8%, L6%, L4%, L2%, R8% were not significant (Table 7.3). The regression analysis between plumule length and concentration of leaf extract showed that 89% of variation in plumule length of the test crops could be explained by the concentration of leaf extracts (R^2 = 0.89, Figure 7.5). The root extract on the other hand, had 95% of variation in plumule length of the test crops which could be explained by the concentration of root extracts (R^2 = 0.95, Figure 7.6).

Table 7.3: Effect of leaf and root extract on plumule length of crops

Treatments	*Phaseolus vulgaris* (cm)	*Zea mais* (cm)	*Lycopersicon lycopersicum* (cm)	*Abelmoschus esculentus* (cm)
Control	4.34^{d}	5.85^{f}	6.09^{de}	2.41^{bc}
L2%	2.42^{c}	4.82^{e}	5.99^{f}	1.38^{ab}
	(-44.24)	(-17.60)	(-1.75)	(-42.73)
L4%	1.33^{ab}	2.89^{bc}	3.39^{bc}	0.85^{a}
	(-69.35)	(-50.59)	(-44.33)	(-64.73)
L6%	1.09^{a}	2.21^{ab}	2.48^{ab}	0.80^{a}
	(-74.88)	(-62.22)	(-59.27)	(-66.80)
L8%	2.02^{bc}	1.75^{a}	2.43^{ab}	0.52^{a}
	(-53.45)	(-70.08)	(-60.09)	(-78.42)
L10%	1.46^{ab}	3.29^{cd}	2.03^{a}	0.30^{a}
	(-66.35)	(-43.76)	(-66.66)	(-87.55)
R2%	2.42^{c}	4.08^{de}	5.96^{ef}	2.37^{bc}
	(-44.20)	(-30.25)	(-2.13)	(-1.65)
R4%	2.48^{c}	2.95^{bc}	5.18^{d}	2.91^{c}
	(-42.85)	(-49.57)	(-14.9)	(-3.73)
R6%	1.91^{bc}	2.49^{abc}	5.14^{d}	2.03^{bc}
	(-55.99)	(-57.43)	(-15.59)	(-15.76)
R8%	1.86^{bc}	2.89^{bc}	3.99^{c}	1.42^{ab}
	(-57.14)	(-50.59)	(-34.48)	(-41.07)
R10%	1.65^{ab}	2.21^{ab}	2.97^{abc}	2.22^{bc}
	(-61.98)	(-62.22)	(-51.23)	(-7.88)
SED	0.31	0.41	0.49	0.51
C.V.(%)	19.3	17.0	15.9	44.3

R = Roots and L = Leaves

Values with similar letter(s) within a column are not significantly different at P = 5% by Duncan's Multiple Range Test (DMRT).

**The data in parenthesis indicate % reduction (-) or increase (+) over control.*

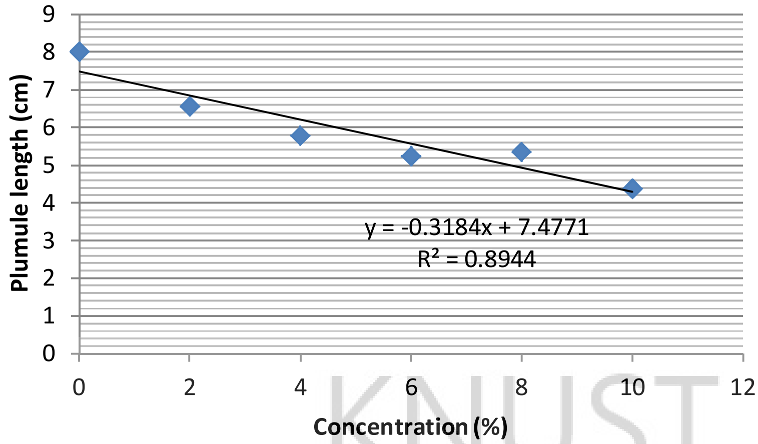

Figure 7.5: Regression analysis of plumule length of all test crops at different concentration of leaf aqueous extracts of J. curcas

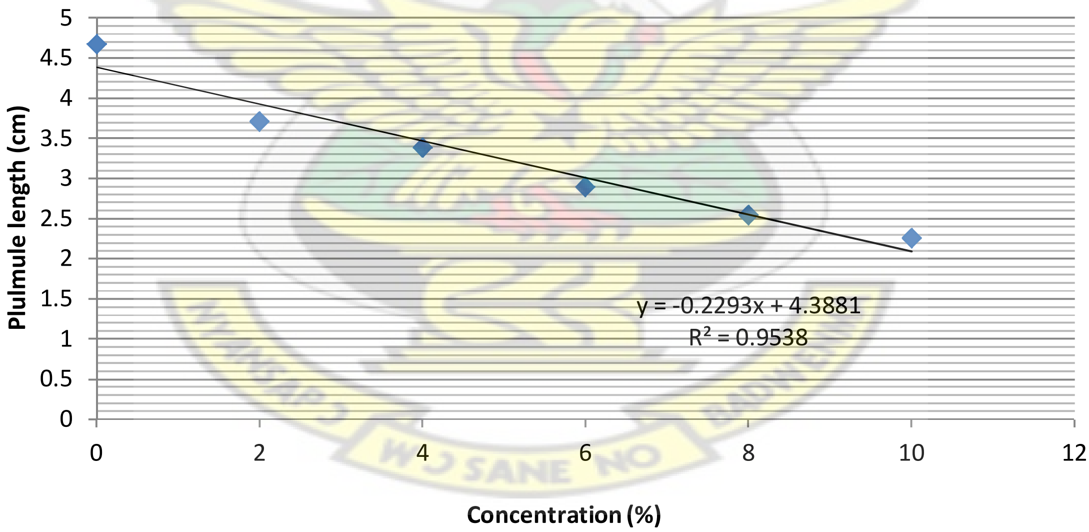

Figure 7.6: Regression analysis of plumule length of all test crops at different concentration of root aqueous extracts of J. curcas

7.5 Discussions

Allelopathy is considered as both harmful and beneficial interactions between plants (Rizvi *et al*., 1986). Generally, the results from this study showed an increase in germination at lower concentration of *J. curcas* roots and leaves extracts. Lower concentrations of L2%, R2% and R4% appeared to promote germination of *P. vulgaris* and *Z. mays* even though it was not significantly different from the control. Purvis *et al*. (1985) reported that lower concentrations of plant residues show promoting effects while higher concentrations had inhibitory effect. They reported that lower concentration of wheat and pea, promoted the germination and growth of *Avena fatua* and *Avena sterilis*. The germination of other weeds was, however, inhibited by higher concentrations of crop residues. Randhawa *et al*. (2002) also found that the germination of *Trianthema portulacastrum* was suppressed by higher concentration of Sorghum water extract.

Generally, there was a decrease in germination as the concentration of the extract increased. Higher concentration of L6%, L8%, L10%, R6%, R8% and R10% significantly affected the germination of *P. vulgaris, L. lycopersicum* and *A. esculentus*. The exception was in *Z. mays* where there was an increase in germination for all the treatments except R8%. These treatments did not differ significantly from the control. The interaction of crop species with leachates indicate that phytotoxic effects may be expressed by more than one chemical compound present in different leachates and crop species react differently to these compounds (Krishna *et al*., 2007).

The most pronounced effect of 97.92% reduction in germination was realized in *A. esculentus*. The reduction in germination could be attributed to inhibitory effect of allelopathic substances present in the extract. The release of phenolic compounds may have adversely affected germination and growth of plants through their interference in energy metabolism, cell division, mineral uptake and biosynthetic processes (Rice, 1984). According to EL Diwani *et al*. (2009) *J. curcas* contain substances such as phenolic compounds, which act as natural anti-oxidant for the protection of oils and their corresponding biodiesel against oxidative deterioration. A profile of secondary metabolites (alkaloids, terpenoids, triterpenes, phenolics, tannins, flavonoids, anthraquinones, flavonols/flavones, and/or chalcones, sterols and saponins) was obtained for three plant species (*J. curcas* L., *Plectranthus barbatus* Andr. and *Pseudospondias microcarpa* Engl (Kisangau, 2007). Akinpelu (2009) has also reported that phytochemical compounds present in the extract of *J. curcas* include alkaloids, saponins, steroids and tannins.

Radicle length was strongly inhibited by aqueous extracts of leaves and roots of *J. curcas* for all the test crops. The reduction ranged from 22.4% ï 66.0% for *P. vulgaris*, 22.0% - 60.6% for *Z. mays*, 33.9% - 91.0% for *L. lycopersicum* and 27.5% ï 94.3% for *A. esculentus*. A similar trend in reduction of plumule length was also observed for all the crops. Higher concentrations of aqueous extract had a strong inhibitory effect on both radicle and plumule length. Preliminary findings showed that allelochemical could have influenced the inhibitory effect on germination, radicle and plumule length of the crops. Randhawa *et al*. (2002) reported that root length and shoot length of *Trianthema portulacastrum* were reduced by higher concentration of sorghum water extract. Ashrafi *et al*. (2008) reported that in all extracts of sunflower allelopathicity increased with increase in concentrations. They further reported that radicle length appeared more sensitive to allelochemicals than hypocotyl length. Investigation on the phytochemical screening of *J. curcas* stem bark extracts revealed the presence of saponins, steroids, tannins, glycosides, alkaloids and flavonoids in the extract (Igbinosa, 2009). These phenolic compounds could be the cause for this reduction in radicle and plumule length.

The plant part that had a strong effect on germination, radicle and plumule length was the leaves. It suggests that more allelochemicals can be found in the leaves than in the roots of *J. curcas*. This is corroborated by the findings of Maharjan *et al*. (2007) where preliminary screening showed that leaf extract had the strongest allelopathic effect on seed germination and was selected for detail experiments. Tefera (2002) also found that the inhibitory allelopathic impact of leaf extract was more powerful than that of other vegetative parts. Earlier works have also reported that foliar leachates of *Parthenium hysterophorus* reduced root and shoot elongation of *Oryza sativa* and *Triticum aestivum* (Singh and Sangeeta, 1991), maize and soybeans (Bhatt *et al*., 1994) as well as some common Australian pasture grasses (Adkins and Sowerby, 1996). This indicates the availability of inhibitory chemicals in higher concentration in leaves than in stem and roots (Kanchan and Jayachandra, 1980).

7.6 Conclusions

J. curcas provides a viable source of bio-diesel. However, the study revealed that higher concentrations (8% and 10%) of aqueous extract of *J. curcas* leaves and roots can have an inhibitory effect on germination, radicle and plumule length of *P. vulgaris, Z. mays, L. lycopersicum and A. esculentus*. The presence of phenolic compounds could be the cause of reduction in germination and growth of seedlings. Germination and growth of *Abelmoschus esculentus* was suppressed to a greater degree by allelochemicals from *J. curcas*. The results also indicate that leaves of *J. curcas* had more inhibitory effect on germination than the roots. There is basis for further research under field conditions to confirm the allelopathic potential of *J. curcas*.

CHAPTER EIGHT

8.0 GENERAL DISCUSSIONS

8.1 Maize performance in hedgerows of *J. curcas*

On the whole, the study has shown that maize is compatible with *J. curcas* in a hedgerow intercropping system. Even though the highest grain yields of 4.47 tons/ha and 2.99 tons/ha were attained in the control plots (No hedgerow) for the first and second year of planting, the highest land equivalent ratio and highest profit were recorded at a hedgerow spacing of 4 m x 1 m. This spacing can therefore be used when intercropping maize with *J. curcas*.

The major limiting factor for the growth and yield of maize with *J. curcas* was probable competition for nutrient, space and water. This is evident in the lower yields attained in closer hedgerow spacing. Khan and Ehrenreich (1994) concluded that proximity of wheat crops to trees under irrigated conditions adversely affected crop tillers/m^2, weight/1000 grains and the yield of wheat planted up to a distance of about 8.5 m from the trees. They concluded that the growth and yield of wheat improved as distance from the trees increased. According to Khan and Ehrenreich (1994) maize grain yield decreased in order of 4 < 6 < 8 m hedgerow spacing in the first year. Singh *et al.* (1989) also reported that yields declined from 30 to 150% of the sole crop yield as the distance from the hedgerows declined from 5 m to 0.3 m.

The determination of whether there was any beneficial or negative interaction between *J. curcas* and maize was assessed by the use of the Land Equivalent Ratio (LER). It was also meant to assess the competitive relationship between the component crops, the best use of land and the overall productivity of the alley cropping system. Generally, all the alley cropping treatments of

J. curcas with maize had a LER greater than 1.00. This is an indication of a beneficial interaction between the components. The highest LER of 1.62 and 1.20 were obtained at 4 m x 1 m hedgerow spacing for the year 2008 and 2009 respectively. This means that 62% and 20% more land would be required as sole of maize to produce the same yield as intercropping of *J. curcas* and maize. In the midst of increasing population and land scarcity, this agroforestry system would seem beneficial and sustainable in our desire to produce *J. curcas*. The results also mean that there was avoidance of competition between the components which helped increase the LER. It implies that interspecific interference between *J. curcas* and maize in the first year was less than the intraspecific interaction in the control treatment. This was corroborated by Kurata (1986) who stated that negative interspecific interference that exists in the mixture is not as intensive as the intraspecific interference that exist in the monoculture.

Economically, the study showed that the highest profit was obtained from the 4 m x 1 m hedgerow spacing. This was largely due to reduced cost of weeding and fertilizer application in the alley cropping treatments. The reduced cost of weeding was the result of the low biomass of weeds attained in hedgerows. This ultimately reduced the cost of production in the hedgerows. Studies in Kenya by Jama and Getahun (1992) showed 42% - 98% reduction in weed biomass in maize and green gram (*Phaseolus aureus*) alley cropped with *Faidherbia albida* and *L. leucocephala* compared with respective monocrops. On alfisols in Nigeria, hedgerow of *L. leucocephala* and *G. sepium* reduced the population of spear grass by 51% - 67% (Anoka *et al*., 1996). Similarly, on ultisols in Indonesia, hedgerow of *G. sepium* reduced spear grass infestation (ICRAF, 1996). The yields obtained from maize and *J. curcas* alley cropped plots culminated in the higher revenue for the plots. The high economic returns from the alley cropped plot are the result of increased revenue and reduced cost of production.

8.2 Storage period of *J. curcas* seeds on germination and growth

The goal of seed storage is to conserve seeds in a way that maintains their viability and vigour for the longest possible time from harvest to sowing (Hilli *et al*., 2003). The findings from this study showed that germination of *J. curcas* seeds was 98% within the first month of storage. No significant difference in germination was realized within the first 2 months but after this significant differences emerged. To obtain the optimum germination from *J. curcas*, seeds should not be stored for more than two months.

Germination energy is a reliable index for evaluation of seed resistance to adverse environmental conditions (Jelena, 2010). The number of germinated seeds at first germination also declined with time (Fig. 4.2). The highest germination was during the first 2 months. Although seed longevity is an intrinsic characteristic that varies from species to species (Walters et al., 2005), the period during which seeds remain viable will depend on their quality at the time of harvest, the treatment received between collection and storage conditions (Rajjou and Debeaujon, 2008). The decline in storage overtime could be attributed to membrane deterioration. Seed deterioration is an inexorable and an irreversible process (Copeland and McDonald, 1985).

8.3 Effect of fertilizer on growth and yield of *J. curcas*

Physic nut is well adapted to marginal soils with low nutrient content (Heller, 1996) and annual seed yield of 2 ï 3 tons/ha has been reported in semi-arid areas (Kumar and Sharma, 2008). The yields obtained for physic nut is low compared to other crops with potential for biodiesel production (Suriharn *et al*., 2011). The use of inorganic fertilizer is therefore necessary to increase the yield of *J. curcas*. The study showed that fertilizer treatment at 150 kg/ha of NPK increased seed yield by 56.4%, fruit yield by 51.8%, number of seeds harvested by 54.9% and number of fruits harvested by 55.5%. The fertilizer treatment also increased weight of seed husk, seed length and seed width by 39.2%, 1%, and 1.7% respectively.

Yin *et al*. (2010) observed that different level of nitrogen fertilizer significantly affected growth, development, kernel set and yield of physic nut. Suriharn *et al*., (2011) reported that application of fertilizer at the rate of 312.5kg/ha of NPK gave the highest seed yield of *J. curcas* whereas no application gave the lowest yield. The claim by Jongschaap, *et al*. (2007) that *J. curcas* is hardy, low nutrient requirement crop and can grow on marginal land with low fertility should be carefully examined again.

8.4 Seed source variation in *J. curcas*

Seed source did not significantly affect the performance of *J. curcas*, even though seed from Kpetoe appeared to perform better. No difference in the source of seed with respect to germination and survival were obtained. Basha and Sujathad (2007) reported that initial variations in fruit and seed yield of *J. curcas* planted on a common site in India were found to be insignificant, indicating low variability in the genetic resource of the plant. Genetic variation is manifested through provenance test designed to assess the degree and pattern of variation across species. The results obtained therefore show a no variability of *J. curcas* as a seed source. Sunil *et al*. (2008) reported that identification of promising lines among perennials such as *J. curcas* would entail a concerted study over a period of time usually 5 ï 10 years.

8.5 Polybag size on early growth of *J. curcas*

The different sizes of poly bag also showed significant effect on growth and dry weights of roots and shoots. Poly bag of 13 cm x 17.80 cm (medium) is recommended for raising *J. curcas* seedlings since it did not differ significantly from poly bag size of 16 cm x 19.80 cm (large). These findings are similar to that of Martin and Banik (1993) who reported that height and diameter growth of teak increased with increasing size of polybag. Milks *et al*. (1989) reported that plants growing in small containers have growth problems due to poor aeration or low water holding capacity of the growing medium.

8.6 Trends in litter fall and decomposition of *J. curcas* biomass

The total quantity of litter produced in a year at different spacing were 2.27 ton/ha, 1.10 tons/ha and 0.79 ton/ha for 1 m x 1 m, 2 m x 1 m and 3 m x 1 m, respectively. However, the highest litter fall was recorded in the month of November which is a dry period. The increase in litter fall during the dry season is an indication that physiological response to drought and reduced humidity plays a major role in liter fall. Factors such as low rainfall and high temperatures that prevail during the season are known to stimulate abscisic acid synthesis in plant foliage, which in turn, stimulate leaf senescence (Yang *et al*., 2003). The resultant effect is the increased litter fall recorded during the dry period.

The process of biological disintegration of dead organic materials whereby mineralization of complex organic carbon into simple inorganic forms takes place is a key process governing the availability of nutrients in ecosystem (Moore *et al*., 2006). The study showed that 97-99% of leaf litter had decomposed at the end of the experimental period of five months. Within the first 30 days leaf litter decreased by 52.4% and 57.8% in closed and open canopy respectively. These were more than half the initial leaf litter. Sangha *et al*. (2006) suggested that early decomposition is regulated by nutrient concentrations (especially nitrogen and phosphorus) whereas the late-stage decay is regulated by lignin concentration. When litter is exposed to decomposition microorganisms, the easily decomposable components are attacked first. The soluble and polymer carbohydrates (cellulose and hemicellulose) therefore begin disappearing sooner than the lignin (Hirobe *et al*., 2004). The rapid decomposition of *J. curcas* leaves can be attributed to litter quality, favourable moisture and greater microbial activity in the soil.

8.7 Allelopathic properties of *J. curcas*

Generally, the results from this study showed an increase in germination at lower concentration of *J. curcas* roots and leaves extracts. Lower concentrations of L2%, R2% and R4% appeared to promote germination of *P. vulgaris* and *Z. mays* even though it was not significantly different from the control. There was a decrease in germination, radicle and plumule length as the concentration of the extract increased. Higher concentration of L6%, L8%, L10%, R6%, R8% and R10% significantly reduced the germination, radicle and plumule length of *P. vulgaris, L. lycopersicum* and *A. esculentus*. The exception was in *Z. mays* where there was an increase in germination for all the treatments except R8%. The findings of this study suggest that *J. curcas* may not have any allelopathetic effect on maize; however, it does have a significant influence on *A. esculentus*. The findings of this study suggest that *J. curcas* should not be planted with *A. esculentus* in an alley cropping system; however, it is important to confirm this assertion. The inhibition of germination and growth suggest the presence of allelochemicals in *J. curcas*.

8.8 Future of *J. curcas* in agroforestry systems in Ghana

In the midst of increasing population and decline in land size for agricultural crops, agroforestry is the panacea to promoting *J. curcas* as a biofuel crop. Preliminary findings show the presence of allelochemicals which could affect the performance of the associated crops in an agroforestry system. However, field study with maize showed promising results of incorporating *J. curcas* in an agroforestry system. Planting distance of 4 m or more between the hedgerows of *J. curcas* is ideal for incorporating agricultural crops. Closer spacing could promote competition beween *J. curcas* hedgerows and agricultural crops which is a disincentive to promoting *J. curcas*.

J. curcas is a non edible plant and therefore not easily accepted by farmers for planting. The risk associated with planting *J. curcas* is high. Its use in agroforestry could help reduce the risk and make it acceptable to farmers.

CHAPTER NINE

9.0 GENERAL CONCLUSIONS AND RECOMMENDATIONS

9.1 Conclusions

The study has shown that it is feasible and profitable to integrate *J. curcas* into a hedgerow intercropping system with maize. Although the control (sole maize) treatment produced the highest maize yield, hedgerow intercropping of *J. curcas* with maize at a spacing of 4 m x 1 m had the highest land equivalent ratio of 1.62 and 1.20 for the year 2008 and 2009, respectively. The highest Benefit/Cost ratio of 2.70 was also recorded at the spacing of 4 m x 1 m for 2008. Within the two growing seasons, soil chemical properties did not change significantly from the control. This implies that the system is compatible with the land use system and does not result in rapid depletion of soil nutrients in the short term.

Storage of *J. curcas* seeds at room temperature would affect the viability of the seeds over time. The seeds can, however, be stored for three months without losing their viability. Within a 12 month period, germination of the seeds can be reduced by 51.53%. Germination energy was high in the first 2 months and declined sharply thereafter. This implies the survival of such seedling after germination would be low and will affect crop establishment.

To increase growth and yield of *J. curcas* soil amendments in terms of fertilizer application proved to be more important than spacing. The erroneous impression that *J. curcas* is hardy and can be cultivated on any type of soil should be reconsidered. Fertilizer treatments gave higher yields, therefore soils with high nutrient status should be considered in cultivating *J. curcas* if high yield is the objective of the programme.

It was realized from the study that, there was little or no seed source variations in *J. curcas* in relation to seed germination, survival, seed length and width. The seed weight of the seeds collected from Kpetoe which showed some differences could be the result of high moisture retained in seeds since it was harvested last. Based on this it can be concluded that little variation in phenotypic appearance of *J. curcas* was observed.

Larger polybags recorded the best performance in growth and should be considered in raising seedlings at the nursery. Lateral and tap root length were highly influenced by polybag size, with the larger polybags size outperforming the others.

Closer spacing produced the highest litter fall which mostly occurred during the dry season. Decomposition of leaf litter was higher under bare-soil conditions and during the wet period than under the canopy of trees. *J. curcas* decomposed rapidly with 97-99% of the leaf litter decomposing in 150 days. The litter decomposition and nutrient release pattern of *J. curcas* was variable. Nutrients were immobilized when its concentration in the leaf litter was low.

The study also revealed that higher concentrations (8% and 10%) of aqueous extract of *J. curcas* had inhibitory effect on germination, radicle and plumule length of *P. vulgaris, Z. mays, L. lycopersicum and A. esculentus*. Germination and growth of *A. esculentus* was more suppressed by aqueous extracts (leaves and roots) of *J. curcas*. The results also indicate that leaves of *J. curcas* had more inhibitory effect than the roots. The outcome of this study would serve as a basis for further research under field conditions to confirm the allelopathic potential of *J. curcas*.

9.2: Recommendations

1. A long term period of study of five years into maize performance in hedgerow of *J. curcas* should be carried out to ascertain the yield over a period.
2. If *J. curcas* is to be incorporated into a hedgerow intercropping system with maize, hedgerow width of 4m x 1m can be used.
3. A wider spacing of hedgerow should be investigated to find out if economic returns on investment can be achieved.
4. *J. curcas* does not affect the chemical properties of soils within 2 years, a long term investigation to ascertain its effect on soil properties should be carried out.
5. Seeds of *J. curcas* should not be stored at room temperature for more than 3 months as it would lose its viability.
6. A detailed fertilizer trial should to be carried out to ascertain the optimum rate of fertilizer application.
7. Larger polybags should be used in raising *J. curcas* seedlings in the nursery since it provides better growth and may subsequently enhance survival in the field.
8. *J. curcas* exhibited allelopathic properties in the laboratory experiment, it is important to carry out further research under field conditions to ascertain if the effect would be significant under field conditions.

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